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ORIGINAL SCIENTIFIC PAPERS

Relating Sombor and Euler indices

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Abstract:

Introduction/purpose: The Euler-Sombor index (EU) is a new vertex-degree-based graph invariant, obtained by geometric consideration. It is closely related to the Sombor index (SO). The actual form of this relation is established.

Methods: Combinatorial graph theory is applied.

Results: The inequalities between EU and SO are established.

Conclusion: The paper contributes to the theory of Sombor-index-like graph invariants.

Keywords: degree(of vertex), Sombor index, Euler-Sombor index.

Introduction

Vertex-degree-based (VDB) graph invariants are much studied in the current mathematical and applied-mathematical literature; see for instance the recent papers (Das et al, 2021; Hu et al, 2022; Liu, 2023a; Monsalve & Rada, 2021; Rada et al, 2022; Yuan, 2024). A few years ago, it was discovered that some of these graph invariants have a geometric interpretation (Gutman, 2021). Eventually, this triggered a whole series of geometry-based research studies on VDB invariants (Ali et al, 2024; Gutman, 2022; Gutman et al, 2024; Imran et al, 2022; Liu, 2023b; Tang et al, 2024). The first geometry-motivated VDB invariant is the Sombor index (Gutman, 2021), defined as

$$SO = SO(G) = \sum_{uv \in E(G)} \sqrt{d_u^{\,2} + d_v^{\,2}} \,. \qquad (1)$$

Although relatively new, the Sombor index has been a subject of numerous mathematical studies; see the review (Liu et al, 2022), the most recent papers (Attarzadeh & Behtoei, 2024; Chen & Zhu, 2024; Selenge & Horoldagva, 2024; Shetty & Bhat, 2024), and the references cited therein. The Sombor index found also noteworthy applications, especially in chemistry (Hayat et al, 2024; Rauf & Ahmad, 2024; Redžepović, 2021).

In some recent studies, a similarly-looking quantity has been encountered (Ali et al, 2024, Gutman et al, 2024, Tang et al, 2024), namely

$$EU = EU(G) = \sum_{uv \in E(G)} \sqrt{d_u{}^2 + d_v{}^2 + d_u\, d_v} \,. \qquad (2)$$

For the reasons explained below, it can be named the "Euler-Sombor index".

In this paper, we use the following notation and terminology. By *G* we denote a simple graph with *n* vertices and *m* edges. Let *E*(*G*) be its edge sets, and then $|E(G)| = m$. The edge of the graph *G*, connecting the vertices *u* and *v* is denoted by *uv*. The degree d_u of a vertex *u* is the number of the first neighbors of this vertex.

For additional details of graph theory, see (Harary, 1969; Bondy & Murty, 1976).

A geometric approach to VDB invariants

The general form of a VDB graph invariant is $\sum_{uv \in E(G)} f(d_u, d_v)$, where *f* is a pertinently chosen function with the property *f(x,y)=f(y,x)*. In (Gutman, 2021), it was recognized that the vertex-degree pair (d_u, d_v) can be interpreted as a point in a 2-dimensional coordinate system, representing the edge *uv*, called the *degree-point* of the edge *uv* (point *A* in Figure 1). If so, then (d_v, d_u) would be the *dual degree point*, pertaining to the same edge *uv* (point *B* in Figure 1).

The (Eucldean) distance between the degree-point (d_u, d_v) and the origin *O* is $\sqrt{d_u{}^2 + d_v{}^2}$, which then directly leads to the concept of the Sombor index, Eq. (1).

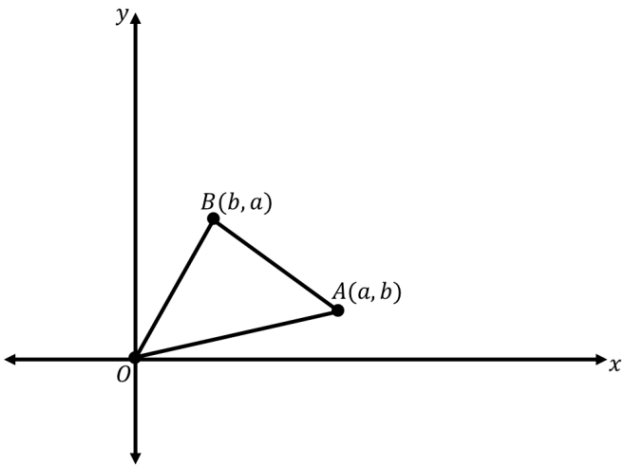

Figure 1 – A geometric representation of the edge uv of a graph G. Here d_u=a and d_v=b. The distance between the origin O and either the degree-point A or the dual degree-point B leads to the Sombor index, Eq. (1). The distance between the points A and B pertains to the Albertson irregularity index, see (Gutman, 2021).

Recently, in (Gutman et al, 2024), a geometric model was proposed, in which the degree-point and the dual degree-point play equivalent roles: these are set to be the two foci of an ellipse passing through the origin (see Figure 2).

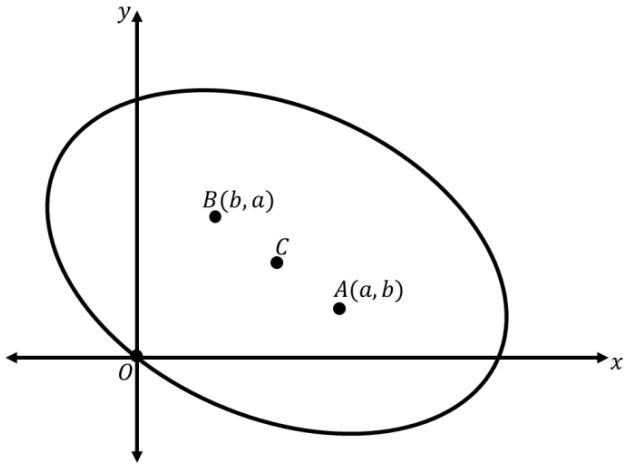

Figure 2 – Ellipse whose foci are the degree-point A and the dual degree-point B of the edge uv of a graph G.The point C is the center of the ellipse.

In (Gutman et al, 2024), it was shown that the lengths of the semi-major and the semi-minor axes of the ellipse in Figure 2 are

$$r_1 = \sqrt{a^2 + b^2} = \sqrt{{d_u}^2 + {d_v}^2} \quad \text{and} \quad r_2 = a + b = d_u + d_v . \qquad (3)$$

Using formulas (3), the area of the ellipse, equal to $\pi\sqrt{r_1 r_2}$, can easily be calculated and related to a VDB graph invariant. On the other hand, the calculation of the perimeter of the ellipse is a difficult task and (because of its importance in astronomy) a large number of various approximations have been proposed; for details, see (Gutman et al, 2024). The approximate formula for the perimeter of an ellipse, proposed by Leonhard Euler (Euler, 1773), is $\pi\sqrt{2({r_1}^2 + {r_2}^2)}$. When relations (3) are substituted into this formula, and the multiplier abandoned (since it is irrelevant for the present considerations), we arrive at the expression

$$\sqrt{{d_u}^2 + {d_v}^2 + d_u d_v} .$$

This expression directly leads to the VDB graph invariant (2). Because of its origin, the name *Euler-Sombor index* for it would be appropriate.

Evidently, there is a close algebraic analogy between the Sombor index, Eq. (1), and the Euler-Sombor index, Eq. (2). In what follows, we determine the actual form of the relation between these two VDB graph invariants.

Estimating *SO* by means of *EU*

From now on, in order to avoid trivialities, we restrict the consideration to connected graphs. The results obtained could then be directly extended to disconnected graphs, taking into account that, for a graph G consisting of disconnected components G_1 and G_2 ,

$$SO(G) = SO(G_1) + SO(G_2) \quad \text{and} \quad EU(G) = EU(G_1) + EU(G_2) .$$

Theorem 1. Let G be a connected graph. Then

$$\sqrt{\frac{2}{3}}\, EU(G) \le SO(G) < EU(G) . \qquad (4)$$

The equality on the left-hand side is attained if and only if the graph G is regular.

Proof. It suffices to verify that the relations

$$\sqrt{\frac{2}{3}}\sqrt{x^2+y^2+xy} \le \sqrt{x^2+y^2} \le \sqrt{x^2+y^2+xy} \qquad (5)$$

hold for all $x \ge 0$ and $y \ge 0$.

The right-hand side inequality in (5) is obvious. The equality in it occurs if and only if either x=0 or y=0 (or both), which in the case of vertex degrees of connected graphs cannot happen.

In order to obtain the left-hand side inequality in (5), we seek λ satisfying

$$\lambda\sqrt{x^2+y^2+xy} \le \sqrt{x^2+y^2}\ . \qquad (6)$$

From (6), we get

$$\lambda^2 xy \le (1-\lambda^2)x^2 + (1-\lambda^2)y^2$$

$$\lambda^2 xy - 2(1-\lambda^2)xy \le (1-\lambda^2)x^2 + (1-\lambda^2)y^2 - 2(1-\lambda^2)xy$$

$$\left[\lambda^2 - 2(1-\lambda^2)\right]xy \le (1-\lambda^2)(x-y)^2 .$$

Assuming that $1-\lambda^2>0$, we conclude that it must be

$$\lambda^2 - 2(1-\lambda^2) \ge 0 \quad \text{i.e.,} \quad \lambda \ge \sqrt{2/3}\ .$$

Then the best choice for relation (5) is the smallest value of λ, i.e., $\lambda = \sqrt{2/3}$.

From the above consideration, it is seen that the equality will hold if and only if x=y. Applying this to graphs, the equality will hold if the end-vertices of the edge uv have equal degrees. If this must be valid for all edges of the (connected) graph G, then all vertices of G must have equal degrees, i.e., then G must be regular.

This completes the proof of Theorem 1. ■

Inequalities (4) provide lower and upper bounds for the Sombor index in terms of the Euler-Sombor index. Of course, these relations can be inverted, so that *EU* is estimated by means of *SO*:

$$SO(G) < EU(G) \le \sqrt{\frac{3}{2}}\, SO(G).$$

Improving the inequality *SO* < *EU*

In this section, if the end-vertices of an edge uv have the degrees d_u=i and d_v=j (or vice versa), we say that the edge uv is of the (i,j)-type.

The right-hand side inequality (4) in Theorem 1 is strict. Therefore, it would be of interest to modify it so as to get equality for some graphs. In order to achieve this goal, we first establish the following:

Lemma 1. For $x, y \ge 0$, the function

$$F(x,y) = \sqrt{x^2+y^2+xy} - \sqrt{x^2+y^2}$$

is monotonically increasing. More precisely, in the domain $D = \{(x,y) \in R^2 \mid x \ge 0, y \ge 0\}$, for any $(x_1,y_1),(x_2,y_2) \in D$, if $x_1 \ge x_2$ and $y_1 \ge y_2$, then $F(x_1,y_1) \ge F(x_2,y_2)$ holds.

Proof. We need to show that the right-hand side of

$$\frac{\partial F(x,y)}{\partial x} = \frac{2x+y}{2\sqrt{x^2+y^2+xy}} - \frac{2x}{2\sqrt{x^2+y^2}} \qquad (7)$$

is positive-valued for all $x, y > 0$. We start with an evident relation

$$x^2y^2 + y^4 + 4xy^3 > 0.$$

Using it, we have

$$4x^4 + 4x^2y^2 + 4x^3y + \left[x^2y^2 + y^4 + 4xy^3\right] > 4x^4 + 4x^2y^2 + 4x^3y$$

$$(4x^4 + y^2 + 4xy)(x^2+y^2) > 4x^2(x^2+y^2+xy)$$

$$(2x+y)^2(x^2+y^2) > (2x)^2(x^2+y^2+xy)$$

$$\frac{(2x+y)^2}{x^2+y^2+xy} > \frac{(2x)^2}{x^2+y^2}$$

$$\frac{2x+y}{\sqrt{x^2+y^2+xy}} > \frac{2x}{\sqrt{x^2+y^2}}$$

from which it immediately follows that the right-hand side expression in Eq. (7) is greater than zero.

Because of F(x,y)=F(y,x), we also have $\partial F(x,y)/\partial y > 0$. ■

In view of Lemma 1, we need to find the minumum value of F(x,y) when x and y are the degrees of adjacent vertices of some graph. Evidently, this would happen if x=1 and y=1, i.e., for an edge of the (1,1)-type, resulting in

$$F(1,1) \le \sqrt{x^2+y^2+xy} - \sqrt{x^2+y^2}$$

i.e.,

$$\sqrt{x^2+y^2} \le \sqrt{x^2+y^2+xy} - (\sqrt{3}-\sqrt{2}) .$$

Recall that in the above inequalities, it is assumed that *x* and *y* pertain to the degrees of vertices of graphs.

Taking into account Eqs. (1) and (2), by summation over all edges of the undelying graph, we arrive at:

Theorem 2. Let *G* be a connected graph with *n* vertices and *m* edges. Then

$$SO(G) \le EU(G) - (\sqrt{3}-\sqrt{2})m .$$

The equality holds if and only if all edges of the graph *G* are of the (1,1)-type, which at connected graphs can happen only if *n*=2, *m*=1, i.e., if *G* is the two-vertex path.

In a fully analogous manner, we obtain the following theorems, which hold not for all connected graphs, but for those satisfying some structural requirements.

Theorem 3. Let *G* be a connected graph with *n*≥3 vertices and *m* edges. Then

$$SO(G) \le EU(G) - (\sqrt{7}-\sqrt{5})m .$$

The equality holds if and only if all the edges of the graph G are of the (1,2)-type, which only can happen if n=3, m=2, i.e., if G is the three-vertex path.

Proof. If a connected graph has 3 or more vertices, then none of its edges can be of the (1,1)-type. Then the next-smallest value of F(x,y) is F(1,2), pertaining to an edge of the (1,2)-type. Graphs possessing (1,2)-edges exist for n≥3, but only the 3-vertex path has all its edges of the (1,2)-type. ■

Theorem 4. Let *G* be a connected graph with *n*≥3 vertices, *m* edges, and without vertices of degree 1. Then

$$SO(G) \leq EU(G) - (\sqrt{12} - \sqrt{8})m$$

The equality holds if and only if all edges of the graph G are of the (2,2)-type, which is the case with the n-vertex cycles, n≥3.

Proof. If pendent vertices (those of degree one) do not exit in the underlying graph, then the minimum possible value of F(x,y) is F(2,2), pertaining to an edge of the (2,2)-type. The connected graphs in which all edges are of the (2,2)-type are the cycles, and these exist for all n≥3. Therefore, the claim of Theorem 4 is applicable to all graphs with 3 or more vertices. ■

Theorem 5. Let *G* be a connected graph with *n* vertices, *m* edges, and let δ be its smallest vertex degree (δ≥1). Then

$$SO(G) \leq EU(G) - (\sqrt{3} - \sqrt{2})\delta m$$

The equality holds if and only if all edges of the graph G are of the (δ,δ)-type, i.e., if G is regular of the degree δ. If δ is even, then graphs of this kind exist for all n≥ δ+1. If δ is odd, then graphs of this kind exist for all even-valued n, n≥ δ+1.

Proof. By the same argument as in the previous proofs, the minimum possible value of of F(x,y) is F(δ,δ). The equality requires that all edges be of the (δ,δ)-type. If so, then all vertices must be of the degree δ. Thus, the graphs for which the equality holds must be δ-regular. In the last part of the statement of Theorem 5, the well-known conditions for the number of vertices of δ-regular graphs are repeated (Harary, 1969; Bondy & Murty, 1976). ■

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Relacionando los índices de Sombor y Euler

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CAMPO: matemáticas (clasificación de materias de matemáticas: primaria 05c07, secundaria 05c09)
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: El índice de Euler-Sombor (EU) es un nuevo gráfico invariante basado en grados de vértice, obtenido mediante consideración geométrica. Está estrechamente relacionado con el índice de Sombor (SO). Se establece la forma real de esta relación.

Métodos: Se aplica la teoría combinatoria de grafos.

Resultados: Se establecen las desigualdades entre UE y SO.

Conclusión: El artículo contribuye a la teoría de las invariantes gráficas similares al índice de Sombor.

Palabras claves: grado (de vértice), índice de Sombor, índice de Euler-Sombor.

Соотношение между индексами Сомбора и Эйлера

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РУБРИКА ГРНТИ: 27.29.19 Краевые задачи и задачи на собственные значения для обыкновенных дифференциальных уравнений и систем уравнений
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Сомборский индекс Эйлера является новым инвариантом графа, основанным на степени вершины, полученным путем геометрического анализа. И он соотносится с индексом Сомбора. В данной статье установлено математическое соотношение между этими двумя инвариантами графа.

Методы: В данной статье применяется комбинаторная теория графов.

Результаты: Верхняя и нижняя границы индекса Сомбора были определены в зависимости от индекса Эйлера-Сомбора и

наоборот. Затем эти границы были откорректированы с учетом структурных особенностей графов.

Выводы: Данное исследование вносит вклад в теорию инвариантов графа сомборского вида.

Ключевые слова: степень (вершины), индекс Сомбора, индекс Эйлера-Сомбора.

Веза између Сомборског и Ојлеровог индекса

Иван Гутман

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ОБЛАСТ: математика
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Ојлер-сомборски индекс је нова, на степенима чворова заснована графовска инваријанта, добијена геометријским разматрањима. Сродан је Сомборском индексу. У раду су утврђене математичке везе између ове две графовске инваријанте.

Методе: Примењена је комбинаторна теорија графова.

Резултати: Одређене су горње и доње границе за Сомборски индекс у зависности од Ојлер-сомборског индекса, и обратно. Ове границе су затим побољшане, узимајући у обзир структурне карактеристике графова.

Закључак: Рад доприноси теорији графовских инваријанти сомборског типа.

Кључне речи: степен (чвора), Сомборски индекс, Ојлер-сомборски индекс.

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Fixed point results for $\beta - F-$weak contraction mappings in complete S-metric spaces

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FIELD: mathematics

ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: This paper introduces the concept of $\beta - F$-weak contraction by using the concepts of $F-$weak contraction and $\alpha - \psi-$ contraction.

Methods: The use of the $\beta - F$-weak contraction proves some fixed points theorems in the framework of $S-$metric spaces.

Results: The obtained results on fixed points in $S-$metric spaces generalize some known results in the literature.

Conclusions: The $\beta - F-$weak contraction generalizes some important contraction types and examines the existence of a fixed point in $S-$metric spaces. The results are used to solve a non-linear Fredholm integral equation.

Key words: fixed point, S-metric space, $\beta - F-$weak contraction, non-linear integral equation.

Introduction and preliminaries

It is well-known that the Banach contraction principle is regarded as one of the most important and useful results in metric fixed point theory. Because of its usefulness and simplicity, several authors generalized the Banach contraction principle in different directions. As one of the generalizations, Wardowski (Wardowksi, 2012) introduced the concept of F-contraction and proved a fixed point theorem that generalized the Banach contraction principle. The definition of F-contraction mapping is as follows:

DEFINITION 1. *(Wardowksi, 2012) Let $\mathcal{F}$ be the family of all functions $F : (0, +\infty) \to \mathbb{R}$ such that*

(F1) *F is strictly increasing, that is, for all $\alpha, \beta \in (0, \infty)$ if $\alpha < \beta$ then $F(\alpha) < F(\beta)$;*

(F2) *For each sequence $\{\alpha_n\}$ of positive numbers, the following holds:*

$$\lim_{n\to\infty} \alpha_n = 0 \text{ if and only if } \lim_{n\to\infty} F(\alpha_n) = -\infty;$$

(F3) *There exist $k \in (0, 1)$ such that $\lim_{\alpha\to 0^+}(\alpha^k F(\alpha)) = 0$.*

Let (X, d) be a metric space. A map $T : X \to X$ is said to be an $F - contraction$ on (X, d) if there exist $F \in \mathcal{F}$ and $\tau > 0$ such that for all $x, y \in X$,

$$d(Tx, Ty) > 0 \Rightarrow \tau + F(d(Tx, Ty)) \leq F(d(x, y)). \tag{1}$$

EXAMPLE 1. (Wardowksi, 2012) The following functions $F : (0, \infty) \to \mathbb{R}$ are the elements of $\mathcal{F}$:

1. $Fu = \ln u$,
2. $Fu = \ln(u^2 + u)$.

REMARK 1. (Wardowksi, 2012) From (1) and $(F1)$ it can be easily concluded that T is contractive, that is,

$$d(Tx, Ty) < d(x, y), \text{ for all } x, y \in X, Tx \neq Ty.$$

Then, T is also continuous.

In 2014, Wardowski and Dung (Wardowski & Dung, 2014) extended the concept of F-contraction to F-weak contraction and obtained a variety of known contractions in the literature from it. The definition of F-weak contraction mapping is as follows:

DEFINITION 2. *(Wardowski & Dung, 2014) Let (X, d) be a metric space. A map $T : X \to X$ is said to be an F-weak contraction on (X, d) if there exist $F \in \mathcal{F}$ and $\tau > 0$ such that, for all $x, y \in X$ satisfying $d(Tx, Ty) > 0$, the following holds:*

$$\tau + F(d(Tx, Ty)) \leq F\left(\max\left\{ d(x, y), d(x, Tx), d(y, Ty), \frac{d(x, Ty) + d(y, Tx)}{2} \right\} \right).$$

For more articles related to F-contractions, see (Secelean, 2013; Dung & Hang, 2015; Piri & Kumam, 2014, 2016).

Recently, Gopal et al. (Gopal et al, 2016) extended the concept of F-contraction mappings to a weaker class of mappings called α-type F-contraction mappings and proved some results on fixed point theory. The consequences of their theorems generalized the results of Wardowski (Wardowksi, 2012), Hardy and Rogers (Hardy & Rogers, 1973), Ćirić (Ćirić, 1974). The definition of α-type F-contraction and α-type F-weak contraction mappings are as follows:

DEFINITION 3. *(Gopal et al, 2016) Let (X, d) be a metric space. A mapping $f : X \to X$ is said to be an α-type F-contraction on X if there exist $\tau > 0$ and two functions $F \in \mathcal{F}$ and $\alpha : X \times X \to \{-\infty\} \cup (0, \infty)$ such that for all $x, y \in X$ satisfying $d(fx, fy) > 0$, the following inequality holds*

$$\tau + \alpha(x, y)F(d(fx, fy)) \leq F(d(x, y)).$$

DEFINITION 4. *(Gopal et al, 2016) Let (X, d) be a metric space. A mapping $f : X \to X$ is said to be an α-type F-weak contraction on X if there exist $\tau > 0$ and two functions $F \in \mathcal{F}$ and $\alpha : X \times X \to \{-\infty\} \cup (0, \infty)$ such that for all $x, y \in X$ satisfying $d(fx, fy) > 0$, the following inequality holds*

$$\tau + \alpha(x, y)F(d(fx, fy)) \leq F\left(\max\left\{ d(x, y), d(x, fx), d(y, fy), \frac{d(x, fy) + d(y, fx)}{2} \right\} \right).$$

Subsequently, L.K. Dey et al. (Dey et al, 2019) introduced the notion of generalized $\alpha-F-$contraction and modified generalized $\alpha-F-$contraction mappings and presented a more generalized version of the results of Gopal et al. (Gopal et al, 2016).

Metric space and its applications have been extensively employed for decades in mathematics and various branches of applied sciences. For its effective applications and useful mathematical results, many researchers have attempted to give a more generalized and extended notion of metric space. As one of the generalizations, Sedghi et al. (Sedghi et al, 2012) introduced the concept of S-metric space as follows:

DEFINITION 5. *(Sedghi et al, 2012) Let X be a nonempty set. An S-metric on X is a function $S : X \times X \times X \to [0, \infty)$ that satisfies the following conditions, for each $x, y, z, a \in X$,*

(1) $S(x, y, z) \geq 0$,

(2) $S(x, y, z) = 0$ *if and if* $x = y = z$,

(3) $S(x, y, z) \leq S(x, x, a) + S(y, y, a) + S(z, z, a)$.

The pair (X, S) is called S-metric space.

LEMMA 1. *(Sedghi et al, 2012) In an S-metric space, there exists $S(x, x, y) = S(y, y, x)$.*

DEFINITION 6. *(Sedghi et al, 2012) Let (X, S) be an S-metric space.*

(1) *A sequence $\{x_n\}$ in X converges to x if and only if $S(x_n, x_n, x) \to 0$ as $n \to \infty$. That is, for each $\epsilon > 0$ there exists $n_0 \in \mathbb{N}$ such that for all $n \geq n_0$, $S(x_n, x_n, x) < \epsilon$ and it is denoted by $\lim_{n\to\infty} x_n = x$.*

(2) *A sequence $\{x_n\}$ in X is called a Cauchy sequence if for each $\epsilon > 0$, there exists $n_0 \in \mathbb{N}$ such that $S(x_n, x_n, x_m) < \epsilon$ for each $n, m \geq n_0$.*

(3) *The S-metric space (X, S) is said to be complete if every Cauchy sequence is convergent.*

DEFINITION 7. *(Sedghi & Dung, 2014) A mapping $T : X \to X$ is said to be S-continuous if $\{Tx_n\}$ is S-convergent to Tx, where $\{x_n\}$ is an S-convergent sequence converging to x.*

For more articles on S-metric space, see (Hieu et al, 2015; Özgür & Taş, 2016).

DEFINITION 8. *(Alghamdi & Karapinar, 2013) Let $T : X \to X$ and $\beta : X \times X \times X \to [0, \infty)$, then T is said to be β-admissible if for all $x, y, z \in X$,*

$$\beta(x, y, z) \geq 1 \Rightarrow \beta(Tx, Ty, Tz) \geq 1.$$

Main results

In this article, $\mathfrak{F}$ denotes the family of all functions $F : (0, \infty) \to \mathbb{R}$ satisfying the following conditions:

($\boldsymbol{F_i}$) F is strictly increasing, that is, for all $u, v \in (0, \infty)$ if $u < v$ then $F(u) < F(v)$;

($\boldsymbol{F_{ii}}$) There exists $k \in (0, 1)$ such that $\lim_{\alpha \to 0^+} \alpha^k F(\alpha) = 0$.

Now, the definition of $\beta - F-$contraction and $\beta - F-$weak contraction mappings is presented as follows:

DEFINITION 9. *Let (X, S) be an S-metric space and $h : X \to X$ be a mapping. Let $\beta : X \times X \times X \to [0, \infty)$ be a function and $F \in \mathfrak{F}$. The mapping h is said to be a $\beta - F-$ contraction on (X, S) if there exists $\tau > 0$ such that, for all $u, v \in X$ satisfying $S(hu, hu, hv) > 0$, the following condition holds:*

$$\tau + \beta(u, u, v)F(S(hu, hu, hv)) \leq F(S(u, u, v)).$$

DEFINITION 10. *Let (X, S) be an S-metric space and $h : X \to X$ be a mapping. Let $\beta : X \times X \times X \to [0, \infty)$ be a function and $F \in \mathfrak{F}$. The mapping h is said to be a $\beta - F-$weak contraction on (X, S) if there exists $\tau > 0$ such that, for all $u, v \in X$ satisfying $S(hu, hu, hv) > 0$, the following condition holds:*

$$\tau + \beta(u, u, v)F(S(hu, hu, hv)) \leq F(M(u, u, v)), \tag{2}$$

where

$$\begin{aligned} M(u, u, v) &= \max\{S(u, u, v)), S(u, u, hu), S(v, v, hv), \\ &\quad \frac{1}{4}(S(u, u, hu) + S(u, u, hv) + S(v, v, hu))\}. \end{aligned}$$

REMARK 2. Every $\beta - F-$contraction is a $\beta - F-$weak contraction but the converse is not necessarily true.

EXAMPLE 2. Consider $X = [0,3]$ together with the S-metric $S(u,v,w) = |u-w| + |v-w|$, for all $u, v, w \in X$.

Let $h : X \to X$ be given by

$$h(u) = \begin{cases} 3, & \text{if } u \in [0,3); \\ 2, & \text{if } u = 3. \end{cases}$$

Then, for all $u, v \in [0,3]$ with $S(hu, hu, hv) > 0$ implies that either $u = 3$ or $v = 3$ but not both. So,

$$M(u,u,v) \geq S(3,3,h3) = 2.$$

Therefore, by choosing $\tau = \ln\sqrt{2}$, $F \in \mathfrak{F}$ as $Fv = \ln v$, for all $v > 0$ and $\beta : X \times X \times X \to [0,\infty)$ by

$$\beta(u,v,w) = \begin{cases} \frac{1}{2}, & \text{if } (u,v,w) \in A; \\ 2, & \text{if } (u,v,w) \in X^3 \backslash A, \end{cases}$$

where $A = \{(u,v,w) : u, v \in [0,3), w = 3 \text{ or } u, v = 3, w \in [0,3)\}$, it is clear that h is a $\beta - F-$weak contraction.

However, for $u = 3, v = 3$ and $w = \frac{5}{2}$, putting $Fv = \ln v$, for all $v > 0$, there is

$$\tau + \beta\big(3,3,\frac{5}{2}\big)F\big(S\big(h3,h3,h\frac{5}{2}\big)\big) = \tau + \beta\big(3,3,\frac{5}{2}\big)\ln 2,$$

and

$$F\left(S\big(3,3,\frac{5}{2}\big)\right) = \ln 1.$$

Clearly,

$$\tau + \beta\big(3,3,\frac{5}{2}\big)\ln 2 \nleq \ln 1$$

for every $\tau > 0$ and $\beta\big(3,3,\frac{5}{2}\big) \in [0,\infty)$. Thus, h is not a $\beta - F-$contraction.

Now, the main results are thus stated and proven.

THEOREM 1. *Let (X, S) be a complete S-metric space and $h : X \to X$ be a $\beta - F-$weak contraction satisfying the following conditions:*
(T1) h is β-admissible,
(T2) there exists $u_0 \in X$ such that $\beta(u_0, u_0, hu_0) \geq 1$,
(T3) h is S-continuous.
Then h has a fixed point.

Proof. By $(T2)$, there exists $u_0 \in X$ be such that $\beta(u_0, u_0, hu_0) \geq 1$. Define a sequence $\{u_n\}$ in X by $u_{n+1} = hu_n$ for all $n \in \mathbb{N}_0$, where $\mathbb{N}_0 = \mathbb{N} \cup \{0\}$. If $u_{n_0} = hu_{n_0}$, for some $n_0 \in \mathbb{N}$, then u_{n_0} is a fixed point of h and the proof is complete. So, let us assume that $u_n \neq hu_n$ for all $n \in \mathbb{N}_0$.

From $(T1)$ and $(T2)$, it follows that

$$\beta(u_0, u_0, u_1) = \beta(u_0, u_0, hu_0) \geq 1 \Rightarrow \beta(hu_0, hu_0, hu_1) = \beta(u_1, u_1, u_2) \geq 1.$$

By induction,

$$\beta(u_n, u_n, u_{n+1}) \geq 1, \text{for all } n \in N_0.$$

Since $S(u_n, u_n, u_{n+1}) > 0$ and h is a $\beta - F-$weak contraction, for some $\tau > 0$, there exists

$$\tau + \beta(u_{n-1}, u_{n-1}, u_n)F(S(hu_{n-1}, hu_{n-1}, hu_n)) \leq F(M(u_{n-1}, u_{n-1}, u_n)), \tag{3}$$

where

$$\begin{aligned}
&M(u_{n-1}, u_{n-1}, u_n) = \max\{S(u_{n-1}, u_{n-1}, u_n), S(u_{n-1}, u_{n-1}, hu_{n-1}),\\
&S(u_n, u_n, hu_n), \frac{1}{4}(S(u_{n-1}, u_{n-1}, hu_{n-1}) + S(u_{n-1}, u_{n-1}, hu_n)\\
&+ S(u_n, u_n, hu_{n-1}))\} = \max\{S(u_{n-1}, u_{n-1}, u_n), S(u_n, u_n, u_{n+1}),\\
&\frac{1}{4}(S(u_{n-1}, u_{n-1}, u_n) + S(u_{n-1}, u_{n-1}, u_{n+1}) + S(u_n, u_n, u_n))\}\\
&= \max\{S(u_{n-1}, u_{n-1}, u_n), S(u_n, u_n, u_{n+1}), \frac{1}{4}(S(u_{n-1}, u_{n-1}, u_n)+\\
&2S(u_{n-1}, u_{n-1}, u_n) + S(u_n, u_n, u_{n+1}))\}
\end{aligned}$$

$$= \max\{S(u_{n-1}, u_{n-1}, u_n), S(u_n, u_n, u_{n+1})\}$$

If $\max\{S(u_{n-1}, u_{n-1}, u_n), S(u_n, u_n, u_{n+1})\} = S(u_n, u_n, u_{n+1})$, then (3) becomes

$$\tau + \beta(u_{n-1}, u_{n-1}, u_n)F(S(u_n, u_n, u_{n+1})) \leq F(S(u_n, u_n, u_{n+1})),$$

a contradiction. Therefore, it must be that

$$\max\{S(u_{n-1}, u_{n-1}, u_n), S(u_n, u_n, u_{n+1})\} = S(u_{n-1}, u_{n-1}, u_n).$$

From (3), it follows that

$$\tau + \beta(u_{n-1}, u_{n-1}, u_n)F(S(u_n, u_n, u_{n+1})) \leq F(S(u_{n-1}, u_{n-1}, u_n)).$$

Therefore

$$\begin{aligned} F(S(u_n, u_n, u_{n+1})) &\leq \beta(u_{n-1}, u_{n-1}, u_n)F(S(u_n, u_n, u_{n+1})) \\ &\leq F(S(u_{n-1}, u_{n-1}, u_n)) - \tau \\ &< F(S(u_{n-1}, u_{n-1}, u_n)). \end{aligned} \tag{4}$$

By (F_i), it must be that

$$S(u_n, u_n, u_{n+1}) < S(u_{n-1}, u_{n-1}, u_n).$$

This shows that $\{\nu_n\}$, where $\nu_n = S(u_n, u_n, u_{n+1})$, is a decreasing sequence of non-negative real numbers, and hence

$$\lim_{n\to\infty} \nu_n = \nu \geq 0.$$

Next, it is shown that $\nu = 0$. On the contrary, it is assumed that $\nu > 0$. Then for every $n \in \mathbb{N}_0$, there exists

$$v \leq \nu_n.$$

Using (F_i) and (4), gives

$$\begin{aligned} F(\nu) \leq F(\nu_n) &\leq F(\nu_{n-1}) - \tau \\ &\leq F(\nu_{n-2}) - 2\tau \\ &\quad . \\ &\quad . \\ &\quad . \\ &\leq F(\nu_0) - n\tau. \end{aligned} \tag{5}$$

Since $\lim_{n\to\infty}(F(\nu_0) - n\tau) = -\infty$, there exists $p_1 \in \mathbb{N}$ such that

$$F(\nu_0) - n\tau < F(\nu), \text{ for all } n > p_1. \tag{6}$$

From (5) and (6), there follows

$$F(\nu) \leq F(\nu_0) - n\tau < F(\nu),$$

a contradiction. Therefore, there must be

$$\lim_{n\to\infty} \nu_n = 0.$$

By (F_{ii}), there exists $k \in (0, 1)$ such that

$$\lim_{n\to\infty} \nu_n^k F(\nu_n) = 0. \tag{7}$$

From (5) and (7), for all $n \in \mathbb{N}$, there follows

$$\lim_{n\to\infty} \nu_n^k (F(\nu_n) - F(\nu_0)) \leq \lim_{n\to\infty} (-\nu_n^k n\tau) \leq 0.$$

This implies that

$$\lim_{n\to\infty} (n\nu_n^k) = 0.$$

Therefore, $p_2 \in \mathbb{N}$ can be found, such that

$$\begin{aligned} n\nu_n^k &\leq 1, \text{ for all } n \geq p_2 \\ \Rightarrow \nu_n &\leq \frac{1}{n^{\frac{1}{k}}}, \text{ for all } n \geq p_2. \end{aligned}$$

Now,

$$\begin{aligned} S(u_n,u_n,u_m) &\leq 2S(u_n,u_n,u_{n+1})+S(u_{n+1},u_{n+1},u_m) \\ &\leq 2S(u_n,u_n,u_{n+1})+2S(u_{n+1},u_{n+1},u_{n+2})+... \\ &\quad ...+2S(u_{m-2},u_{m-2},u_{m-1})+S(u_{m-1},u_{m-1},u_m) \\ &\leq \sum_{q=n}^{\infty} 2S(u_q,u_q,u_{q+1}) \\ &= 2\sum_{q=n}^{\infty}\nu_q \\ &\leq 2\sum_{q=n}^{\infty}\frac{1}{q^{\frac{1}{k}}}. \end{aligned}$$

Since $k\in(0,1)$, the series $\sum_{n=1}^{\infty}\frac{1}{n^{\frac{1}{k}}}$ is convergent. This implies that

$$\lim_{n,m\to\infty} S(u_n,u_n,u_m)=0.$$

This proves that $\{u_n\}$ is a Cauchy sequence. Since (X,S) is complete, there exists $\xi\in X$ such that $\lim_{n\to\infty}u_n=\xi$. Since h is S-continuous, there exists $\lim_{n\to\infty}hu_n=h\xi$.

Finally,

$$\begin{aligned} hu_n &= u_{n+1} \\ \Rightarrow \lim_{n\to\infty} hu_n &= \lim_{n\to\infty} u_{n+1} \\ \Rightarrow h\xi &= \xi. \end{aligned}$$

This proves that ξ is a fixed point of h.

□

In the following theorem, the continuity of h is replaced by the following condition:

$(\mathcal{H})$: *If $\{u_n\}$ is a sequence in X such that $\beta(u_n,u_n,u_{n+1})\geq 1$, for all $n\in\mathbb{N}_0$ and $u_n\to\xi$ as $n\to\infty$, then $\beta(u_n,u_n,\xi)\geq 1$, for all $n\in\mathbb{N}_0$*

THEOREM 2. *Let (X,S) be a complete S-metric space and $h:X\to X$ be a $\beta-F-$weak contraction satisfying the following conditions:*
(T1) h is β-admissible,

(T2) there exists $u_0 \in X$ *such that* $\beta(u_0, u_0, hu_0) \geq 1$,

(T3) $(\mathcal{H})$ *holds,*

(T4) F *is continuous.*

Then h *has a fixed point.*

Proof. Following the proof of Theorem 1, it is known that $\{u_n\}$ defined by $u_{n+1} = hu_n$, is a Cauchy sequence with $\beta(u_n, u_n, u_{n+1}) \geq 1$, for all $n \in \mathbb{N}_0$ and it converges to some $\xi \in X$.

By (T_3), there exists

$$\beta(u_n, u_n, \xi) \geq 1, \text{ for all } n \in \mathbb{N}_0.$$

Next, it is shown that ξ is a fixed point of h. On the contrary, it is assumed that $h\xi \neq \xi$, that is, $S(\xi, \xi, h\xi) > 0$. Then, a number $m \in \mathbb{N}$ can be found, such that

$$\beta(u_n, u_n, h\xi) > 0, \text{ for all } n \geq m.$$

That is,

$$\beta(hu_{n-1}, hu_{n-1}, h\xi) > 0, \text{ for all } n \geq m.$$

Then, it is possible to find some $\tau > 0$ such that

$$\begin{aligned} \tau + F(S(u_n, u_n, h\xi)) &= \tau + F(S(hu_{n-1}, hu_{n-1}, h\xi)) \\ &\leq \tau + \beta(u_{n-1}, u_{n-1}, \xi) F(S(hu_{n-1}, hu_{n-1}, h\xi)) \\ &\leq F(M(u_{n-1}, u_{n-1}, \xi)). \end{aligned} \tag{8}$$

Now,

$$\begin{aligned} &M(u_{n-1}, u_{n-1}, \xi) = \max\{S(u_{n-1}, u_{n-1}, \xi), S(u_{n-1}, u_{n-1}, hu_{n-1}), S(\xi, \xi, h\xi), \\ &\frac{1}{4}(S(u_{n-1}, u_{n-1}, hu_{n-1}) + S(u_{n-1}, u_{n-1}, h\xi) + S(\xi, \xi, hu_{n-1}))\} \\ &= \max\{S(u_{n-1}, u_{n-1}, \xi), S(u_{n-1}, u_{n-1}, u_n), S(\xi, \xi, h\xi), \\ &\frac{1}{4}(S(u_{n-1}, u_{n-1}, u_n) + S(u_{n-1}, u_{n-1}, h\xi) + S(\xi, \xi, u_n))\}. \end{aligned}$$

Taking limit as $n \to \infty$ in (8) and using $(T4)$, yield

$$\tau + F(S(\xi, \xi, h\xi)) \leq F(S(\xi, \xi, h\xi)),$$

a contradiction. Therefore, it must be that $h\xi = \xi$, that is, ξ is a fixed point of h.

□

Next, the following condition is considered to ensure the uniqueness of the fixed point:

$$(\mathcal{U}) \text{ if } \xi, \eta \in Fix(h) = \{u \in X : hu = u\}, \text{ then } \beta(\xi, \xi, \eta) \geq 1.$$

THEOREM 3. *Adding the above condition $(\mathcal{U})$ to the hypothesis of Theorem 1 (respectively, Theorem 2) the uniqueness of the fixed point is obtained.*

Proof. Let $\xi, \eta \in Fix(h)$ with $\xi \neq \eta$. Then, $S(h\xi, h\xi, h\eta) = S(\xi, \xi, \eta) > 0$.

As a h is $\beta - F-$weak contraction, there exists $\tau > 0$ such that

$$\begin{aligned} \tau + F(S(\xi, \xi, \eta)) &= \tau + F(S(h\xi, h\xi, h\eta)) \\ &\leq \tau + \beta(\xi, \xi, \eta) F(S(h\xi, h\xi, h\eta)) \\ &\leq F(M(\xi, \xi, \eta)). \end{aligned} \tag{9}$$

Now,

$$\begin{aligned} M(\xi, \xi, \eta) &= \max\{S(\xi, \xi, \eta), S(\xi, \xi, h\xi), S(\eta, \eta, h\eta), \\ &\quad \frac{1}{4}(S(\xi, \xi, h\xi) + S(\xi, \xi, h\eta) + S(\eta, \eta, h\xi))\} \\ &= S(\xi, \xi, \eta). \end{aligned}$$

From (9), follows

$$\tau + F(S(\xi, \xi, \eta)) \leq F(S(\xi, \xi, \eta)),$$

a contradiction. Therefore, $\xi = \eta$.

□

From Remark 2, the following corollary is obtained:

COROLLARY 1. *Let (X, S) be a complete S-metric space and $h : X \to X$ be a $\beta - F-$contraction mapping satisfying the hypotheses of Theorem 3. Then h has a unique fixed point.*

EXAMPLE 3. Consider $X = [0, 1]$ together with the S-metric $S(u, v, w) = |u - w| + |v - w|$, for all $u, v, w \in X$. Then, (X, S) is a complete S-metric space.

Let $h : X \to X$ be given by $hu = \frac{u}{10}$.

Also, let $F \in \mathfrak{F}$ as $Fv = \ln v$, for all $v > 0$.

Then, taking $\beta(u, v, w) = 1$, for all $u, v, w \in X$ and $\tau = \ln 10$ makes it clear that h is a $\beta - F-$weak contraction. Also, h satisfy all the hypotheses of Theorem 3. So, h has a unique fixed point. Clearly, $\xi = 0$ is the only fixed point of h.

Consequences

In this subsection, some known results in the literature are obtained as the consequences of these results. The examples are as follows:

(1) For all $x, y \in X$ and $0 \leq k < 1$,

$$S(Tx, Tx, Ty) \leq kS(x, x, y)$$

implies

$$\begin{aligned} S(Tx, Tx, Ty) &\leq k \max\{S(x, x, y), S(x, x, Tx), S(y, y, Ty), \\ &\quad \frac{1}{4}(S(x, x, Tx) + S(x, x, Ty) + S(y, y, Tx))\} \\ &= kM(x, x, y). \end{aligned}$$

If $S(Tx, Tx, Ty) > 0$, then

$$\tau + \ln S(Tx, Tx, Ty) \leq \ln(M(x, x, y)),$$

where $\tau = -\ln k > 0$.

Therefore, the contraction condition in Definition 2.13 of (Sedghi et al, 2012) becomes the condition (2) with $Fv = \ln v$, for all $v > 0$ and $\beta(u, v, w) = 1$, for all $u, v, w \in X$. This shows that Theorem 3 is a generalization of Theorem 3.1 of (Sedghi et al, 2012).

(2) For all $x, y \in X$ and $h \in [0, 1)$,

$$S(Tx, Tx, Ty) \leq h \max\{S(Tx, Tx, x), S(Ty, Ty, y)\},$$

that is,

$$S(Tx, Tx, Ty) \leq h \max\{S(x, x, Tx), S(y, y, Ty)\}$$

implies

$$\begin{aligned} S(Tx, Tx, Ty) &\leq h \max\{S(x, x, y), S(x, x, Tx), S(y, y, Ty), \\ &\quad \frac{1}{4}(S(x, x, Tx) + S(x, x, Ty) + S(y, y, Tx))\} \\ &= hM(x, x, y). \end{aligned}$$

If $S(Tx, Tx, Ty) > 0$, then

$$\tau + \ln S(Tx, Tx, Ty) \leq \ln(M(x, x, y)),$$

where $\tau = -\ln h > 0$.

Therefore, the contraction condition in Corollary 2.10 of (Sedghi & Dung, 2014) becomes the condition (2) with $Fv = \ln v$, for all $v > 0$ and $\beta(u, v, w) = 1$, for all $u, v, w \in X$. This shows that Theorem 3 is a generalization of Corollary 2.10 of (Sedghi & Dung, 2014).

(3) For all $x, y \in X$ and $a, b, c \geq 0$ with $a + b + c < 1$,

$$S(Tx, Tx, Ty) \leq aS(x, x, y) + ab(Tx, Tx, x) + cS(Ty, Ty, y),$$

that is,

$$S(Tx, Tx, Ty) \leq aS(x, x, y) + ab(x, x, Tx) + cS(y, y, Ty)$$

implies

$$\begin{aligned} S(Tx,Tx,Ty) &\leq (a+b+c)\max\{S(x,x,y), S(x,x,Tx), S(y,y,Ty), \\ &\quad \frac{1}{4}(S(x,x,Tx)+S(x,x,Ty)+S(y,y,Tx))\} \\ &= (a+b+c)M(x,x,y). \end{aligned}$$

If $S(Tx,Tx,Ty) > 0$, then

$$\tau + \ln S(Tx,Tx,Ty) \leq \ln(M(x,x,y)),$$

where $\tau = -\ln(a+b+c) > 0$.

Therefore, the contraction condition in Corollary 2.12 of (Sedghi & Dung, 2014) becomes the condition (2) with $Fv = \ln v$, for all $v > 0$ and $\beta(u,v,w) = 1$, for all $u,v,w \in X$. This shows that Theorem 3 is a generalization of Corollary 2.12 of (Sedghi & Dung, 2014).

(4) Taking $\beta(u,v,w) = 1$ for all $u,v,w \in X$, we obtain Theorem 2.1 of (Ranjbar & Samei, 2019) from Corollary 1. Note that we are not using the condition $(F2)$ in our results.

Application

In this section, Theorem 3 is used to prove the existence and uniqueness of a solution of a non-linear Fredholm integral equation.

Let $X = (C[a,b],\mathbb{R})$ be the set of all continuous functions defined on $[a,b]$. Let the S-metric $S : X \times X \times X \to [0,\infty)$ be defined by

$$S(u,v,w) = \max_{s\in[a,b]} |u(s) - w(s)| + \max_{s\in[a,b]} |v(s) - w(s)|.$$

Then (X,S) is a complete S-metric space.

Now, the following non-linear Fredholm integral equation is considered:

$$v(t) = \varsigma(t) + \frac{1}{b-a}\int_a^b K(t,s,v(s))ds, \tag{10}$$

where $t,s \in [a,b]$. Assume that $K : [a,b]\times[a,b]\times X \to \mathbb{R}$ and $\varsigma : [a,b] \to \mathbb{R}$ are continuous.

Define the operator $T : X \to X$ by

$$Tv(t) = \varsigma(t) + \frac{1}{b-a}\int_a^b K(t,s,v(s))ds. \tag{11}$$

Note that (10) has a solution if and only if T has a fixed point.

THEOREM 4. *Let K be a continuous function satisfying*

$$\begin{aligned}|K(t,s,v(s)) - K(t,s,\varsigma(s))| \;\leq\; & k\max\Big\{|v(s)-\varsigma(s)|, |v(s)-Tv(s)|,\\ & |\varsigma(s)-T\varsigma(s)|, \frac{1}{4}(|v(s)-Tv(s)| +\\ & |v(s)-T\varsigma(s)| + |\varsigma(s)-Tv(s)|)\Big\},\end{aligned}$$

for all $v, \varsigma \in X$ with $v \neq \varsigma$; $s, t \in [a,b]$ and for some $k \in [0,1)$. Then the integral equation (10) has a unique solution.

Proof. Define $\beta : X \times X \times X \to [0,\infty)$ by $\beta(u,v,w) = 1$ for all $u, v, w \in X$. Then T is β-admissible. Take $F \in \mathfrak{F}$ as $Fu = \ln u$, for all $u > 0$.

Now,

$$\begin{aligned}2|Tv(t) - T\varsigma(t)| \;&=\; \frac{2}{b-a}\left|\int_a^b K(t,s,v(s))ds - \int_a^b K(t,s,\varsigma(s))ds\right|\\ &\leq\; \frac{2}{b-a}\int_a^b \big|(K(t,s,v(s)) - K(t,s,\varsigma(s)))\big|ds\\ &\leq\; \frac{2k}{b-a}\int_a^b \max\big\{|v(s)-\varsigma(s)|, |v(s)-Tv(s)|,\\ &\qquad |\varsigma(s)-T\varsigma(s)|, \frac{1}{4}(|v(s)-Tv(s)| +\\ &\qquad |v(s)-T\varsigma(s)| + |\varsigma(s)-Tv(s)|)\big\}ds.\end{aligned}$$

Taking the maximum on both sides, yields

$$\begin{aligned}&S(Tv,Tv,T\varsigma) = 2\max_{t\in[a,b]}|Tv(t) - T\varsigma(t)|\\ &\leq \frac{2k}{b-a}\max_{t\in[a,b]}\int_a^b \max\big\{|v(s)-\varsigma(s)|, |v(s)-Tv(s)|, |\varsigma(s)-T\varsigma(s)|,\\ &\frac{1}{4}(|v(s)-Tv(s)| + |v(s)-T\varsigma(s)| + |\varsigma(s)-Tv(s)|)\big\}ds\end{aligned}$$

$$\leq \frac{k}{b-a}\max\Big(\max_{t\in[a,b]}\big\{2|\upsilon(s)-\varsigma(s)|, 2|\upsilon(s)-T\upsilon(s)|, 2|\varsigma(s)-T\varsigma(s)|,$$
$$\frac{1}{4}(2|\upsilon(s)-T\upsilon(s)|+2|\upsilon(s)-T\varsigma(s)|+2|\varsigma(s)-T\upsilon(s)|)\big\}\Big)\int_a^b ds$$
$$= k\max\{S(\upsilon,\upsilon,\varsigma), S(\upsilon,\upsilon,T\upsilon), S(\varsigma,\varsigma,T\varsigma),$$
$$\frac{1}{4}(S(\upsilon,\upsilon,T\upsilon)+S(\upsilon,\upsilon,T\varsigma)+S(\varsigma,\varsigma,T\upsilon))\} = kM(\upsilon,\upsilon,\varsigma).$$

Taking the natural logarithm on both sides, gives

$$-\ln k + \ln S(T\upsilon,T\upsilon,T\varsigma) \leq \ln(M(\upsilon,\upsilon,\varsigma)).$$

So,

$$-\ln k + \beta(\upsilon,\upsilon,\varsigma)\ln S(T\upsilon,T\upsilon,T\varsigma) \leq \ln(M(\upsilon,\upsilon,\varsigma)).$$

Thus,

$$\tau + \beta(\upsilon,\upsilon,\varsigma)F(S(T\upsilon,T\upsilon,T\varsigma)) \leq F(M(\upsilon,\upsilon,\varsigma)),$$

where $-\ln k = \tau$.

This shows that T is a $\beta-F-$weak contraction. Thus, all the conditions of Theorem 3 are satisfied. Hence, the integral equation (10) has a unique solution.

□

Conclusions

In this paper, the concepts of $\beta-F-$contraction and $\beta-F-$weak contraction mappings are introduced and used to prove some fixed point results in the setting of S-metric space. Also, we obtain some known results in the literature as the consequences of our results. Also, some known results in the literature are obtained as the consequences of the results from this work. Finally, the obtained results are applied to prove the existence of a solution for a non-linear Fredholm integral equation.

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Resultados de punto fijo para mapeos de contracción débil $\beta - F-$ en espacios $S-$ métricos completos

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CAMPO: matemáticas
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: En este artículo presentamos el concepto de contracción $\beta - F-$débil utilizando los conceptos de contracción $F-$débil y contracción $\alpha - \psi$.

Métodos: Utilizando la contracción $\beta - F-$débil demostramos algunos teoremas de puntos fijos en el marco de espacios $S-$métricos.

Resultados: Los resultados obtenidos en puntos fijos en espacios $S-$métricos generalizan algunos resultados conocidos en la bibliografía.

Conclusión: La contracción débil $\beta - F$ generaliza algunos tipos de contracción importantes y examina la existencia de puntos fijos en espacios $S-$métricos. Los resultados se utilizan para resolver una ecuación integral de Fredholm no lineal.

Palabras claves: punto fijo, espacio S-métrico,
$\beta - F-$contracción débil, ecuación integral no lineal.

Результаты с фиксированной точкой для $\beta - F-$слабых сжимающих отображений в полных S-метрических пространствах

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РУБРИКА ГРНТИ: 27.25.17 Метрическая теория функций,
27.39.15 Линейные пространства, снабженные топологией, порядком и другими структурами

ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В данной статье введено понятие $\beta - F-$ слабого сокращения, используя концепт $F-$слабого сокращения и $\alpha - \psi-$ сжатия.

Методы: С помощью $\beta - F-$слабого сжатия, доказываются некоторые теоремы о неподвижных точках в рамках $S-$метрических пространств.

Результаты: Результаты исследования о неподвижных точках в $S-$метрических пространствах обобщают некоторые известные в литературе результаты.

Выводы: $\beta - F-$слабое сжатие обобщает некоторые важные виды сокращений, исследуя существование неподвижной точки в $S-$метрических пространствах. Результаты статьи используются для решения нелинейного интегрального уравнения Фредгольма.

Ключевые слова: неподвижная точка, S-метрическое пространство, $\beta - F-$слабое сжатие, нелинейное интегральное уравнение.

Резултати фиксне тачке за $\beta - F-$слаба мапирања контракције у потпуним S-метричким просторима

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ОБЛАСТ: математика
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: У овом раду уводи се појам $\beta - F-$слабе контракције користећи концепте $F-$слабе контракције и $\alpha - \psi-$контракције.

Методе: Коришћењем $\beta-F-$слабе контракције доказују се неке теореме о фиксним тачкама у оквиру $S-$метричких простора.

Резултати: Добијени резултати о фиксним тачкама у $S-$метричким просторима генерализују неке познате резултате у литератури.

Закључак: $\beta - F-$слаба контракција генерализује неке важне типове контракција и испитује постојање фиксне тачке у $S-$метричким просторима. Резултати се користе за решавање нелинеарне Фредхолмове интегралне једначине.

Кључне речи: фиксна тачка, $S-$метрички простор,

$\beta - F-$слаба контракција, нелинеарна интегрална једначина.

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Dominance number on cyclooctane chains

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FIELD: materials and chemical technologies, mathematics
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: Chemical structures are conveniently represented by graphs where atoms are nodes (vertices) and chemical bonds are branches (lines) in the graph. A graphical representation of a molecule provides a lot of useful information about the chemical properties of the molecule. It is known that numerous physical and chemical properties of molecules are highly correlated with theoretical invariants of graphs, which we call topological indices. One such theoretical invariant is the dominance number. The aim of this research is to determine the k-dominance number for cyclooctane chains COC_n^1, COC_n^2, COC_n^3 *and* COC_n^4, *for k ∈ {1,2,3}, n ∈* N.

Methods: The cyclooctane chain is a chain of octagons connected by a single line. The vertices of the octagon are treated as nodes of the graph, and the sides and the line connecting them, as branches in the graph. Using mathematical methods, k-dominance was determined on one octagon, k∈{1,2,3}. Then, by representing the cyclooctane chains COC_n^1, COC_n^2, COC_n^3 *and* COC_n^4, *in a convenient, isomorphic way, we determined their k-dominance number, k∈{ 1,2,3}.*

Results: Determining k-dominance, k∈{1,2,3}, for 4 cyclooctane chains COC_n^1, COC_n^2, COC_n^3 *and* COC_n^4, *we obtained 12 different formulas to calculate their k-dominance number. All formulas are composed of several alternative algebraic expressions, the selection of which is conditioned by the divisibility of the number n by the number 2, 3 or 4, depending on the type of cyclooctane chain and k-dominance to be determined. The results of the research are fully presented in the paper through mathematically proven theorems and graphical representations.*

Conclusion: The results show that the k-dominance numbers, k∈{1,2,3}, on cyclooctane chains COC_n^1, COC_n^2, COC_n^3 *and* COC_n^4, *are determined and explicitly expressed by mathematical expressions. They also indicate the possibility of their application in molecular graphs of cyclooctane rings, in computational chemistry, chemical and biological industry.*

Key words: cyclooctane, cyclooctane chain, dominance number.

Introduction

Graph theory occupies an important place in many fields of science. Among them are chemistry and biology. Chemical structures are conveniently represented by graphs, where atoms are nodes (vertices) in the graph and chemical bonds are lines (branches) in the graph (Trinajstić, 1992). Graphical representation of molecules provides a wealth of useful information about the chemical properties of molecules (Gupta et al, 2001, 2022). It has been shown that numerous physical and chemical properties of molecules are highly correlated with theoretical invariants of graphs, which we call topological indices or molecular descriptors (Todeschini & Consonni, 2000). Topological indices are extremely useful in calculating the physicochemical characteristics of large chemical structures, which are otherwise difficult to calculate for large networks (Baig et al, 2018).

One of the latest concepts that represents a combination of chemistry, mathematics and informatics is chemical informatics (Ahmed et al, 2021). In computational chemistry, cyclooctane chains are an imperative class of cycloalkanes, which has led to the investigation of their structural characteristics with basic graph parameters (Raza et al, 2023). The authors of the mentioned paper derived the mathematical expected values of topological descriptors of cyclooctane. They also performed a comparative analysis for different descriptors and pointed to special classes of cyclooctane chains with exact values.

In the paper (Raza & Imran, 2021), the expected values of some molecular descriptors in a random cyclooctane chain were investigated. The authors of the paper (Wei et al, 2018) determined the exact formulas for the expected value of the Wiener index in a random cyclooctane chain. Research was also carried out on the expected values of three types of Kirchhoff indices (Liu et al, 2021), Gutman and Schultz indices (Liu et al, 2023) in the cyclooctane chain. In the previous period, other research studies were also carried out on cyclooctanes and cyclooctane chains (Bharadwaj, 2000).

It is known that the dominance number is one of the theoretical invariants of graphs (Vukičević & Klobučar, 2007). In the previous period, dominance research was carried out on various graphs. Cactus graphs, as a special type of connected graphs in which no branch is found in more than one cycle, have been investigated in numerous works. Dominance on rhomboidal cactus chains (Carević et al, 2020), pentagonal (Carević, 2022), hexagonal (Majstorović et al, 2012, 2016) was investigated. Research was also carried out on linear benzenoids (Vukičević &

Klobučar, 2007), hexagonal network (Klobučar & Klobučar, 2019), and icosahedral hexagonal network (Carević, 2021).

In this paper, we deal with k-dominance on cyclooctane chains COC_n^1, COC_n^2, COC_n^3 and COC_n^4, for $k \in \{1, 2, 3\}$.

Cyclooctane chains

A cyclooctane chain is a chain of octagons in which each node is in only one octagon. The octagons are connected to each other by a line that joins two nodes from two adjacent octagons, thus forming a cyclooctane chain (Figure 1).

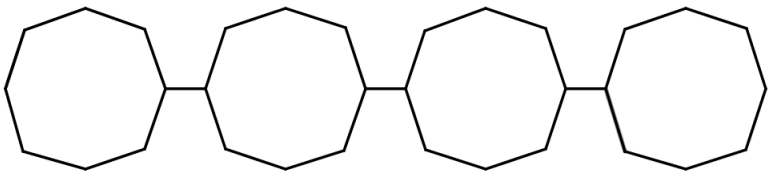

Figure 1 – Cyclooctane chain length 4

The nodes in the octagon joined by the connecting line are called cut (intersected) nodes. The minimum distance between two cut nodes in one octagon is denoted by *p*. In the cyclooctane chain in Figure 1, the distance between two cut nodes in each octagon is *p* = 4. We denote the cyclooctane chain of the length *n* formed in this way by COC_n^4, where the length of the chain *n* is determined by the number of octagons in the chain. The minimum distance between two cut nodes can be *p* = 3 (Figure 2); it can also be *p* = 2 (Figure 3) or *p* = 1 (Figure 4), whereby we denote the corresponding cyclooctane chains, respectively, with COC_n^3, COC_n^2 and COC_n^1.

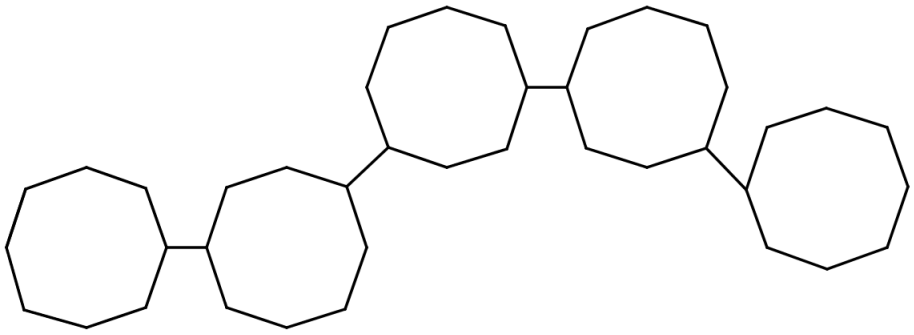

Figure 2 – Cyclooctane chain COC_5^3

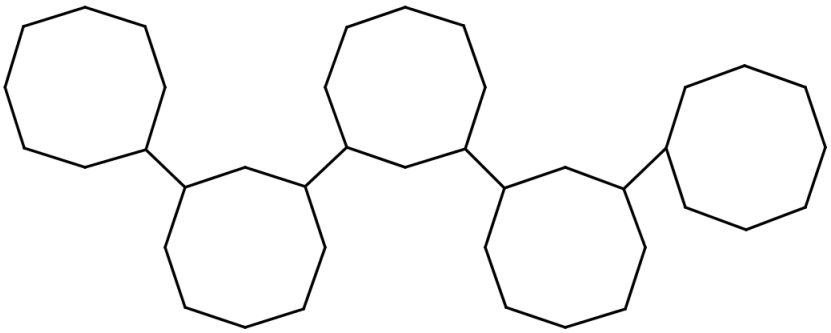

Figure 3 – Cyclooctane chain COC_5^2

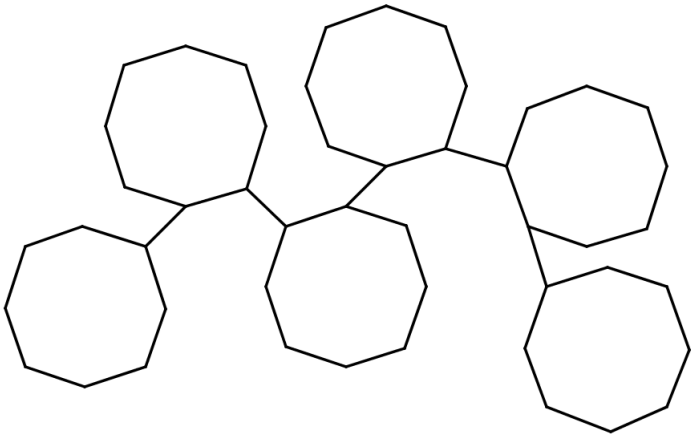

Figure 4 – Cyclooctane chain COC_6^1

Research results

Preliminaries

At the beginning of this section, we will consider *k*-dominance on one octagon O_8, $k \in \{1, 2, 3\}$. We denote the set of nodes (vertices) in each graph *G* by *V(G)*. A set $D \subset V(G)$ is said to be a *k*-dominant set in the graph *G* if for every node *y* outside the set *D* there is at least one node $x \in D$ such that $d(x, y) \leq k$ where with $d(x, y)$ labeled distance between the nodes *x* and *y*. The number of elements of the smallest *k*-dominant set is called the *k*-dominance number and is denoted by γ_k.

Lemma 1: The 1-domination number for the octagon is $\gamma_1(O_8) = 3$.
Proof: Let us denote the nodes of the octagon with $x_1, x_2, \ldots, x_8$ (Figure 5).

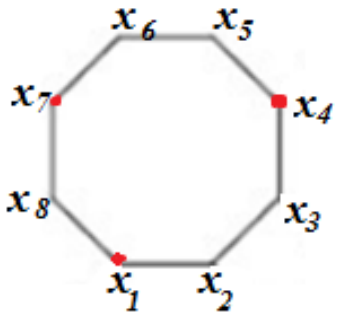

Figure 5 – 1-dominant set on an octagon

One node of the octagon dominates two neighboring nodes. Let us take the node x_1. It dominates the nodes x_2 and x_8. There are 5 nodes left in the octagon. Based on the proof of Lemma 2.1 presented in the paper (Carević, 2022), the 1-dominance number for 5 nodes is 2. Let these be the nodes x_4 and x_7 in the given octagon. Thus, the set D = $\{x_1, x_4, x_7\}$ is a 1-dominant set for the given octagon, but it is not the only one. They are also sets containing any 3 nodes of an octagon with the mutual distance d = 2 and d = 3. Based on the proof of Lemma 2.1 in the mentioned paper, there is no 1-dominating set D' of lesser cardinality. Therefore, the minimal 1-dominant set on the octagon is a three-membered set, so the 1-dominant number for the octagon is $\gamma_1(O_8) = 3$.

Lemma 2: The 2-domination number for the octagon is $\gamma_2(O_8) = 2$.
Proof: Let us denote the nodes of the octagon with $x_1, x_2, \ldots, x_8$ (Figure 6).

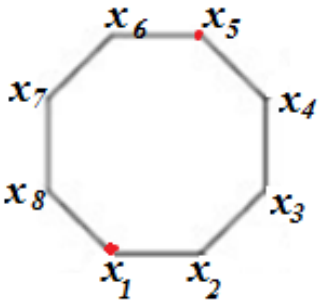

Figure 6 – 2-dominant set on an octagon

The node x_1 has 2-dominance over the nodes x_2 and x_3, on the one hand, and over the nodes x_8 and x_7 , on the other hand. For the remaining nodes x_4, x_5, x_6, it is necessary to determine one 2-dominant node. Let it be a node x_5. So the set D = $\{x_1, x_5\}$ is a 2-dominant set for the given octagon, but it is not the only 2-dominant set whose cardinality is equal to 2, analogous to the previous consideration, where the distance between the dominant nodes must be 3 or 4. Let us prove that there is no set D' of lesser cardinality which is a 2-dominating set on the octagon. Assuming it exists, its cardinality would be 1. But one node cannot 2-dominate the 7 remaining nodes in the octagon. Therefore, the minimal 2-dominant set on the octagon is a two-membered set, so the 2-dominant number for the octagon is $\gamma_2(O_8)$ = 2.

Lemma 3: The 3-domination number for the octagon is $\gamma_3(O_8)$ = 2.
Proof: Let us look at Figure 6. The node x_1 has 3-dominance over the nodes x_2 ,x_3 and x_4, on the one hand, and over the nodes x_8, x_7 and x_6, on the other hand. The node x_5 is not dominated. So the set D = $\{x_1, x_5\}$ is a 3-dominant set for the given octagon, but it is not the only 3-dominant set whose cardinality is equal to 3, analogous to the previous consideration. Analogous to the proof of Lemma 2, there is no set D' of lesser cardinality which is a 3-dominating set on the octagon. Therefore, the minimal 3-dominant set on the octagon is a two-membered set, so the 3-dominant number for the octagon is $\gamma_3(O_8)$ = 2.

Let us now define the coverage index of the nodes of the graph by the dominating node:

Definition 1: The node coverage index by the dominating node is the total number of nodes covered by the dominance including the dominant node. For *k*-dominance, we denote the coverage index by $index_k$.

Based on what was stated in Lemma 1, Lemma 2 and Lemma 3, in the octagon there is: $index_1$= 3, $index_2$ = 5, $index_3$= 7.

In the next part of the presentation, we consider k-dominance, for k∈{1,2,3}, on cyclooctane chains COC_n^1, COC_n^2, COC_n^3 and COC_n^4, $n \in N$, $n \geq 2$.

It is known that two isomorphic graphs have equal dominance numbers (Vukičević & Klobučar, 2007). Based on this, we will present cyclooctane chains COC_n^1, COC_n^2, COC_n^3 and COC_n^4 in a convenient, isomorphic way and determine the *k*-dominance, for *k*∈ {1,2,3}.

Cyclooctane chain $\boldsymbol{COC_n^1}$

Theorem 1. The 1-dominance number on the cyclooctane chain COC_n^1 is

$$\gamma_1(COC_n^1) = \begin{cases} 8 \cdot \frac{n}{3} \ , \ for n = 3k, k \in N \\ 8 \cdot \left[\frac{n}{3}\right] + 6, \ for n = 3k-1, k \in N \\ 8 \cdot \left[\frac{n}{3}\right] + 3, \ for n = 3k-2, k \in N \end{cases}$$

Proof: We observe the isomorphic graph of the cyclooctane chain COC_n^1 in Figure 7:

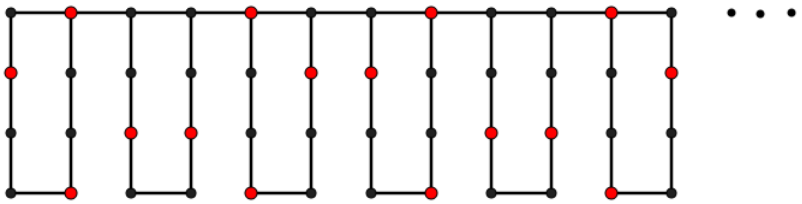

Figure 7 – 1-dominance on COC_n^1

Based on Lemma 1, the 1-dominance number in the first octagon is 3. Let us assume that the third dominant node is a cut node. Since in COC_n^1 the distance between cut nodes is p = 1, the third dominant node of the first octagon will dominate over the first cut node in the second octagon. In the same way, the first cut node in the third octagon will dominate the second cut node in the second octagon. Therefore, in the second octagon, two nodes will be enough to dominate the remaining 6 nodes because the coverage index of one node is $index_1$= 3. In the third octagon, 3 nodes are necessary for dominance, and based on Lemma 1, they cannot be adjacent. Therefore, in the fourth octagon we must have 3 dominant nodes, one of them will be a cut node as in the first octagon. In this way, we have a periodic repetition of the position of the dominant nodes with a period of ω = 3 octagons. If n = 3k – 1, k∈N, the last octagon cannot have only 2 dominant nodes because $index_1$= 3, so it will have 3 dominant nodes. Based on Lemma 1 and everything presented, we get that:

$$\gamma_1(COC_n^1) = \begin{cases} 8 \cdot \frac{n}{3} \ , \ for n = 3k, k \in N \\ 8 \cdot \left[\frac{n}{3}\right] + 6, \ for n = 3k-1, k \in N \\ 8 \cdot \left[\frac{n}{3}\right] + 3, \ for n = 3k-2, k \in N \end{cases}$$

Theorem 2. The 2-dominance number on the cyclooctane chain COC_n^1 is

$$\gamma_2(COC_n^1) = \begin{cases} 3 \cdot \frac{n}{2}, & for n = 2k, k \in N \\ 3 \cdot \left[\frac{n}{2}\right] + 2, & for n = 2k-1, k \in N \end{cases}$$

Proof: We observe the isomorphic graph of the cyclooctane chain COC_n^2 in Figure 8. As the coverage index for 2-dominance is $index_2$= 5, in the first octagon one node will dominate over five nodes while 3 nodes remain without dominance. Let us choose a suitable dominating node so that the nodes not covered by dominance are the intersected node and its neighboring nodes.

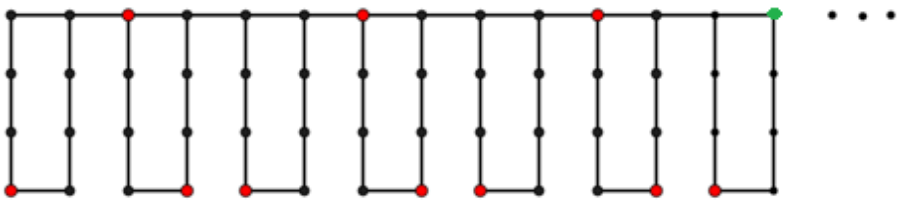

Figure 8 – 2-dominance on COC_n^1

In the second octagon, we take the dominant node so that it dominates the uncovered nodes of the previous octagon. In this octagon, we must have one more dominant node that will dominate the remaining nodes of that octagon. In the first two octagons, we have a total of 16 nodes dominated by 3 nodes (marked in red). The dominance repeats with a period of ω = 2 octagons. If *n* is an odd number, the last octagon will have one more dominant node (marked in green in Figure 8) because $index_2$= 5. Based on Lemma 2 and everything presented, we get that:

$$\gamma_2(COC_n^1) = \begin{cases} 3 \cdot \frac{n}{2}, & for n = 2k, k \in N \\ 3 \cdot \left[\frac{n}{2}\right] + 2, & for n = 2k-1, k \in N \end{cases}$$

Theorem 3. The 3-dominance number on the cyclooctane chain COC_n^1 is

$$\gamma_3(COC_n^1) = \begin{cases} 5 \cdot \frac{n}{4}\ ,\ for n = 4k, k \in N \\ 5 \cdot \left[\frac{n}{4}\right] + 4,\ for n = 4k-1, k \in N \\ 5 \cdot \left[\frac{n}{4}\right] + 3,\ for n = 4k-2, k \in N \\ 5 \cdot \left[\frac{n}{4}\right] + 2,\ for n = 4k-3, k \in N \end{cases}$$

Proof: As the coverage index for 3-dominance is $index_3$= 7, in the first octagon one node will dominate all nodes except one. Let us choose a suitable dominating node so that the node that is not covered by the dominance is the intersected node (Figure 9).

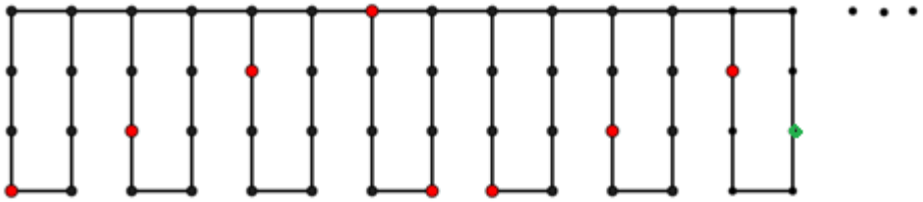

Figure 9 – 3-dominance on COC_n^1

In the second octagon, we take the dominant node so that it dominates the uncovered node of the previous octagon. Analogously, this applies in the third and fourth octagons. In four octagons, there are a total of 32 nodes where $index_3$= 7, so it follows that there must be 5 dominant nodes. These 5 dominant nodes completely cover the first 4 octagons with dominance, so from the fifth octagon there is a repetition of dominance. The dominance repeats with a period of ω = 4 octagons. If *n* is not divisible by 4 in the last octagon, we must have another dominant node (marked in green in Figure 9) because $index_3$= 7. Based on Lemma 3 and everything presented, we get that:

$$\gamma_3(COC_n^1) = \begin{cases} 5 \cdot \frac{n}{4}\ ,\ for n = 4k, k \in N \\ 5 \cdot \left[\frac{n}{4}\right] + 4,\ for n = 4k-1, k \in N \\ 5 \cdot \left[\frac{n}{4}\right] + 3,\ for n = 4k-2, k \in N \\ 5 \cdot \left[\frac{n}{4}\right] + 2,\ for n = 4k-3, k \in N \end{cases}$$

Cyclooctane chain $\boldsymbol{COC_n^2}$

Theorem 4. The 1-dominance number on the cyclooctane chain COC_n^2 is $\gamma_1(COC_n^2) = 3n$.

Proof: We observe the isomorphic graph of the cyclooctane chain COC_n^2 in Figure 10:

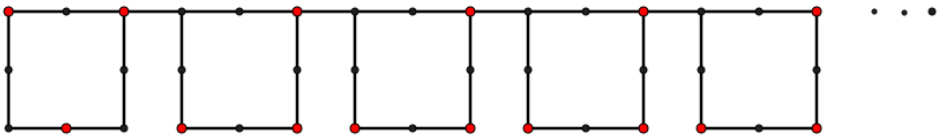

Figure 10 – 1-dominance on COC_n^2

By Lemma 1, the 1-dominance number in the first octagon is 3. Let us assume that the third dominant node is a cut node. As the distance between the cut nodes in COC_n^2 is p = 2, the third dominant node of the first octagon will dominate over the first cut node in the second octagon, but not over its neighboring nodes. In the second octagon, there are 7 nodes left, for which 2 dominant nodes are not enough, which would dominate over 6 nodes because $index_1$= 3. Therefore, in the second octagon, we must have 3 dominant nodes, where one of them will be a cut node as in the first octagon. In this way, we have a periodic repetition of the position of the dominant nodes in each subsequent octagon. Based on Lemma 1 and everything presented, we get that $\gamma_1(COC_n^2) = 3n$.

Theorem 5. The 2-dominance number on the cyclooctane chain COC_n^2 is

$$\gamma_2(COC_n^2) = \begin{cases} 3 \cdot \frac{n}{2}, & for\, n = 2k, k \in N \\ 3 \cdot \left[\frac{n}{2}\right] + 2, & for\, n = 2k-1, k \in N \end{cases}$$

Proof: We observe the isomorphic graph of the cyclooctane chain COC_n^2 in Figure 11. As the coverage index for 2-dominance is $index_2$= 5, in the first octagon one node will dominate over five nodes while 3 nodes remain without dominance. Let us choose a suitable dominating node so that the nodes that are not covered by dominance are the cut node and its neighboring nodes.

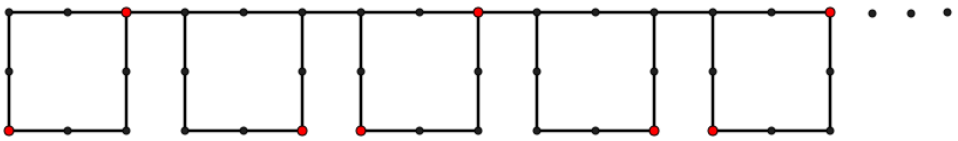

Figure 11 – 2-dominance on COC_n^2

This cut node will dominate the first cut node in the second octagon and its adjacent nodes. In the second octagon, we must have another dominant node that will dominate the remaining 5 nodes. As $index_2$= 5, this node will complete the dominance in the second octagon. In the first two octagons we have a total of 16 nodes dominated by 3 nodes (marked in red). The dominance repeats with a period of ω = 2 octagons. Based on Lemma 2 and everything presented, we get that:

$$\gamma_2(COC_n^2) = \begin{cases} 3 \cdot \frac{n}{2}, & for n = 2k, k \in N \\ 3 \cdot \left[\frac{n}{2}\right] + 2, & for n = 2k-1, k \in N \end{cases}$$

Theorem 6. The 3-dominance number on the cyclooctane chain COC_n^2 is $\gamma_3(COC_n^2) = n + 1$.

Proof: As the coverage index for 3-dominance is $index_3$= 7, in the first octagon one node will dominate all nodes except one. Let us choose a suitable dominating node so that the node that is not covered by dominance is a cut node (Figure 12).

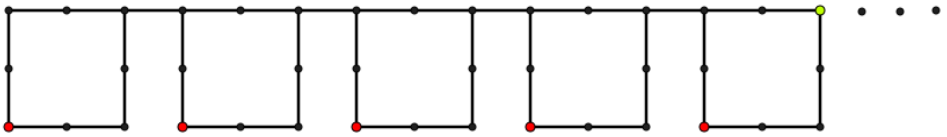

Figure 12 – 3-dominance on COC_n^2

In the second octagon, we select the dominating node so that it dominates the intersected node in the first octagon (Figure 12). This node, similar to the previous one, will dominate all the nodes of the second octagon except the second cut node in it. In this way, the previously described dominance is repeated, so it follows that in each octagon we have one dominant node, except in the last octagon in the chain, where we must have two nodes

(the node marked in green in Figure 12). Based on Lemma 3 and everything presented, we get that $\gamma_3(COC_n^2) = n + 1$.

Cyclooctane chain $\boldsymbol{COC_n^3}$

Theorem 7. The 1-dominance number on the cyclooctane chain COC_n^3 is $\gamma_1(COC_n^3) = 3n$.

Proof: We observe the isomorphic graph of the cyclooctane chain COC_n^3 in Figure 13.

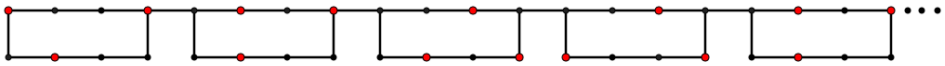

Figure 13 – 1-dominance on COC_n^3

By Lemma 1, the 1-dominance number in the first octagon is 3. Assume that the third dominant node is a cut node. Since in COC_n^3 the distance between intersected nodes is p = 3, the third dominant node of the first octagon will dominate over the first cut node in the second octagon, but not over its neighboring nodes. In the second octagon, there are 7 nodes left, for which 2 dominant nodes are not enough, it would dominate over 6 nodes because $index_1$= 3. Therefore, in the second octagon, we must have 3 dominant nodes with the mutual distance of d = 2 and d = 3 as proved in Lemma 1. In the same way, we must have 3 dominant nodes in each subsequent octagon. Based on everything presented, we get that $\gamma_1(COC_n^3) = 3n$.

Theorem 8. The 2-dominance number on the cyclooctane chain COC_n^3 is:

$$\gamma_2(COC_n^3) = \begin{cases} 3 \cdot \frac{n}{2}, & for\, n = 2k, k \in N \\ 3 \cdot \left[\frac{n}{2}\right] + 1, & for\, n = 2k+1, k \in N \end{cases}$$

Proof: We observe the isomorphic graph of the cyclooctane chain COC_n^3 in Figure 14:

Figure 14 – 2-dominance on COC_n^3

As the coverage index for 2-dominance is $index_2$= 5, in the first octagon one node will dominate over five nodes while 3 nodes remain without dominance. Let us choose the first intersected node of the second octagon

as the dominant node. It will dominate the remaining 3 nodes of the first octagon and a total of 5 nodes of the second octagon because $index_2$= 5. In the second octagon, we must have another dominant node that will dominate the second intersected node and the remaining 2 nodes. Assume that the dominant node is the second cut node. It will also dominate 3 nodes in the third octagon, so one dominant node will be enough in the third octagon. The dominance repeats with a period of ω = 2 octagons. Based on Lemma 2 and everything presented, we get that:

$$\gamma_2(COC_n^3) = \begin{cases} 3 \cdot \frac{n}{2}, & for n = 2k, k \in N \\ 3 \cdot \left[\frac{n}{2}\right] + 1, & for n = 2k+1, k \in N \end{cases}$$

Theorem 9. The 3-dominance number on the cyclooctane chain COC_n^3 is $\gamma_3(COC_n^3) = n + 1$.
Proof: We observe the isomorphic graph of the cyclooctane chain COC_n^3 in Figure 15:

Figure 15 – 3-dominance on COC_n^3

As the coverage index for 3-dominance is $index_3$= 7, in the first octagon one node will dominate all nodes except one. Let us choose a suitable dominating node so that the node not covered by the dominance is the intersected node. In the second octagon, we select the dominating node so that it dominates the intersected node in the first octagon (Figure 15). This node, similar to the previous one, will dominate all the nodes of the second octagon except the second intersected node in it. In this way, the previously described dominance is repeated, so it follows that in each octagon we have one dominant node, except in the last octagon in the chain, where we must have two nodes (the node marked in green in Figure 15). Based on Lemma 3 and everything presented, we get that $\gamma_3(COC_n^3)$ = n + 1.

Cyclooctane chain COC_n^4

Theorem 10. The 1-dominance number on the cyclooctane chain COC_n^4 is:

$$\gamma_1(COC_n^4) = \begin{cases} 8 \cdot \frac{n}{3} \quad , \quad forn = 3k, k \in N \\ 8 \cdot \left[\frac{n}{3}\right] + 6, \ forn = 3k-1, k \in N \\ 8 \cdot \left[\frac{n}{3}\right] + 3, \ forn = 3k-2, k \in N \end{cases}$$

Proof: We observe the isomorphic graph of the cyclooctane chain COC_n^4 in Figure 16:

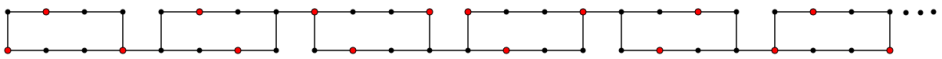

Figure 16 – 1-dominance on COC_n^4

By Lemma 1, the 1-dominance number in the first octagon is 3. Assume that the third dominant node is a cut node. The third dominant node of the first octagon will dominate the first cut node in the second octagon. In the same way, the first cut node in the third octagon will dominate the second cut node in the second octagon. Therefore, in the second octagon, two nodes will be sufficient to dominate the remaining 6 nodes because the coverage index of one node is $index_1$= 3. In the third octagon, 3 nodes are necessary for dominance, and based on Lemma 1, they cannot be adjacent. Therefore, in the fourth octagon we must have 3 dominant nodes, one of which will be a cut node as in the first octagon. It will dominate the first cut node of the fifth octagon. Also, the first cut node in the sixth octagon will dominate the second cut node in the fifth octagon. Therefore, in the fifth octagon, 2 nodes will be enough to dominate the remaining 6 nodes. In the sixth octagon, 3 dominant nodes are necessary. In this way, we have a periodic repetition of the position of the dominant nodes with a period of ω = 3 octagons. If $n = 3k - 1$, $k \in N$, the last octagon cannot have only 2 dominant nodes because $index_1$= 3, will already have 3 dominant nodes. Based on Lemma 1 and everything presented, we get that:

$$\gamma_1(COC_n^4) = \begin{cases} 8 \cdot \frac{n}{3} \quad , \quad forn = 3k, k \in N \\ 8 \cdot \left[\frac{n}{3}\right] + 6, \ forn = 3k-1, k \in N \\ 8 \cdot \left[\frac{n}{3}\right] + 3, \ forn = 3k-2, k \in N \end{cases}$$

Theorem 11. The 2-dominance number on the cyclooctane chain COC_n^4 is $\gamma_2(COC_n^4) = n + 1$.

Proof: We observe the isomorphic graph of the cyclooctane chain COC_n^4 in Figure 17.

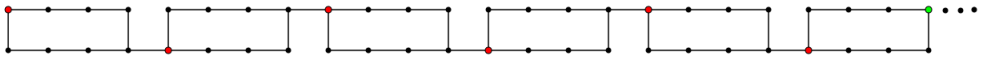

Figure 17 – 2-dominance on COC_n^4

As the coverage index for 2-dominance is $index_2$= 5, in the first octagon one node will dominate over five nodes while 3 nodes remain without dominance. Let us choose a suitable dominating node so that nodes that are not covered by dominance are a cut node and its neighboring nodes. In the second octagon, we take the dominant node so that it dominates the uncovered nodes of the previous octagon. This node will dominate over 5 nodes of the second octagon, leaving 3 nodes without dominance (as in the first octagon). Therefore, in the third octagon, we take the first cut node as the dominant node. It will dominate the remaining 3 nodes of the second octagon and the 5 nodes of the third octagon. In this way, the previously described dominance is repeated, so it follows that in each octagon we have one dominant node, except in the last octagon in the chain, where we must have two nodes (the node marked in green in Figure 17). Based on Lemma 2 and everything presented, we get that $\gamma_2(COC_n^4) = n + 1$.

Theorem 12. 3-dominance number on the cyclooctane chain COC_n^4 is $\gamma_3(COC_n^4) = n + 1$.
Proof: We observe the isomorphic graph of the cyclooctane chain COC_n^4 in Figure 18.

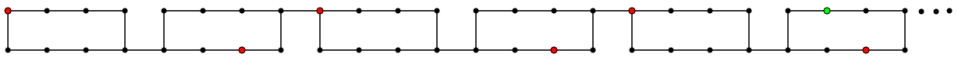

Figure 18 – 3-dominance on COC_n^4

As the coverage index for 3-dominance is $index_3$= 7, in the first octagon one node will dominate all nodes except one. Let us choose a suitable dominating node so that the node not covered by the dominance is the cut node. In the second octagon, we select the dominating node so that it dominates the cut node in the first octagon (Figure 18). This node, similar to the previous one, will dominate all but one of the nodes of the second octagon. In the third octagon, we take the first cut node as the dominant node. It will dominate the aforementioned node of the second octagon and the 7 nodes of the third octagon. In this way, the previously described dominance is repeated, so it follows that in each octagon we have one dominant node, except in the last octagon in the chain, where we must

have two nodes (the node marked in green in Figure 18). Based on Lemma 3 and everything presented, we get that $\gamma_3(COC_n^4) = n + 1$.

Conclusion

Numerous physical and chemical properties of molecules are highly correlated with graph theoretical invariants. One of the theoretical invariants is the dominance number. In this paper, we determined *k*-dominance numbers, $k \in \{1,2,3\}$, for cyclooctane chains COC_n^1, COC_n^2, COC_n^3 and COC_n^4, $n \geq 2$. The obtained results have a potential practical application in molecular graphs of cyclooctane rings containing saturated hydrocarbons. In computational chemistry, cyclooctane chains are an important class of cycloalkanes. There are numerous applications of cyclooctane in the chemical and biological industry.

Also, the obtained results can be applied in the manufacturing industry, transport and other branches of industry where series of connected elements are present.

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Número de dominancia en las cadenas de ciclooctano

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CAMPO: materiales, tecnologías químicas, matemáticas
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: Las estructuras químicas se representan convenientemente mediante gráficos donde los átomos son nodos (vértices) y los enlaces químicos son ramas (líneas) en el gráfico. Una representación gráfica de una molécula proporciona mucha información útil sobre las propiedades químicas de la molécula. Se sabe que numerosas propiedades físicas y químicas de las moléculas están altamente correlacionadas con invariantes teóricas de las gráficas, que llamamos índices topológicos. Uno de esos invariantes teóricos es el número de dominancia. El objetivo de esta investigación es determinar el número de k-dominancia para las cadenas de ciclooctano COC_n^1, COC_n^2, COC_n^3 y COC_n^4, for k ∈ {1,2,3}, n ∈ N.

Métodos: La cadena de ciclooctano es una cadena de octágonos conectados por una sola línea. Los vértices del octágono se tratan como nodos del gráfico, y los lados y la línea que los conecta, como ramas del gráfico. Utilizando métodos matemáticos, se determinó la k-dominancia en un octágono, k∈{1,2,3}. Luego, al representar las cadenas de ciclooctano COC_n^1, COC_n^2, COC_n^3 y COC_n^4, de una manera conveniente e isomorfa, determinamos su número de k-dominancia, k∈{ 1,2,3}.

Resultados: Determinando la k-dominancia, k∈{1,2,3}, para 4 cadenas de ciclooctano COC_n^1, COC_n^2, COC_n^3 y COC_n^4, Obtuvieron 12 fórmulas diferentes para calcular su número de k-dominancia. Todas las fórmulas se componen de varias expresiones algebraicas alternativas, cuya selección está condicionada por la divisibilidad del número n por el número 2, 3 o 4, según el tipo de cadena de ciclooctano y k-dominancia a determinar. Los resultados de la investigación se presentan íntegramente en el artículo a través de teoremas matemáticamente probados y representaciones gráficas.

Conclusión: Los resultados muestran que los números de k-dominancia, k∈{1,2,3}, en las cadenas de ciclooctano COC_n^1, COC_n^2, COC_n^3 y COC_n^4, están determinados y expresados explícitamente mediante expresiones matemáticas. También indican la posibilidad de su aplicación en gráficos moleculares de anillos de ciclooctano, en química computacional, industria química y biológica.

Palabras claves: ciclooctano, cadena de ciclooctano, número de dominancia.

Число доминирования в циклооктановых цепочках

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РУБРИКА ГРНТИ: 27.45.17 Теория графов,
61.13.21 Химические процессы
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Химические структуры удобно представлять в виде графов, причем *атомы являются узлами (вершинами), а химические связи − ветвями (линиями)* графа*. Графическое представление молекулы предоставляет полезную информацию о химических свойствах молекулы. Как известно, многочисленные физические и химические свойства молекул сильно коррелируют с теоретическими инвариантами графов, которые мы называем топологическими индексами. Одним из таких теоретических инвариантов является число доминирования. Цель данного исследования − определить k-*числа *доминирования циклооктановых цепочек* COC_n^1, COC_n^2, COC_n^3 *и* COC_n^4, *причем k*$\in \{1,2,3\}$, *n*$\in N$.

Методы: *Циклооктановая цепочка представляет собой цепочку восьмиугольников, соединенных одной линией. Вершины восьмиугольника рассматриваются как узлы графа, а стороны и соединяющая их линия − как ветви графа. Используя математические методы, было определено k-доминирование в одном восьмиугольнике, k*$\in${*1,2,3*}*. Затем, представляя циклооктановые цепи* COC_n^1, COC_n^2, COC_n^3 *и* COC_n^4, *соответствующим изоморфным образом было определено их k-число доминирования, k*$\in${*1,2,3*}*.*

Результаты: Определив k-доминирование, k$\in \{1,2,3\}$ *по 4 циклооктановым цепочкам* COC_n^1, COC_n^2, COC_n^3 *и* COC_n^4, *получено 12 разных формул для вычисления их k-числа доминирования. Все формулы состоят из нескольких альтернативных алгебраических выражений, выбор которых обусловлен делимостью числа n на числа 2, 3 или 4, в зависимости от типа циклооктановой цепи и определяемого k-доминирования. Результаты исследования полностью представлены в статье с помощью математически доказанных теорем и графических изображений.*

Выводы: Результаты показывают, что k-числа доминирования k$\in \{1,2,3\}$, *в циклооктановой цепочке* COC_n^1, COC_n^2, COC_n^3 *и* COC_n^4 *получены и эксплицитно выражены математическими выражениями. Они также указывают на возможность их*

применения в молекулярных графах циклооктановых колец, в вычислительной химии, а также в химической и биологической промышленности.

Ключевые слова: циклооктан, циклооктановая цепочка, число доминирования.

Доминацијски број за циклооктанске ланце

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ОБЛАСТ: материјали и хемијске технологије, математика
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Хемијске структуре се најпогодније приказују графовима при чему су атоми чворови (врхови), а хемијске везе гране (линије) у графу. Графичко представљање молекула пружа многобројне корисне информације о њиховим хемијским својствима. Познато је да су многобројна физичка и хемијска својства молекула у високој корелацији са теоријским инваријантама графова које називамо тополошки индекси. Једна од таквих теоријских инваријанти је доминацијски број. Циљ овог истраживања јесте одређивање k-доминацијског броја за циклооктанске ланце COC_n^1, COC_n^2, COC_n^3 *и* COC_n^4, *где је k*$\in \{1,2,3\}$, *n*$\in N$.

Методе: Циклооктански ланац је ланац осмоуглова повезаних по једном линијом. Темена осмоугла су третирана као чворови графа, а странице и линија која их спаја као гране у графу. Применом математичких метода одређена је k-доминација на једном осмоуглу k$\in \{1,2,3\}$. *Затим је, представљањем циклооктанских ланаца* COC_n^1, COC_n^2, COC_n^3 *и* COC_n^4 *на погодан, изоморфан начин, одређен њихов k-доминацијски број k*$\in \{1,2,3\}$.

Резултати: Одређујући k-доминацију k$\in \{1,2,3\}$ *за 4 циклооктанска ланца* COC_n^1, COC_n^2, COC_n^3 *и* COC_n^4 *добили смо 12 различитих формула за израчунавање њиховог k-доминацијског броја. Све формуле су састављене од више алтернативних алгебарских израза чији одабир је условљен дељивошћу броја n бројем 2, 3 или 4, зависно од врсте циклооктанског ланца и k-доминације која се одређује. Резултати истраживања су комплетно изложени у раду путем теорема, које су математички доказане, и графичких приказа.*

Закључак: Резултати показују да су k-доминацијски бројеви k$\in \{1,2,3\}$ *на циклооктанским ланцима* COC_n^1, COC_n^2, COC_n^3 *и* COC_n^4 *одређени и експлицитно исказани математичким изразима. Такође, упућују на могућност њихове примене у молекуларним графовима*

циклооктанских прстенова, у рачунарској хемији, хемијској и биолошкој индустрији.

Кључне речи: циклооктан, циклооктански ланац, доминацијски број.

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Application of mathematical optimization in decision making relevant to the resilience of national security: networked society as the basis of interdependence of critical resources

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FIELD: applied mathematics, military sciences
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: Destabilization of critical resources (CRs) or critical infrastructure (CI) important for the stability of the state can be dangerous for society, economy, and especially national security. Disruption of one CI object or one of its parts often affects and causes disruption of other dependent CI, because the modern society has become a "networked society". The paper proposes a model for quantifying and defining the interdependence between different CIs and their priorities, based on statements of experts.

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Methods: The proposed methods that combine the Laboratory for Testing and Evaluation of Decision Making (DEMATEL) and the Analytical Network Process (ANP) have been successfully modified by fuzzy logic theory in this work.

Results: Integrating multiple methods into a unique input data analysis model significantly affects the change in ranking.

Conclusion: The work contributes to military science in making strategic decisions related to national security management through increasing the resilience of CRs and the societies that rely on them.

Key words: fuzzy logic, DEMATEL, ANP, MCDM, resources, national security.

Introduction

At the beginning of the 21st century, mankind is more than ever faced with large-scale natural disasters (Our World in Data, 2023) and man-made disasters, pandemics and major cyber attacks (Publications Office of the European Union, 2020). Terrorist acts and violent protests aimed at destroying state foundations and accompanied by human casualties have become an integral attribute of the modern world. Researchers have generally agreed that critical resources comprise critical infrastructure, critical sectors, and critical technologies of vital importance to a society; therefore, destructive impacts on them can pose a danger to a country as a whole and directly to its citizens who often do not even realize their importance. (Berlovsky & Alexandrov, 2022; Tomalska, 2023)

CI security, as an extremely important factor of national security, is only one of the aspects of broader changes in the security discourse since the end of the 20th century. Manuel Castells pointed out the importance of social changes brought about by the information technology revolution, i.e., the connection of the organizational logic of the network and information technologies in his book "The Rise of the Networked Society". (Castells, 2010)

For a better understanding of global processes and social changes, he offers an analytical tool in which the main functions and processes are viewed as networks (e.g. financial, political, military and security networks, etc.) where the actors are therefore not individuals but organizations, states and nations. (Starčević & Milenković, 2023)

Exposure to a wide range of security challenges, risks and threats (SCRTs) that are not necessarily of a military nature, and which threaten the security of a state and its citizens, requires a balance between reactive

and proactive activities of decision makers. (Ninković, 2021; Milenković & Subotić, 2022)

Progressive increase and the unpredictability of modern SCRTs originating from the turbulent geopolitical environment, as well as those immanent to the structures of the internal system, have brought numerous changes regarding the national security of modern states. SCRTs are identified "as part of the national security planning process and are reflected in the basic strategic and doctrinal documents (National Security Strategy, Defense Strategy and Doctrine of the Serbian Army) of the Republic of Serbia" (Bojanić, 2022). The SCRTs identified in these documents (Golubović & Saković, 2023) often reflect the political inclinations and preferences of policy makers, who suffer from the same cognitive biases as anyone else, which can only be overcome with a scientific approach. As a result, these documents and decisions routinely overestimate the relative importance of some threats while underestimating others, or they are simply presented as a phrase "challenge, risk and threat" without prioritization or ranking. In support of this, there is an observation that in the past national security strategies of the Republic of Serbia (2009 and 2019), the term CI was not mentioned at all. (Milosavljević & Vučinić, 2021) The Republic of Serbia adopted the Law on Critical Infrastructure for the normative regulation of CI, in order to harmonize it with European legislation. In order to protect "European critical infrastructure" (Publications Office of the European Union, 2020), its interdependence and importance, the EU regulated this area in order primarily to protect the energy network and gas pipelines that cross the territory of several countries.

Therefore, the importance of safe and resilient CI is imposed not only as a response to SCRTs (whether caused by climate change, political or economic phenomena), but also because of the networking and so-called interdependence between CIs at the national level. According to the Law on Critical Infrastructure: "CI is systems, networks, facilities or their parts, interruption of functioning or interruption of delivery of goods or services can have serious consequences for national security, health and lives of people, property, environment, safety of citizens, economic stability, that is, disrupting the functioning of the Republic of Serbia (Službeni glasnik Republike Srbije, 87/2018). CI is essential for the production and distribution of a continuous flow of basic goods and services (Huang et al, 2014). CI systems are highly interdependent and interact at different levels, which makes them vulnerable to disasters and failures, and ultimately leads to losses. Modeling of hybrid methods for the analysis of interdependence and significance of CI is very important for social and

economic security. Such methods provide important input data that is the basis for the management of the CI system and related decision making. CI enables society to carry out day-to-day activities that support the production and transmission of electricity, natural gas and oil and includes telecommunications (information and communications), transportation, water supply systems, banking, and finance (Serre & Heinzlef, 2018). Providing CI makes the society and the state safe and resilient. Currently, a large number of quantitative methods have been developed to help solve problems in all areas of life and work. These are first of all mathematical optimization methods, especially multi-criteria methods, suitable for solving problems when viewed from multiple aspects - criteria based on which decisions are made (Jamwal et al, 2021).

The aim of this work is to determine the interdependence of CIs and to improve the strategic framework for evaluating the overall challenges, risks, and threats in Strategic National Security Management (SNSM). The paper proposes an integrated method that combines DEMATEL, ANP, and fuzzy logic – the method evaluates the perspective of experts in evaluating interdependence and determining the potential importance of CI.

Description of the problem and the contribution

In the previous two decades, in the academic and practical discourse, there was a greater focus on the concept of CI resistance, rather than on the concept of protection. According to the above, the analysis focuses on the shortcomings of classic risk management based on quantitative assessments and crisis management principles. The disaster in Fukushima in 2011 focused analysis on the phenomena of interdependence, cascading effects and simultaneous crises. The interdependence of CIs is defined by the impact of failure or destabilization of one CI (sector) on other infrastructures. (Keković & Ninković, 2021)

Figure 1 shows an example of interdependence, the importance of CIs and the cascading effect of addictive disorders (Luiijf, et al, 2016). The interdependence of CIs can be more closely described by the impact of disruption or damage of one CI (sector, sub-sector) on other infrastructures. Therefore, CI systems necessary to meet the needs of society represent another challenge for evaluating the interdependence and potential importance of CIs. It can be stated that this complexity and infrastructural interdependencies bring increasing uncertainty, and this implies a shift in security trends from an approach focused on individual risk factors, through an all-hazards approach, all the way to an approach oriented towards system resistance, i.e. strategy for confronting and

managing systemic challenges, risks and threats. Therefore, the aim of the paper is to find an adequate strategy to minimize the challenges, risks and threats to CIs, in order to propose a method for their evaluation with the participation of experts. In this paper, we seek answers to the following questions: (1) Do the preferences of experts affect the ranking of sectors and sub-sectors? (2) What would be the result of applying the fuzzy DEMATEL-ANP method for the analysis of interrelationships in sectors and sub-sectors of CIs?

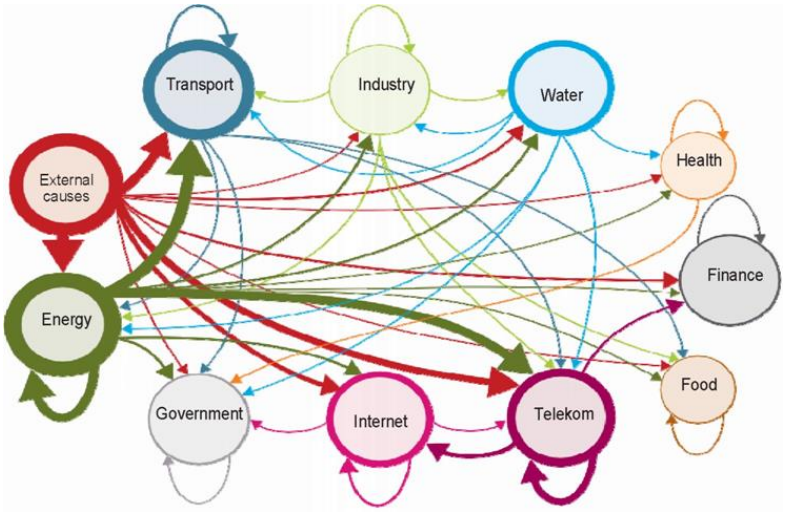

Figure 1 – An example of the interdependence and the cascading effect of addictive disorders

The contribution of this study is two-fold. Firstly, in conventional methods for interdependence and significance analysis where expert opinions are missing as input data. Some authors have noted that numerous analytical methods developed in earlier studies mainly focus on decision making by a single decision maker (Laugé et al, 2015). Individual evaluation and ranking of alternatives are the key aspects of decision making; therefore, they must be considered as part of a group decision-making process in order to generate objective and reliable multi-expert decisions (Deng & Jiang, 2019). Experts' subjectivity significantly affects the order of alternatives, i.e., the decision-making process, and therefore needs to be taken into account (Trivedi, 2018). Accordingly, the purpose of our research is to propose a procedure for interdependence and significance analysis that is suitable for CIs. Secondly, this study explores the prioritization of the interdependencies of critical sectors and sub-

sectors necessary in the SNSM process. In this sense, DEMATEL is used to construct the interrelationships between influencing factors in an integrated model. This method tests the relative strength between influencing factors. The ANP technique used to define the relative importance of influencing factors is also presented. This method is used to weight and prioritize critical impact factors between sectors and sub-sectors.

Literature review

The complexity and uncertainty of infrastructural interdependence causes a shift in protection trends from an approach focused on individual threats, through an all-hazards approach, to an approach oriented toward system resilience, i.e., strategies for dealing with and managing systemic risks and uncertainties. (Tomalska, 2023)

In her study, this author emphasizes the need to understand the concept of CI vulnerability in terms of system attributes, not deficiencies. Ninkovic (Ninković Vladimir) states in his hypothesis that: "...the sources of strategic risks can be identified in natural disasters caused by climate change, challenges of global networks (primarily in the digital sphere) and interdependencies of CIs, and not in isolated attacks of terrorist or criminal groups". (Ninković, 2021, p.1206)

It is precisely this uncertainty, carried by the interdependence of CIs, which is the imperative of our research for the application of mathematical optimization.

Various models and methods have been used to evaluate and analyze the interdependence of CIs. In their paper, Lin and Pan presented a CI interdependence model based on Leontief's (Wassily Leontief) input-output model for the simulation and analysis of CI interdependence, which can input real data from real public open source data (Lin & Pan, 2022). Rinaldi proposed a model for characterizing and evaluating the interdependencies of CI systems that includes the use of sector-specific designs, for example, gas pipelines, electricity networks or ICT. (Rinaldi, 2004)

To analyze infrastructure interdependence in the Netherlands which is relevant due to its high rate of urbanization and innovative development, the group of authors used a multi-mode relationship framework to identify the interrelationships between infrastructure systems. (Gürsan et al, 2023)

They recognized seven types of interdependence of socio-technical infrastructure which can influence change in urban sustainability: functional, evolutionary, spatial, life cycle interdependence, policy/procedural, market, and culture/norm. The authors Huang et al.

(2014) proposed an integrated method consisting of: Decision Making Testing and Evaluation Laboratory (DEMATEL) and Analytical Network Process (ANP) for the analysis of CI interdependencies that takes into account the feedback effects between different CIs (Trivedi, 2018). The study Kasmi et al. (2021) presents the fuzzy logic-based clustering algorithm to better identify and analyze the overall interdependencies between entities in CIs. ANP and DEMATEL were used to find interdependencies between components in an urban area. (Sarmadia & Aghababaei, 2023)

Modeling hybrid methods for evaluating the interdependence and significance of CIs is of essential importance in order to respond to the challenges in creating a strategy for the CI management. Therefore, a quantitative model is necessary for determining interdependence and identifying the priority CI system based on the perception of each expert. The neutralization of subjectivity in expert statements in (Pamučar et al, 2019) was performed by applying interval rough numbers using only internal knowledge from the data. In the study, they showed that the limits of the interval do not depend on subjective assessment, but are defined based on the imprecision of the data. According to (Fazli et al, 2015), the combination of DEMATEL and ANP is the best model for risk reduction due to the fact that DEMATEL can display complex interrelationships between criteria. Therefore, we can say that DEMATEL-ANP is an effective method that helps managers to choose the best strategies in order to effectively respond to overall challenges, risks and threats.

General model description

A hybrid method that integrates fuzzy logic, DEMATEL and ANP is called FDEMANP, Figure 2. Fuzzy set theory is usually combined with other theories to derive new theories. (Deng & Jiang, 2019; Pribićević et al, 2020)

Another important contribution of fuzzy set theory is that it provides a systematic procedure for transforming a knowledge base into a non-linear mapping. In contrast to conventional logic, in fuzzy logic the belonging of one element to a specific set is not precisely defined, which is why it is very close to human perception. It uses the experience of a human expert in the form of linguistic "If-Then" rules, and the mechanism of approximate reasoning calculates the degree of direct influence. In this paper, the algorithm of approximate reasoning will be used to show the degree of direct influence of each criterion (sub-sector) in order to obtain the interdependence and importance of sectors and sub-sectors.

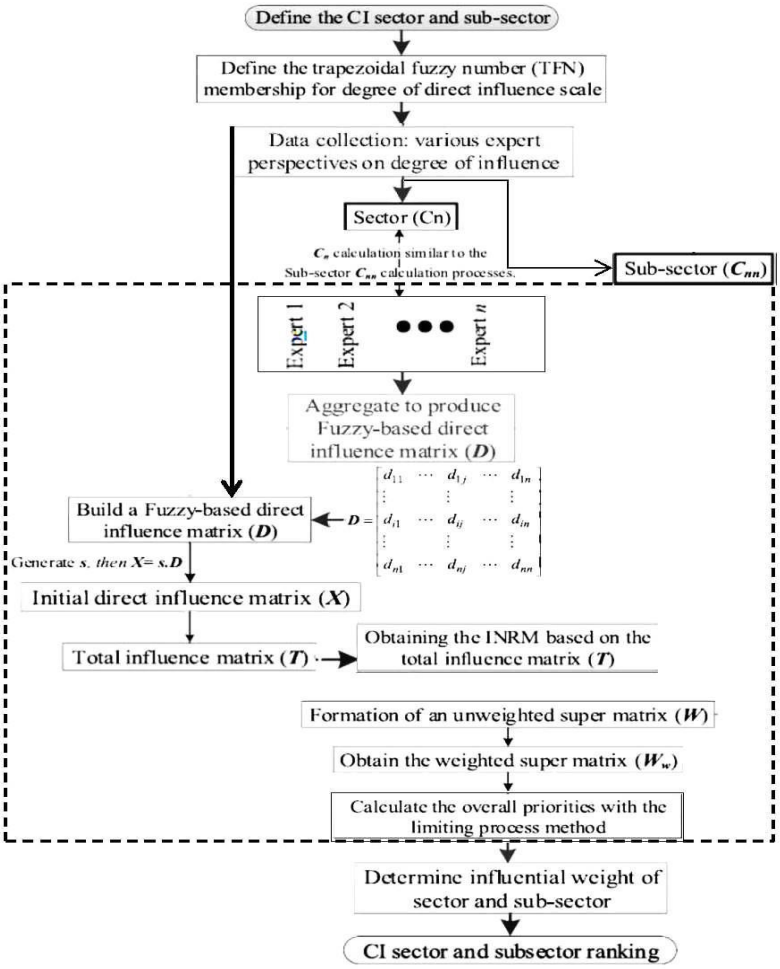

Figure 2 – Hybrid method FDEMANP

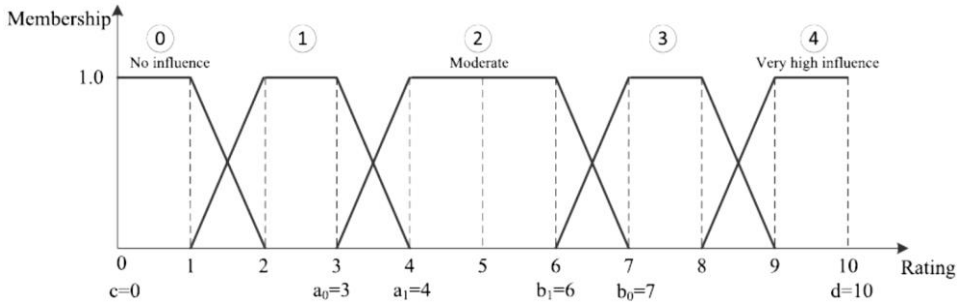

Figure 3 – Five-point Likert scale

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Therefore, the arguments for the application of fuzzy logic are: 1. It considers the subjectivity of perception and uncertainty, allowing the use of expert ratings and fuzzy indicators, respectively. 2. It processes and generates qualitative and quantitative evaluations with immediate and easy transitions between them. To this end, it introduces/uses linguistic and quantitative variables, scales and logical rules. 3. It enables thinking about processes, connections and interactions between its sub-sectors. 4. There are no strict methodological requirements for its implementation. 5. The simplicity in its use enables quick and easy change of logical rules and scales.

Table 1 – TFN determined for the degree of influence

Influence rating	**Likert scale**	**TFN**
Very high influence	4	(8,9,10,10)
High influence	3	(6,7,8,9)
Moderate	2	(3,4,6,7)
Low influence	1	(1,2,3,4)
No influence	0	(0,0,1,2)

In the decision-making process, the fuzzy technique is used to transform rational (crisp) numbers into fuzzy numbers that, with the help of the membership function, show the degree of belonging of the elements to a given set. According to (Zadeh, 1965), linguistic expressions (linguistic variables) can be very successfully used for quantification of uncertainty in complex and uncertain situations (Božanić et al, 2015). According to this, before the first step, the Likert scale and the membership functions of the Trapezoidal Fuzzy Number (TFN) should be defined for the degree of direct influence, Figure 3. For this study, we took the Likert scale from 0 to 4, which means "no impact" to "very big impact", i.e., five TFNs, Table 1. The reason why we took a five-point scale is that the ANP analysis is based on the DEMATEL technique, which usually uses a scale of 0–4 (Pamučar et al, 2017). The contribution of this fuzzy Likert approach is in the precision of the measurement, as it allows the points of the scale to be stacked, thus regulating the imprecise information in the statements given by experts.

After the preliminary steps, the collected data can be imported to obtain expert observations on the degree of impact. In his research, Hu (Hu et al, 2009) determined that for the DEMATEL technique, the optimal number of respondents is in the range of three to nine.

A concise mathematical representation of the FDEMANP method is presented in Figure 4:

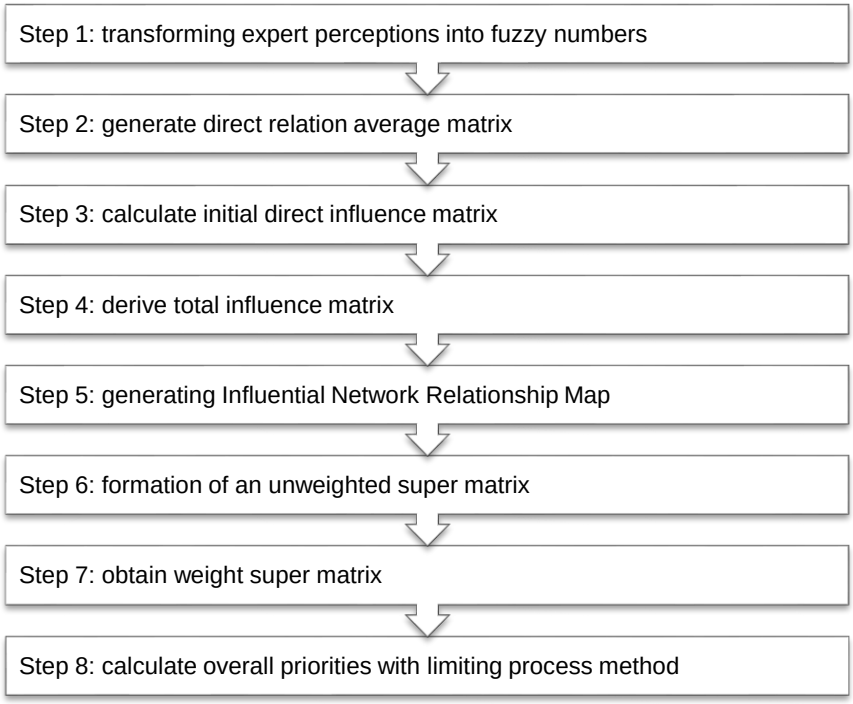


Figure 4 – Presentation of the steps of applying the FDEMANP method

The proposed method

The limitation of prediction and prevention of the occurrence of all BIRPs - the CI protection strategy requires adaptation based on the identification of the root causes of vulnerability related to the functioning of CIs. (Tomalska, 2023)

Confirmation and justification of the application of the hybrid method of FDEMANP - this section shows its application on the example of critical resources of the Republic of Serbia. Before applying the hybrid method, it is necessary to define the CI sectors and sub-sectors, which will be the boundary of the problem analysis, shown in Table 2 (Službeni glasnik Republike Srbije, 87/2018).

In the work, we limited ourselves to 4 sectors due to a simple presentation of the model, compared to 8 identified in the Official Gazette. For each sector, there are identified sub-sectors that are of vital importance for the sustainability of the economy and society as a whole.

Table 2 – Defined sectors and sub-sectors of critical infrastructure

Sector	Sub-sector	Description of the criteria
Energy (C1)	Electricity (C_{11})	Electricity infrastructure (power plants, transmission systems, control stations)
	Oil (C_{12})	Oil infrastructure (storage, processing systems, control stations, pumps, and pipelines)
	Natural gas (C_{13})	Gas infrastructure (storage, control stations, pumps and pipelines)
Water (C2)	Watersheds (C_{21})	Watersheds and upstream areas of major rivers
	Dams (C_{22})	Reservoirs, pipelines and pumping stations
	Water treatment (C_{23})	Water treatment plants, pipelines and pumping stations
	Water supply (C_{24})	Service piping systems and control centers
IKT (C3)	Information (C_{31})	Software, hardware, cyber-security and Internet
	Telecommunication (C_{32})	Infrastructure for telecommunications (stations and broadcasting equipment)
Transportation (C4)	Ground (C_{41})	Road and rail infrastructure used for transport, tunnels and bridges
	River (C_{42})	Infrastructure for ship traffic (ports and facilities)
	Aviation (C_{43})	Airports, air traffic control centers, control towers
	Postal services and logistics (C_{44})	Major distribution centers and related facilities

Nine experts from different areas were interviewed: three experts from the transport sector, two experts from the energy sector, one expert from the water sector, and three experts from the telecommunications sector. These experts have a minimum of 10 years of experience in infrastructure planning and management in the mentioned areas.

Step 1. The function of linguistic affiliation, which will be used to quantify the direct influence of the criteria of critical resources, is formed based on the statement of experts, by which they proposed the degree of direct influence of each criterion (sub-sector) *i* on each criterion *j*, marked as d_{ij}.

After the collected expert statements, the base of fuzzy rules for DEMANP is formed by quantification through the five-point Likert scale (Figure 3) using a linguistic term (Table 1). Defuzzification of attachment functions is performed in order to obtain a crisp numerical form of the fuzzy set based on the formula:

$$F(d_{ij}) = \frac{[b_0 - c] + [b_1 - c]}{\{[b_0 - c] + [b_1 - c]\} - \{[a_0 - d] + [a_1 - d]\}} \quad (1)$$

In defuzzification, *c* has the same value for all linguistic concepts. The membership function has a value of zero for the values a_0 and b_0 at the extreme limits of each linguistic term, while it has a maximum value when the membership function is one for the values a_1 and b_1. In the second step, in order to generate a matrix of direct relations for each expert's statement, the mean value of expert statements D is calculated (Table 3):

$$D = \begin{bmatrix} d_{11} & \cdots & d_{1j} & \cdots & d_{1n} \\ \vdots & & \vdots & & \vdots \\ d_{i1} & \cdots & d_{ij} & \cdots & d_{in} \\ \vdots & & \vdots & & \vdots \\ d_{n1} & \cdots & d_{nj} & \cdots & d_{nn} \end{bmatrix} \quad (2)$$

Using equations (3) and (4), the initial direct influence matrix (Table 4) is obtained by normalizing the average matrix D.

$$X = s * D \quad (3)$$

$$s = min\left[\frac{1}{\max_i \sum_{j=1}^{n} |d_{ij}|}, \frac{1}{\max_j \sum_{i=1}^{n} |d_{ij}|} \right] \quad (4)$$

By carrying out the listed steps in order, the weight value of the impact of each CI sector is obtained from the total impact matrix, followed by the unweighted supermatrix. Applying mathematical expressions, a weighted supermatrix is obtained, generated from FDEMANP, which includes different degrees of influence among infrastructure sectors.

Finally, the value of each sector or sub-sector is obtained by calculating the boundary matrix of the supermatrix through the use of the ANP procedure. According to the final results, "traffic" has the highest impact weight value among sectors, while "information" within the sub-sector has the highest weight value.

Table 3 – Initial decision matrix

	E1									
	C_{11}	C_{12}	C_{13}	C_{21}	C_{22}		C_{32}	C_{41}	C_{42}	C_{43}	C_{44}
C_{11}	(0;0)	(3;4)	(3;3)	(2;3)	(2;3)		(2;3)	(2;5)	(1;1)	(4;4)	(4;4)
C_{12}	(3;4)	(0;0)	(3;5)	(1;5)	(2;3)		(3;3)	(3;5)	(2;3)	(4;4)	(4;4)
C_{13}	(3;4)	(3;5)	(0;0)	(4;5)	(3;4)		(3;3)	(3;5)	(2;5)	(4;5)	(4;4)
C_{21}	(3;4)	(4;4)	(4;4)	(0;0)	(2;3)		(3;4)	(4;5)	(3;4)	(3;4)	(5;5)
.....						...					
C_{41}	(3;3)	(2;3)	(4;5)	(1;5)	(2;2)		(2;3)	(0;0)	(2;2)	(3;5)	(3;3)
C_{42}	(4;4)	(2;3)	(2;5)	(5;5)	(1;1)		(2;3)	(2;3)	(0;0)	(3;4)	(3;4)
C_{43}	(2;2)	(1;5)	(2;3)	(2;5)	(1;1)		(3;5)	(2;5)	(1;2)	(0;0)	(5;5)
C_{44}	(3;3)	(2;5)	(1;3)	(2;3)	(4;5)		(3;3)	(3;5)	(4;5)	(4;4)	(0;0)
...											
	E9									
	C_{11}	C_{12}	C_{13}	C_{21}	C_{22}		C_{32}	C_{41}	C_{42}	C_{43}	C_{44}
C_{11}	(0;0)	(2;5)	(2;5)	(1;5)	(1;5)		(1;5)	(1;4)	(2;2)	(3;4)	(3;3)
C_{12}	(2;4)	(0;0)	(3;4)	(1;4)	(1;5)		(2;4)	(2;4)	(2;2)	(3;5)	(3;5)
C_{13}	(1;4)	(3;3)	(0;0)	(3;4)	(3;5)		(2;4)	(2;3)	(3;4)	(4;4)	(3;5)
C_{21}	(2;4)	(4;4)	(4;4)	(0;0)	(2;5)		(4;4)	(4;4)	(2;5)	(2;5)	(4;5)
.....						...					
C_{41}	(1;3)	(1;2)	(4;4)	(1;4)	(2;4)		(1;4)	(0;0)	(3;3)	(2;3)	(4;5)
C_{42}	(3;5)	(1;2)	(1;4)	(4;4)	(1;3)		(1;5)	(1;4)	(0;0)	(4;4)	(4;4)
C_{43}	(1;2)	(1;3)	(1;4)	(1;4)	(1;3)		(4;5)	(1;4)	(2;2)	(0;0)	(3;3)
C_{44}	(1;2)	(2;4)	(1;4)	(1;4)	(4;4)		(5;5)	(4;5)	(3;4)	(4;5)	(0;0)

Table 4 – Initial matrix of direct influence

D	C_{11}	C_{12}	C_{13}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{41}	C_{42}	C_{43}	C_{44}
C_{11}	0.000	2.283	2.513	1.744	1.831	3.056	2.556	3.722	3.889	3.611	3.556	3.056	2.667
C_{12}	3.999	0.000	1.828	0.621	0.536	0.536	0.687	0.839	0.839	3.854	3.988	3.856	4.111
C_{13}	3.344	1.234	0.000	0.317	0.456	0.415	0.489	0.687	0.741	1.729	1.811	1.815	1.358
C_{21}	2.281	0.833	0.556	0.000	3.722	3.056	3.000	1.231	1.231	0.844	0.628	1.231	0.727
C_{22}	2.737	0.511	0.454	3.238	0.000	2.299	2.632	0.833	0.833	0.388	0.443	0.434	0.332
C_{23}	1.443	0.668	0.566	2.168	2.112	0.000	3.000	0.834	0.763	0.387	0.622	0.342	0.546
C_{24}	1.510	0.933	0.888	2.334	2.055	2.622	0.000	0.953	0.722	0.613	0.386	0.386	0.613
C_{31}	2.415	1.456	1.434	0.911	1.232	1.787	1.567	0.000	3.388	1.776	1.944	1.777	1.723
C_{32}	2.334	1.445	1.168	0.776	1.168	1.277	1.223	3.343	0.000	2.712	3.268	3.165	2.502
C_{41}	1.389	2.333	2.111	0.500	0.444	0.667	0.833	0.722	0.889	0.000	2.056	2.278	3.343
C_{42}	1.000	1.722	1.333	0.325	0.556	0.611	0.389	1.212	1.056	2.056	0.000	2.345	3.389
C_{43}	1.135	3.664	3.132	0.634	0.543	0.778	0.556	0.889	0.889	2.056	2.000	0.000	3.121
C_{44}	0.650	0.989	0.528	0.671	0.646	0.430	0.341	0.978	0.936	1.576	1.549	1.569	0.000

Discussion of the obtained results

Table 5 shows the values obtained using the DEMANP method and FDEMANP with multiple experts for decision making. Tables 5 a) and b) show the effect of the interdependence values of CI sectors, where small changes in values can be seen, and the most significant thing is that all CI sectors have negative values (di-ri). The negative (di-ri) values of the CI sector in both cases indicate that all four sectors mutually influence each other and are mutually dependent on each other.

According to the results using the FDEMANP method, two sub-sectors (Water supply C_{21} and road transport C_{41}) have different impact values. Regarding the analysis of the CI sub-sector, both analytical methods have similar values (di-ri). Interestingly, the two sub-sectors (C_{21} and C_{41}) have different patterns of (di-ri) outcomes. According to the DEMANP methodology, the C_{21} sub-sector has a negative (di-ri) value, which shows that it is influenced by other sub-sectors.

Table 5 – Sums of influences on, and exerted by, CI sector and sub-sectors
a) Conventional method (DEMANP)

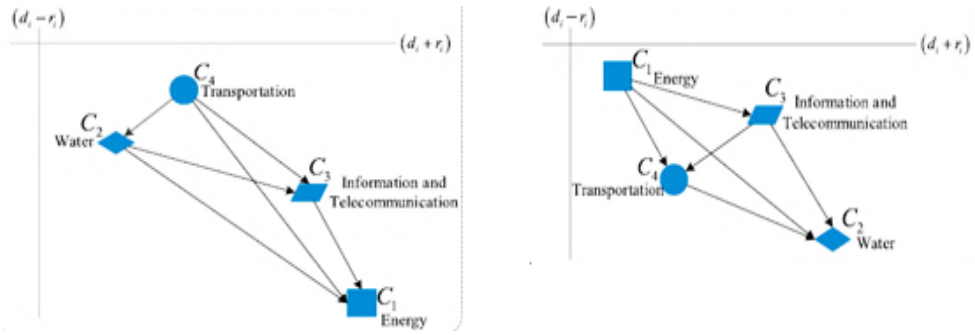
Sect.	**r_i**	**d_i**	**d_i+r_i**	**d_i-r_i**	**Sub-sec.**	**r_i**	**d_i**	**d_i+r_i**	**d_i-r_i**
C1	21.640	9.361	30.971	-12.288	(C_{11})	6.272	6.176	12.438	-0.126
					(C_{12})	5.853	7.485	13.358	1.653
					(C_{13})	6.988	6.689	13.687	-0.270
C2	19.083	9.078	28.171	-10.015	(C_{21})	6.633	6.516	13.129	-0.126
					(C_{22})	6.342	6.272	12.573	-0.037
					(C_{23})	7.314	6.785	14.108	-0.528
					(C_{24})	6.963	6.986	13.948	0.037
C3	20.963	9.644	30.587	-11.368	(C_{31})	6.923	7.474	14.387	0.562
					(C_{32})	7.141	6.872	13.983	-0.259
C4	18.680	10.147	28.827	-8.553	(C_{41})	5.508	5.625	11.143	0.148
					(C_{42})	5.743	5.793	11.526	0.059
					(C_{43})	6.664	5.910	12.574	-0.755
					(C_{44})	6.265	5.916	12.180	-0.349

b) Proposed method (FDEMANP)

Sect.	r_i	d_i	d_i+r_i	d_i-r_i	Sub-sect.	ri	di	di+ri	di-ri
C1	12.345	6.903	19.248	-5.442	(C_{11})	6.972	6.862	13.854	-0.080
					(C_{12})	6.331	7.728	14.029	1.387
					(C_{13})	7.534	7.163	14.687	-0.381
C2	16.255	7.335	23.580	-8.930	(C_{21})	7.167	7.389	14.516	0.243
					(C_{22})	6.823	6.662	13.426	-0.152
					(C_{23})	7.615	7.197	14.783	-0.427
					(C_{24})	7.467	7.477	14.943	0.043
C3	15.339	7.254	22.524	-8.145	(C_{31})	7.377	7.973	15.339	0.653
					(C_{32})	7.445	7.053	14.466	-0.323
C4	15.057	6.052	21.148	-9.032	(C_{41})	6.155	6.115	12.242	-0.035
					(C_{42})	6.529	6.738	13.228	0.189
					(C_{43})	7.264	6.530	13.784	-0.764
					(C_{44})	6.958	6.639	13.627	-0.289

However, the FDEMANP methodology gives a positive value (di-ri) for C_{21}, indicating that the sub-sector influences the others. Thus, both methods exhibit distinct differences (di-ri) C_{41}. Also, according to the DEMANP calculation, C_{41} has an impact on other CI sub-sectors, while according to FDEMANP, C_{41} is a sub-sector that is affected by other CI sub-sectors. The relations between sectors and sub-sectors, i.e., the network of influence can be visually displayed by data mapping (di+ri, di-ri). Mapping is done to create a cause and effect relationship diagram (CERD) of four sectors, as presented in Figures 5 (a) and (b), respectively. A diagram is created to visually represent complex relationships in order to conclude which sectors/sub-sectors are most important and how they influence each other.

The arrows show the directions of influence. In Figures 5 (a) and (b), sectors with positive net impacts are grouped as causes while those with negative net impacts are grouped as effects. Using the FDEMANP method, the obtained calculation and display results on the CERD show different mutual influence values compared to those generated by the conventional DEMANP method. Accordingly, it can be concluded that C_{21} is a sub-sector of CI that affects other sub-sectors while C_{41} is a sub-sector that is influenced by other sub-sectors (negative value (di-ri)).



(a) *(b)*

Figure 5 – CERD generated using DEMANP and FDEMANP

Table 6 – Influential weights of sectors and sub-sectors - comparision between DEMANP (DA) and FDEMANP (FDA)

Sector	Local weight		Ranking		Order	Sub-sector	Local weight		Ranking		Order
	DA	FDA	DA	FDA			DA	FDA	DA	FDA	
Energy (C1)	0.247	0.207	3	4	▼	(C_{11})	0.076	0.062	8	12	▼
						(C_{12})	0.067	0.059	11	13	▼
						(C_{13})	0.083	0.067	7	9	▼
Water (C2)	0.281	0.277	1	1	●	(C_{21})	0.066	0.065	12	10	▲
						(C_{22})	0.062	0.062	13	11	▲
						(C_{23})	0.071	0.070	9	7	▲
						(C_{24})	0.069	0.068	10	8	▲
IKT (C3)	0.256	0.262	2	2	●	(C_{31})	0.118	0.120	2	2	●
						(C_{32})	0.120	0.123	1	1	●
Transport. (C4)	0.218	0.256	4	3	▲	(C_{41})	0.083	0.104	6	6	●
						(C_{42})	0.089	0.106	5	5	●
						(C_{43})	0.106	0.119	3	3	●
						(C_{44})	0.095	0.115	4	4	●

▲ *and* ▼*indicate a change in rank order (increasing and decreasing, respectively);*
● *indicates no change in rank order.*

The limit matrix of the supermatrix is calculated in the same way as for the ANP procedure to obtain the final priorities of each sector/sub-sector of CI. Table 6 presents the absolute local weight and ranking of individual CI sectors and sub-sectors based on their influential weight values, obtained using both DEMANP and FDEMANP. Using the

DEMANP method, we obtained that the sector C2 is "water" CI which has the highest weight value; this result can be understood according to the display on CERD; based on the weight coefficient, information and telecommunications – C3 follow, then energy – C1 and transport - C4 which has the least weight. According to the FDEMANP hybrid method, the ranking of CI sector weight values is as follows: water - C2, information-telecommunications - C3, transport - C4 and energy - C1. The FDEMANP analysis at the CI sub-sector level revealed that ICT telecommunications C_{32} and information C_{31} have the highest impact weights. This result is expected, accordingly Information and telecommunications play a key role in critical infrastructures, as almost every sector or sub-sector is controlled by ICT and network systems in today's "networked society". The failure of the ICT system could not only affect banking, finance, and transport, but also energy and water distribution systems. This is then followed by aviation C_{43}, postal services and logistics C_{44}, river C_{42}, land C_{41}, etc. From Table 6, we can conclude that the ranking of all sub-sectors of the CI infrastructure sectors C1 and C2 has changed significantly compared to the results obtained by the DEMANP method. Accordingly, this would be the answer to the first question, that the change in rank is influenced by the input data which includes the preferences of experts and which is processed using various quantitative methods integrated into our analysis model.

The answer to the second question (What is the result of the application of the proposed method?) would be that, compared to other methodologies (for example, Monte Carlo simulation or network theory), the proposed hybrid method FDEMATEL provides an easy and fast way to evaluate the interdependence and importance of CIs with expert preferences. The advantage of this method is that it gives the possibility of CERD display of complex interdependencies between sectors and sub-sectors without the use of software tools and time-consuming data collection.

Conclusions

The term "Networked Society" points out the vulnerability of modern society and the fact that the interdependence of critical resources brings increasing uncertainty. This kind of society requires a change in the protection process, from one aimed at individual challenges, risks and threats, to a process aimed at the resilience of the state, i.e. strategies for dealing with and managing systemic risks and uncertainties.

Appreciation of uncertainty at the strategic level of management is a very important aspect for objective and unbiased multi-criteria decision making. Difficulties often arise in presenting data on decision attributes through exact (precise) numerical values. The aforementioned aggravating circumstances are caused by doubts when making decisions, as well as by the complexity and vagueness of numerous realistic indicators. This paper presents a successful modification of the DEMANP method with the theory of fuzzy sets, on the example of the evaluation of interdependence and CI priorities within the process of Strategic National Security Management.

The result of the applied hybrid FDEMANP method is a confirmation that, in terms of the complex interdependence of CIs, all CI sectors are simultaneously affected by other CI sectors and sub-sectors. By introducing the statements of numerous experts into the calculation in the decision-making process, the FDEMANP method represents a very suitable tool for considering uncertainty when making key decisions. The presented hybrid method showed superiority in dealing with uncertainty in the sense of ambiguity, subjectivity, imprecision and vagueness, when the input data relies exclusively on the statements of experts.

The paper confirmed that connecting different quantitative methods into a unique model of evaluation of input data processed in order to process different statements of experts significantly affects the change in rank. The analyzes also showed that the hybrid method of FDEMANP can be used to evaluate the causes and consequences of interdependence and importance of CI sectors and sub-sectors.

Therefore, by applying the hybrid method of FDEMANP, the Strategic Management of National Security can be improved by making development planners and CI operators understand how the disruption of one part of the CI system prevents the delivery of gas, water, electricity, information, etc., which has an impact on the stability of other CI systems.

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Aplicación de la optimización matemática en la toma de decisiones relevantes para la resiliencia de la seguridad nacional: la sociedad en red como base de la interdependencia de recursos críticos

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CAMPO: matemáticas aplicadas, ciencias militares
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: La desestabilización de recursos críticos (RC) o infraestructura crítica (IC) importantes para la estabilidad del estado puede ser peligrosa para la sociedad, la economía y especialmente la seguridad nacional. La interrupción de un objeto de IC o de una de sus partes a menudo afecta y causa la interrupción de otros IC dependientes, porque la sociedad moderna se ha convertido en una "sociedad en red". El artículo propone un modelo para cuantificar y definir la interdependencia entre diferentes IC y sus prioridades, basado en declaraciones de expertos.

Métodos: Los métodos propuestos que combinan el Laboratorio de Ensayo y Evaluación de la Toma de Decisiones (DEMATEL-por sus siglas en inglés) y el Proceso Analítico de Redes (ANP- por sus siglas en inglés) han sido modificados exitosamente mediante la teoría de la lógica difusa en este trabajo.

Resultados: La integración de múltiples métodos en un modelo único de análisis de datos de entrada afecta significativamente el cambio en la clasificación.

Conclusión: El trabajo contribuye a la ciencia militar en la toma de decisiones estratégicas relacionadas con la gestión de la seguridad nacional mediante el aumento de la resiliencia de los RC y las sociedades que dependen de ellos.

Palabras claves: lógica difusa, DEMATEL, ANP, MCDM, recursos, seguridad nacional.

Применение математической оптимизации при принятии решений об устойчивости национальной безопасности: сетевое общество как основа взаимозависимости критических ресурсов

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РУБРИКА ГРНТИ: 27.47.19 Исследование операций,
28.17.31 Моделирование процессов управления,
78.21.49 Военная электроника и кибернетика
ВИД СТАТЬИ: оригинальная научная статья

Bojanić, D. et al, Application of mathematical optimization in decision making relevant to the resilience of national security: networked society as the basis of interdependence of critical resources, pp.56-79

Резюме:

Введение/цель: Дестабилизация таких важных факторов стабильности государства, как критические ресурсы (КР) и критическая инфраструктура (КИ) представляет опасность для общества, экономики и особенно для национальной безопасности. Разрушение одного объекта КИ или одной из его частей зачастую влияет на другие зависимые КИ и вызывает их разрушение, поскольку современное общество стало «сетевым обществом». В данной статье представлена модель для количественной оценки и определения взаимозависимости между различными КИ и их приоритетами, основанная на мнении экспертов.

Методы: В данном исследовании применялось сочетание метода пробно-оценочной лаборатории для принятия решений (DEMATEL) с методом аналитического сетевого процесса (ANP), которые были успешно модифицированы теорией нечеткой логики.

Результаты: Интеграция нескольких методов в единую модель анализа входных данных существенно влияет на изменение ранжирования.

Выводы: Данное исследование вносит вклад в военную науку, в частности, в области принятия стратегических решений, связанных с управлением национальной безопасностью, за счет повышения устойчивости КР и обществ, которые на них полагаются.

Ключевые слова: нечеткая логика, DEMATEL, ANP, MCDM, ресурсы, национальная безопасность.

Примена математичке оптимизације у одлучивању значајна за отпорност националне безбедности: умрежено друштво као основ међузависности критичних ресурса

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ОБЛАСТ: математика, војне науке
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Дестабилизација критичних ресурса (КР) или критичне инфраструктуре (КИ) важне за стабилност државе може бити опасна по друштво, економију, а посебно националну безбедност. Поремећај једног објекта КИ, или једног његовог дела, често утиче и изазива поремећај других зависних КИ, јер смо постали „умрежено друштво". У раду је предложен модел за квантификовање и дефинисање међузависности између различитих КИ и њихових приоритета, на основу исказа стручњака.

Методе: Предложене методе које комбинују Лабораторију за тестирање и евалуацију одлучивања (DEMATEL) и аналитички мрежни процес (ANP) успешно су модификоване теоријом fuzzy логике.

Резултати: Интегрисање више метода у јединствени модел анализе улазних података значајно утиче на промену рангирања.

Закључак: Рад доприноси војној науци у доношењу стратешких одлука у вези са управљањем националном безбедношћу, кроз повећање отпорности КР и друштва које се на њих ослања.

Кључне речи: fuzzy логика, DEMATEL, ANP, MCDM, ресурси, национална безбедност.

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Optimal adjusting of simulated annealing parameters

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Abstract:

Introduction/purpose: Simulated annealing is a powerful technique widely used in optimization problems. One critical aspect of using simulated annealing effectively is a proper and optimal adjustment of its parameters. This paper presents a novel approach to efficiently adjust the parameters of simulated annealing to enhance its performance and convergence speed.

Methods: Since the simulated algorithm is inspired by the cooling Metropolis process, the basic idea is to simulate and analyze this process using a mathematical model. The proposed work tends to properly imitate the Metropolis cooling process in the algorithmic field. By intelligently adjusting the temperature schedule, temperature reduction and cooling rate, the algorithm optimizes the balance between exploration and exploitation, leading to improved convergence and higher-quality solutions.

Results: To evaluate the effectiveness of this approach, it was applied first on a chosen sample function to be minimized, and then on some usual known optimization functions. The results demonstrate that our approach, called Optimal Adjusting of Simulated Annealing parameters (OASA), achieves superior performance compared to traditional static parameter settings and other existing approaches, showing how to well adjust the parameters of the simulated annealing algorithm to improve its efficiency in terms of solution quality and processing time.

Conclusion: Adjusting the algorithm parameters could have a significant contribution in the optimization field even for other metaheuristics.

Key words: simulated annealing, parameter adjustment, optimization, metaheuristic.

Introduction

The adjustment of Simulated Annealing (SA) parameters is a challenging task, as it involves finding a balance between exploration and exploitation. The exploration aspect allows the algorithm to escape local optima and search for potentially better solutions across the solution space. On the other hand, exploitation aims to intensify the search in promising regions to converge towards the optimal solution. Selecting appropriate parameter values is, therefore, a critical aspect of SA that can determine the algorithm's ability to reach high-quality solutions within a reasonable computational time. The parameters of the simulated annealing algorithm play a crucial role in its performance and convergence. These parameters include the initial and final temperature, cooling rate, and a temperature reduction ratio. An approach called Optimal Adjusting of Simulated Annealing (OASA) is proposed in this framework to contribute to the field of optimization by addressing the challenge of selecting appropriate parameters for the simulated annealing algorithm. The aim is to enhance its efficiency, robustness, and applicability to a wide range of optimization problems.

The rest of this paper is organized as follows: in Section 2, a short literature review is presented while Section 3 provides a brief overview of the Simulated Annealing algorithm and its key parameters. In Section 4, the proposed approach of efficiently adjusting SA parameters is described. Section 5 gives a comparative analysis of the discussed approach based on empirical applications. Finally, Section 6 summarizes the findings and discusses future research directions.

Related work

Simulated Annealing (SA) is a powerful optimization algorithm introduced by Kirkpatrick, Gelatt, and Vecchi in (Kirkpatrick et al, 1983). Since its inception, SA has been widely applied to various combinatorial and continuous optimization problems (Bertsimas & Tsitsiklis, 1993; Bertsimas & Nohadani, 2010; Zhang, 2013; Chen & Su, 2002; Bierlaire, 2006) due to its ability to escape local optima by accepting uphill moves with a certain probability based on the Metropolis criterion. Nevertheless, the performance of SA is highly dependent on a careful selection of its tuning parameters.

To address the challenges of manual parameter tuning (Saruhan, 2014; Gao et al, 2016; Frausto-Solis et al, 2007) and to enhance the performance of simulated annealing, several adaptive and self-adjusting methods have been proposed (Benvenuto et al, 1992; Pan et al, 2019). In

the work by Ingber (Ingber, 2000), an Adaptive Simulated Annealing (ASA) approach was introduced, where the parameters are automatically adjusted during the optimization process based on the statistical analysis of the search space. ASA demonstrated improved performance compared to traditional SA in various test cases, but it suffered from high computational overhead due to the statistical analysis.

Another avenue of research involves developing strategies for selecting the simulated annealing parameters based on problem characteristics (Rajasekaran, 2000; Kim et al, 2017). Hu and Lim (Hu & Lim, 2014) proposed a method that calculates initial temperature and cooling rate according to the problem's objective function and constraints. Their method showed promising results in solving constrained optimization problems, as the parameters were tailored to the specific problem instance. Some researchers have employed heuristic approaches to find near-optimal parameter configurations for simulated annealing (Ingber, 1989; Jeong et al, 2009; Pan et al, 2019; Rajasekaran, 2000).

Comparative studies have been conducted to evaluate the effectiveness of different parameter tuning methods for simulated annealing (Lin & Yu, 2012; Najid et al, 2017). Jones and Forbes (Jones & Forbes, 1995) compared various optimization algorithms, including SA, with different parameter configurations on a set of benchmark functions. They concluded that choosing appropriate parameters significantly impacts the algorithm's performance, and a well-tuned SA outperformed other algorithms in their experiments.

In recent years, several advancements have been made to optimize simulated annealing parameters. (Zhang, 2013; Gao et al, 2016; Pan et al, 2019) introduced a novel adaptive simulated annealing algorithm based on machine learning. Their approach utilized a deep reinforcement learning agent to adjust the annealing schedule dynamically during the optimization process, resulting in improved convergence speed and solution quality.

Simulated Annealing Algorithm overview

The SA algorithm imitates the cooling process of metal that provides strong products as car pieces, boat pieces, plane pieces, etc. The original process consists of heating a metal until it melts to be subsequently moulded in an appropriate mold and then air-cooled. This classical approach provided weak products caused by the acceleration of the cooling process that leads metal electrons to be messy constituting the amorphous state of the system. SA aims to slow down the cooling process

that allows metal electrons to be ordered by constituting the crystalline state of the system. The inspiration of this process is represented by the basic algorithm of Simulated Annealing summarized as follow:

1. SA_ALGO(search space S)
2. Read problem input data
3. Choose SA parameters:
4. initial temperatureT_{max} ; // amorphous (melt) state temperature
5. final temperature T_{min} ; // crystalline state temperature
6. annealingscalek ; // annealing time at temperature t_i
7. temperature reduction ratio ($r \approx 1$)
8. Define objective function f to be optimized
9. Define neighborhood function N ;
10. Generate random initial solution x_0 uniformly from S
11. Take optimal solution $x^* = x_0$
12. Initialize temperature $t = T_{max}$
13. Main loop:
14. While $t > T_{min}$
15. For j=1 to k (annealing rate)
16. generate random neighbor x1of the current solution x0: $x1 \in N(x0)$
17. if x1 is better than x0 then
18. accept x1 (x0=x1)
19. if x1 better than x* then update x*(x*=x1)
20. else accept x1 with the metropolis probability
21. end for
22. reduce t (t = r*t)
23. end while
24. output (x*, f(x*))
25. endSA_ALGO

where ‘accept x1 with the metropolis probability’ means:

If $\text{random}\,(0,1) < e^{-\frac{\Delta f}{T}}$ then $x_0 = x_1$ ($\Delta f = |f(x_1) - f(x_0)|$, it is the energy variation that allows moving the metal atoms).

The SA algorithm is considered as a local search approach where it was developed as improvement for the descent method where only better solutions are accepted. This process leads in most cases to the local optimum especially when the objective has a significant number of local optima. Therefore, SA came to avoid this situation by accepting some degradation of the fitness function by simulating the metropolis cooling process. Thus, SA has proved its efficiency in many situations. However,

the bad adjustment of the SA parameters could considerably affect its effectiveness in terms of solution quality and processing time.

Optimal adjustment of the SA parameters

Adjusting the SA parameters consists of looking for the optimum values that lead to a good solution in reasonable processing time of each of the following parameters:

- initial (maximum) temperature T_{max} (to reach the melting point of the metal);
- temperature reduction function r defined as $t_{i+1} = r(t_i)$;
- cooling rate, that is the annealing time $c(t_i)$ (number of iterations) at the temperature t_i.
- neighborhood exploration process that allows to compute a neighbor $x(t_i)$ of the state x_0 at the temperature t_i.

Since SA is inspired from the metropolis process probability, it is needed to adjust its parameters regarding the variation of the real function g such that $g(t) = e^{\frac{-d}{t}}$ with the real positive variable t and the positive parameter d (t represents the temperature and d represents the fitness variation Δf) the function g whose sample curve is represented in Figure 1 below:

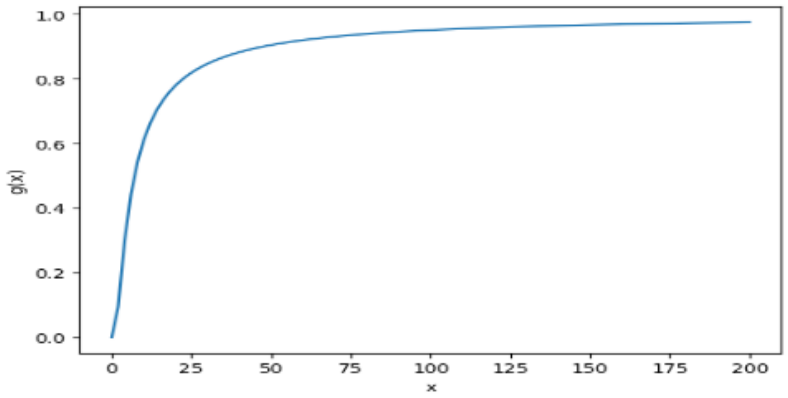

Figure 1 – Curve of g(t) = exp(-d/t) for t>0, d>0

The interpretation of this curve in the SA algorithm semantic shows clearly that:

SA starts as random search and terminate as a descent algorithm;

In order to explore the search space uniformly, d_{mean} is computed as the mean of a sufficient sample of Δf by generating m random solutions. Then, Tmax and Tmin are computed such as:

$\exp(-d_{mean}/T_{max}) = \alpha$, $\alpha \approx 1$, $\alpha < 1$ and $\exp(-d_{mean}/T_{min}) = \beta$, $\beta \approx 0$, $\beta > 0$ (for instance: take α=0.99 and β= 0.0001).

The algorithm below shows how dmean, Tmin, Tmax are computed:

1. Compute_Tmin_Tmax
2. s =0
3. For i=1 to m
4. a = random(S)
5. b = random(S)
6. s = s+|f(a)-f(b)|
7. end for
8. d_{mean}= s/m
9. $T_{max} = -d_{mean} / \log \alpha$
10. $T_{min} = -d_{mean} / \log \beta$

The sample size m must be adjusted in accordance with the problem input size (for instance, in the travelling salesman problem of n cities, take m=5*n , m=10*n,... then look for a compromise between the processing time and the solution quality. Therefore, the complexity of this algorithm is linear.

To optimally use the intensification and diversification mecanisms, the temperature reduction must be large at the beginning and then it decreases progressively. The best way to realize this variation is to define the reduction function r as a geometric sequence with the variable base r_i as it follows: $r_{i+1} = a*r_i$ and $t_{i+1} = r_{i+1}*t_i$, where a is a positive real such that $r_0 \approx 1$, $r_i < 1$, $a \approx 1$, $a>1$.

Application of OASA

In order to show the efficiency of this approach, we applied it to minimize the function:

$f(x) = 4 - 19.0167x + 36.39167x^2 - 25.2917x^3 + 8.041667x^4 - 1.19167x^5 + 0.066667x^6$ which was a sample study in Michel Bierlaire's Algorithm (MBA). This function has two local optima $x_1 = 0.4052$, $x_2 = 3.1045$ and one global optimum $x^* = 5.5541$ as shown in Figure 2 below:

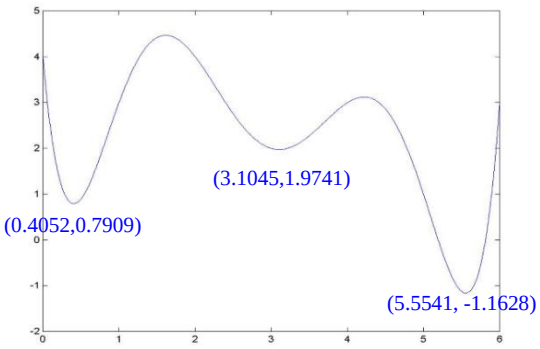

Figure 2 – Results for 100 runs

The table below gives the parameter values used in our OASA and in MBA:

Table 1 – Parameter values

Parameters	In OASA	MBA
Initial solution x0	3	3
Initial temperature Tmax	Adjusted	10000
Final temperature Tmin	Adjusted	Not specified
Reduction factor	Adjusted	0.9
Annealing rate	10	100
Neighborhood of x	[x-0.1,x+0.1]	[x-0.1,x+0.1]

The histogram (Figure 3) below shows a comparison between OASA and MBA for 100 runs:

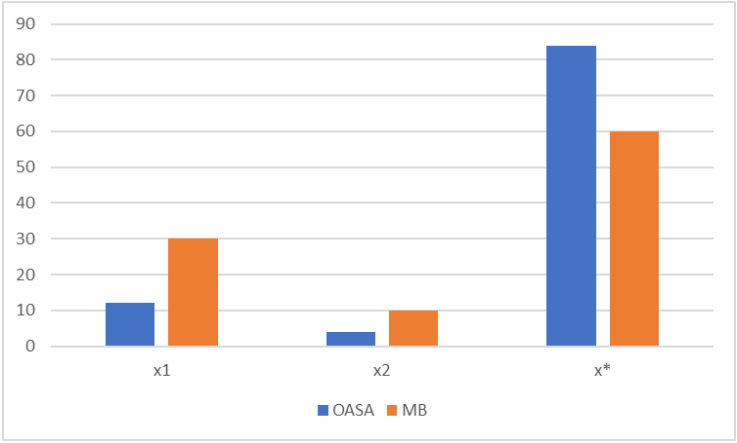

Figure 3 – Results for 100 runs

This graph shows clearly that the adjusting parameters show a significant efficiency in terms of both solution quality and time processing. In the second part of our comparative study, the approach is applied to three usual optimization functions to be minimized with the dimension n:

Rastrigin function:

$Rastrigin\,(x) = 10n + \sum_{i=1}^{n}[x_i^2 - 10cos(2\pi x_i)]$, $x_i \in [-5.12, 5.12]$. There are many extrema. The global minimum is $Rastrigin\,(0) = 0$.

Rosenbrock function:

$\text{Rosenbrock}\,(x) = \sum_{i=1}^{n-1}[100(x_{i+1} - x_i^2) + (1 - x_i)^2]$, $x_i \in R$.

There are many extrema. The global minimum is $Rosenbrock\,(1, 1, \ldots, 1) = 0$.

Sphere function:

$Sphere(x) = \sum_{i=1}^{n} x_i^2$. $x_i \in [-5.12, 5.12]$.

The global minimum is $Sphere\,(0) = 0$,

where n is the dimension of the function.

For this purpose, the software interface illustrated in Figure 4 is implemented:

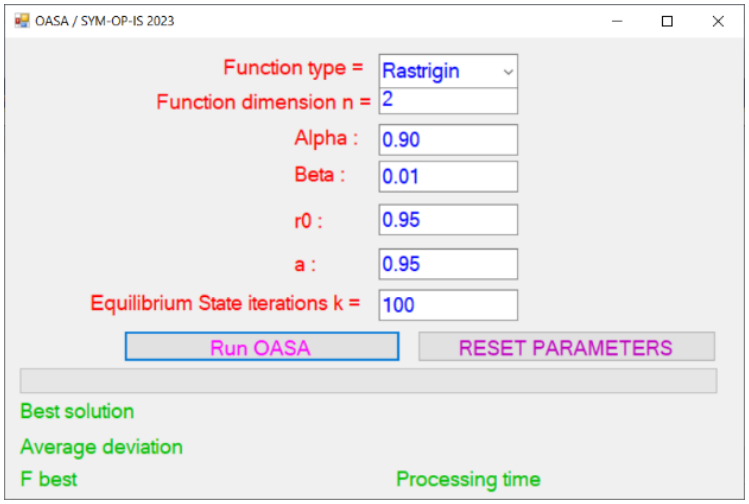

Figure 4 – Interface of the approach implementation

The table below summarizes the deviation $\rho = |F(x_{opt}) - F(x^*)|$ where $F(x_{opt})$ is the global minimum of F and $F(x^*)$ is the obtained minimum using our approach OASA for different values of the dimension n**:**

Table 2 – Results for the optimization functions

Dimension n	Function F	Deviation ρ
2	Rastrigin	0.000000
	Rosenbrock	0.000000
	Sphere	0.000000
5	Rastrigin	0.000000
	Rosenbrock	0.000019
	Sphere	0.000000
20	Rastrigin	0.000002
	Rosenbrock	0.000041
	Sphere	0.000035
50	Rastrigin	0.000105
	Rosenbrock	0.000328
	Sphere	0.000087

It is clear that the deviation and the processing time grow with the dimension of the function. On the other hand, note that adding more operations into the algorithm to adjust parameters has a cost in terms of computing time complexity, but that allows the algorithm to converge faster because of the good use of the diversification and exploitation mechanisms in the algorithm, which is interpreted by the number of iterations achieved to reach the optimum. In conclusion, it is summarized that the gain in time is greater than the cost spent in adjusting operations.

Conclusion

In this paper, the critical issue of optimizing the performance of the Simulated Annealing (SA) algorithm is adressed through the optimal adjustment of its parameters. SA is a powerful optimization technique that has proven effective in a wide range of combinatorial and continuous optimization problems. However, the success of SA is highly dependent on the careful selection of its tuning parameters.

Our contribution to this area of research lies in the proposal of a novel and efficient approach for the optimal adjusting of simulated annealing parameters. Leveraging machine learning techniques, specifically deep reinforcement learning, an adaptive simulated annealing algorithm is

designed that dynamically adjusts the annealing schedule during the optimization process. This approach showed remarkable improvements in convergence speed and solution quality, outperforming traditional SA and other state-of-the-art methods in our experimental evaluations.

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Ajuste óptimo de los parámetros del recocido simulado

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CAMPO: matemáticas, ciencias de computación
TIPO DEL ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: El recocido simulado es una técnica poderosa ampliamente utilizada en problemas de optimización. Un aspecto crítico del uso de simulación recocer eficazmente es un ajuste adecuado y óptimo de

sus parámetros. Este artículo presenta un enfoque novedoso para ajustar eficientemente los parámetros de recocido simulado para mejorar su rendimiento yvelocidad de convergencia.

Métodos: Dado que el algoritmo simulado está inspirado en el Proceso de enfriamiento Metrópolis, la idea básica es simular y analizar este proceso utilizando un modelo matemático. El trabajo propuesto tiende a imitar adecuadamente el proceso de enfriamiento de Metrópolis en el campo algorítmico. Al ajustar inteligentemente el programa de temperatura, la reducción de temperatura y velocidad de enfriamiento, el algoritmo optimiza el equilibrio entre exploración y explotación, lo que conducirá a una mejor convergencia y una mayor calidad soluciones.

Resultados: Para evaluar la efectividad de este enfoque, se aplicó primero en una función de muestra elegida que se va a minimizar, y luego en alguna función habitual de optimización conocida. Los resultados demuestran que nuestro enfoque, llamado Ajuste Óptimo de los Parámetros de Recocido Simulado (OASA-por sus siglas en ingles-), logra un rendimiento superior en comparación con el parámetro estático tradicional y otros enfoques existentes, mostrando cómo ajustar bien los parámetros del algoritmo de recocido simulado para mejorar su eficiencia en términos de calidad de la solución y tiempo de procesamiento.

Conclusión: Ajustar los parámetros del algoritmo podría tener un impacto significativo y una contribución en el campo de la optimización incluso para otras metaheurísticas.

Palabras claves: recocido simulado, ajuste de parámetros, optimización, metaheurístico.

Оптимальная настройка параметров имитации отжига

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РУБРИКА ГРНТИ: 27.37.17 Математическая теория управления.
Оптимальное управление
27.47.00 Математическая кибернетика
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Имитация отжига является мощным методом, широко используемым в задачах оптимизации. Одним из важнейших аспектов эффективного использования имитационного отжига является правильная и оптимальная настройка его параметров. В данной статье представлен новый подход к эффективной

настройке параметров имитационного отжига для повышения его производительности и скорости сходимости.

Методы: Поскольку моделируемый алгоритм вдохновлен процессом охлаждения „Метрополис“, основная идея статье заключается в моделировании и анализе этого процесса с использованием математической модели. Целью данной статьи является описание точной имитации процесса охлаждения „Метрополис“ в области алгоритмики. Рационально регулируя температурный режим, снижение температуры и скорость охлаждения, алгоритм оптимизирует баланс между разведкой и эксплуатацией, что способствует улучшению конвергенции и более качественным решениям.

Результаты: Для того чтобы оценить эффективность данного подхода, его сначала применили в минимизации выбранной выборки функций, а затем в некоторых известных функциях оптимизации. Результаты показали, что данный подход, называемый оптимальной настройкой параметров имитации отжига (OASA), обеспечивает лучшую производительность по сравнению с традиционными настройками статических параметров и другими существующими подходами, показывая, как правильно настроить параметры алгоритма имититации отжига в целях повышения его эффективности с точки зрения качества решения и времени обработки.

Выводы: Настройка параметров алгоритма может внести значительный вклад в методы оптимизации даже при разработке других метаэвристических алгоритмов.

Ключевые слова: имитация отжига, настройка параметров, оптимизация, метаэвристика.

Оптимално подешавање параметара симулираног каљења

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Сажетак:

Увод/циљ: Симулирано каљење је моћна техника широко примењивана у проблемима оптимизације. Критични моменат при ефикасном коришћењу симулираног каљења јесте правилно и оптимално подешавање његових параметара. У раду је представљен иновативни приступ ефикасном подешавању

параметара симулираног каљења чији је циљ побољшање његових перформанси и брзине конвергенције.

Методе: Будући да је симулирани алгоритам инспирисан Метрополис процесом хлађења, основна идеја је да се овај процес симулира и анализира помоћу математичког модела. Предложени рад се фокусира на правилно пресликавање Метрополис процеса хлађења у област алгоритама. Интелигентно подешавајући температурни распоред, као и брзину редукције температуре и хлађења, алгоритам оптимизује равнотежу између експлорације и експлоатације, што резултира побољшаном конвергенцијом и решењима високог квалитета.

Резултати: Да би се испитала ефикасност овог приступа, најпре је примењен за минимизацију изабраног узорка функције, а затим на већ познатим функцијама оптимизације. Резултати показују да наш приступ, назван оптимално подешавање параметара симулираног каљења (Optimal Adjusting of Simulated Annealing parameters (OASA)), демонстрира супериорне перформансе у поређењу са традиционалним статичким подешавањима параметара, као и са осталим постојећим приступима, тако што показује како да се успешно подесе параметри алгоритма симулираног каљења ради побољшавања његове ефикасности, односно квалитета решења и времена процесирања.

Закључак: Подешавање параметара алгоритма могло би значајно да допринесе области оптимизације, чак и када је реч о другим метахеуристикама.

Кључне речи: симулирано каљење, подешавање параметара, оптимизација, метахеуристика.

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Railway stations in the Republic of Serbia in the function of transportation of goods: efficiency according to the DEA system

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FIELD: mathematics
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Abstract:

*Introduction/*purpose*: Data Envelopment Analysis (DEA) is commonly used to calculate the efficiency of similar Decision-Making Units (DMUs), which as such are elements of one set. In the article, it is considered that each such element of a set (of similar elements) is at the same time an element of a system (of various elements). An example of DMUs are 27 railway stations in the Republic of Serbia (RS) as an element of a set of railway stations and as an element of the railway transportation system, in the function of transporting goods, after division of the company Serbian Railways in 2015 (into "passengers" and "goods"). For the sake of better service, attraction and retention of clients, in the newly opened, free, transport market, the purpose of this article is to find the efficiency of the RS stations iin the period of 2018-2022.*

Methods: Set-systemic-model comparative DEA analysis of railway stations as a DMUs. A unit is an element of the set, a unit is an element of the system, and a unit is the subject of the mathematical DEA-CCR/BCC/SE model.

Results: The final efficiency, the average of all average values, is 0.7666, as a result of a triple comparative DEA analysis: 27 DMU, three DEA models and five years of functioning.

Conclusion: Stations are functionally different in terms of efficiency and each station functionally differs by years and by model. The final aim is an input-output balance and the 27/27 option which is achieved with corrective actions – reduction/addition, input or output.

Key words: efficiency, DEA-CCR/BCC/SE, railway stations, set-system, transportation of goods.

Introduction

The article is intended to those aiming to achieve as much as possible with as little investment as possible, especially in wider and wider environments.

The environment here refers to the system, the structure of various elements-subsystems and more structures in the supersystem. A concrete element-subsystem is a railway station, as an object of research, in the function of transporting goods.

Efficiency is the issue here. It is a property of someone or something, on the one hand, and a mathematical quantity, on the other. Hence, it is treated here in two levels: (1) practically, shown through the examples of other authors and the example of the RS railway stations, and (2) theoretically, shown by the first DEA mathematical method, the CCR model, named after its authors - Charnes, Cooper and Rhodes (Charnes et al, 1978). Later, the method was innovated over several decades, through numerous mathematical models by other authors.

In terms of such a tendency, a new idea is presented here, which is an upgrade to a known method. The emergence of a new idea – set-system DEA analysis – originates from the reality and that is now open free transport market.

But why railways, why railway stations and why efficiency assessment? The railway, as a complex, profit-making system, is a good sample for this kind of research. Furthermore, railway stations, as a numerous set, are a true example of decision-making units. Furthermore, after more than eight years from the division of the Serbian Railways company (in 2015) and the start of the new business, further system changes follow, according to the guidelines of developed countries, according to the principles of dynamic market economy. On the basis of the guidelines and the transition process there are business indicators as input-output parameters. Hence the topic of efficiency, evaluation of the efficiency of railway stations and measures for better competitiveness in the newly opened, free, transport market. This article deals with a DEA analysis from the time of its creation, the railway stations of the RS from the recent era and the multi-year transition process of the ŽS (Serbian Railways).

Set-systemic DEA analysis

Set-systemic DEA analysis is a combination of the DEA method and system theory, and the important determinants are:

1. Set analysis, where the decision-making unit is an element of the set, and an important step is the correct selection of the set size, i.e., the number of analyzed units.
2. System analysis, where the decision-making unit is an element of the system, which according to system theory has many diverse elements (subsystems) and complex connections between them, and an important step is the correct selection of inputs and outputs.
3. DEA analysis – a mathematical DEA model which solves the problem of linear programming; for a concrete sample from practice and for each decision-making unit, it determines whether a particular is either efficient or inefficient in regard to the remaining units. There are two options for the functioning of decision-making units – they are either followed by other (inefficient) units or they are followers of other (efficient) units. The numerical value of efficiency is from zero to one. Efficient units are best practice units, where Eff=1. The other, opposite, inefficient units, where 0<Eff<1, emulate the efficient units, the best practice units, as their role model. The logic of inefficient units reads: Under the same conditions, here in the same set and with the same input-output variables, inefficient units can be efficient, because the model (best practice) is realistic (already achieved) and relative (valid for a concrete sample, i.e., one and the same set of decision units). One can go further and ask which one is the most exemplary.

Set-systemic DEA analysis is mathematically represented by models where the mathematical model consists of:
1. Set DEA models (a unit is an element of a set of similar elements):
- CCR CRS model is with constant returns to scale (Charnes et al, 1978):

$$\max h_0 = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \tag{1}$$

$$\text{s.t.} \quad \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, \; j = 1, \dots, n$$

$$u_r, \; v_i \geq 0; \; r = 1,\dots,s; \; i = 1,\dots,m$$

where:
h_0 – relative efficiency of the 0th DMU;
n – number of DMU; m – number of inputs; s – number of outputs;
u_r – weight coefficient of the rth output;
v_i – weight coefficient of the ith input.

- BCC VRS is a model with variable returns to scale or the extended CCR model (1) for an additional variable u_0, in the numerator of the efficiency formula (Banker et al, 1984):

$$\max h_0 = \frac{\sum_{r=1}^{s} u_r y_{r0} - u_0}{\sum_{i=1}^{m} v_i x_{i0}} \quad (2)$$

where (Banker et al, 1984, p.1087):
- Increasing returns to scale <=> $u_0^* < 0$,
- Constant returns to scale <=> $u_0^* = 0$, and
- Decreasing returns to scale <=> $u_0^* > 0$.

- SE model (Panwar et al, 2022) is:

$$Scale\ efficiency = E_{CCR}/E_{BCC}, \quad (3)$$

where: E_{CCR} – CCR efficiency and E_{BCC} – BCC efficiency.

2. System DMU model (a unit is an element of a system of *N* diverse elements, among which there are connections):

$$DMU1,..., DMUn \in SISTEMA\ (E1, E2,...,EN) \quad (4)$$

where are the links between *N* elements:

$$E1 \leftrightarrow E2,\ E1 \leftrightarrow E3, \ldots, E1 \leftrightarrow EN,\ E2 \leftrightarrow E3, \ldots, E2 \leftrightarrow EN, \ldots$$

In the set approach, the DEA mathematical method and the classical DEA models - CCR, BCC and SE - are applied. In the systems approach, system theory and a multi-component transportation system are applied. How to adequately mathematically model railway stations? Defining inputs and outputs in the DEA procedure is a complex and crucial issue. In the example of railway stations, it is known that inputs and outputs are economic, commercial activities, invested or realized, in the goods transport sector. How to select, re-select or not select them? What are inputs and outputs? Indeed, what is a railway station?

Railway station as an element of a set and a system

A railway station is seen here as an element of a set of railway stations and, more broadly, as an element of the railway transportation system.

A railway station is an element of a set of official places on the railway network, which consists of a set of supervisory and a set of subordinate

official places, Figure 1. Official places that deal with loading/unloading (in tons of transported goods) in the respective year of the analyzed period are called active official places.

The end stations of the traffic route are called terminuses and determine the type of traffic:
1. Domestic traffic (initial and final terminuses in the RS);
2. International traffic:
- import (initial terminus abroad, final terminus in the RS);
- export (initial terminus in the RS, final terminus abroad); and
- transit (both terminuses abroad).

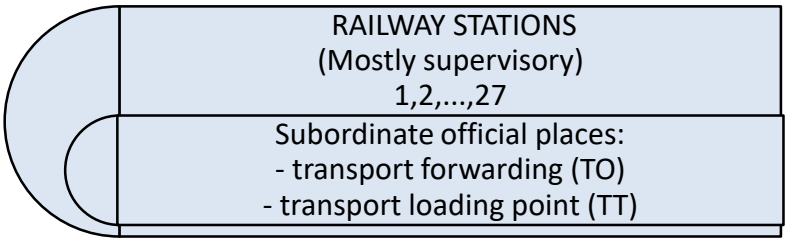


Figure 1 – Railway station as an element of the set of railway stations of RS

The railway station is an element of the transportation system according to model (4), where the transportation system has *N*=5 basic elements (Filipović, 2013):
1. Vehicles (V);
2. Traffic roads (TR);
3. Terminals (T);
4. Energy (E); and
5. Organization and management (OM).

Specifically, in the goods transport sector, the railway transportation system has the following five elements, Figure 2:
V – freight cars;
TR – railway lines;
T – railway stations (there are 27 stations on the RS railway network);
E – diesel and electric energy, facilities, equipment and people; and
OM – station (executive) staff.

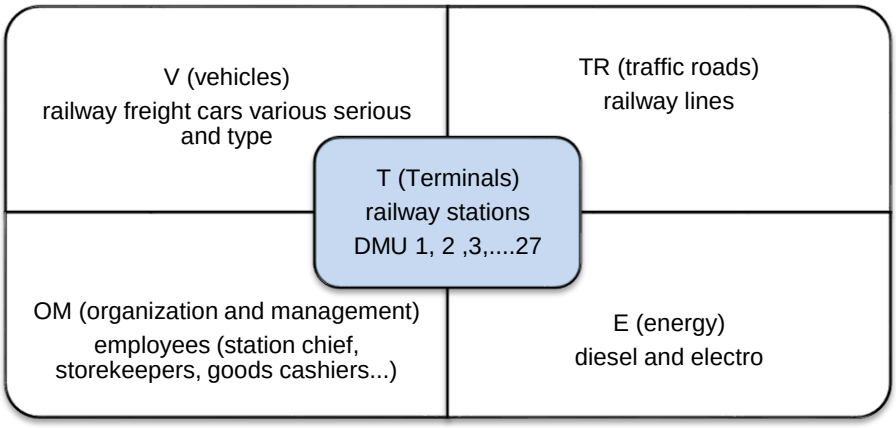


Figure 2 – The railway station as an element of the RS transportation system

"A transportation system has several components. First, it can be defined in terms of infrastructure, vehicles, operations, and policies." (Sinha, 2007, p.3)

The assessment of the efficiency and re-efficiency of the railway station (T) in the business course of the newly formed company is an assessment of the ratio of activities achieved and invested, for each decision-making unit, by years. If the station, T, is defined as an element of the transportation system, then the activities invested and the service provided are simply determined.

The invested activities are:
- resource activities: work of employees, in the number of executors, OM and E; and
- operational activities: reception/dispatch of freight cars, in the number of cars, V.

The accomplished activities are:
- transport flows – transport service: import, export, transit and domestic transport of goods, in tons of transported goods, as a transport indicator; and
- traffic flows – tariff kilometers per car, as a traffic indicator, TR.

Therefore, as an element of the set, as an element of the system and as a unit of efficiency decision making, when applying the DEA method, the railway station has two inputs and two outputs.

Literature review

Efficiency and DEA begin with the first DEA authors: Charnes, Cooper and Rhodes, and the first DEA paper from 1978, as well as the first basic CCR model. (Charnes et al, 1978) Many decades later, the first published paper is the first in the ranking list of cited papers. As stated in the bibliometric report: "The most cited paper is also the most cited paper of all time in the field of OR and MS and was published by Charnes, Cooper and Rhodes". (Laengle et al, 2017, p.812) A brief review of the literature contains the papers published in the relatively recent period of 2013-2023 from the field of DEA, a subfield of traffic and transport engineering, with data on efficiency decision-making units as a research subject, listed in Table 1.

Table 1 – Literature review

Journal	Autor(s)	No. DMU	DMU Sample
Military Technical Courier/Vojnotehnički glasnik	Andrejić (2013)	20	Distribution centers[1] in Serbia
Transportation Research Part D	Park et al. (2018)	50	The transport sector of the US states
Transport Policy	Kyriacou et al. (2018)	34	Transport infrastructure investments of countries
Transport	Zeng et al. (2020)	20	Airports in Eastern China
International Journal Technology, Policy and Management	Ghanem et al. (2020)	28	Turkish and EU railways
Case Studies on Transport Policy	Fancello et al. (2020)	9	Italian city roads
Axioms	Nguyen et al. (2022)	24	Maritime transport in EU countries
Discrete Dynamics in Nature and Society	Shang et al. (2022)	40	Airports in China
Journal of Navigation and Port Research	Bernal et al. (2022)	17	Container terminals in Spain
Procedia Computer Science	Jiang et al. (2022)	30	Transport in Chinese provinces

[1] A distribution center consists of (Andrejić, 2013): a storage subsystem and a transport subsystem.

Journal	Autor(s)	No. DMU	DMU Sample
Transport Policy	Tomikawa & Goto (2022)	6	Railway passenger companies
Research Square	Niu et al. (2022)	38	Railway operators
Energy	Lee & Kim (2023)	6	Road passenger vehicles in EU countries

In a broader sense, the listed similar units from each sample are additionally similar to the units of the other samples as components of the transportation system, which according to Sinha (2007) constitute:
1. Infrastructure: distribution centers (Andrejić, 2013), airports (Zeng et al, 2020), (Shang et al, 2022), roads (Fancello et al, 2020) and container terminals (Bernal et al, 2022);
2. Vehicles: electric vehicles and internal combustion engine vehicles (Lee & Kim, 2023);
3. Operations: rail transport of passengers and goods (Ghanem et al, 2020), (Tomikawa & Goto, 2022), (Niu et al, 2022) and maritime transport of passengers and goods (Nguyen et al, 2022); and
4. Policies: transport infrastructure investments (Kyriacou et al, 2018), or the entire transport sector (Park et al, 2018), (Jiang et al, 2022).

According to Andrejić (2013, p.86), "it is possible to make a difference among the following efficiency measurement aspects in logistic: activity efficiency, process efficiency, subsystem efficiency, system efficiency and chain efficiency", viewed vertically, from the bottom up. But the activities, processes, subsystems and systems themselves are different, for the same level of observation, viewed horizontally. Therefore, we distinguish vertical and horizontal structures when measuring efficiency of diverse and few/many decision-making units.

Thanks to the research studies of earlier authors, today there are numerous multivariate DEA models and numerous theoretical/practical examples of application. At the world level, according to the State of the Art from 2011 (Markovits-Somogyi, 2011), the share of studies with the DEA application in the railway transport sector, in the total number of studies in the field of transport, is 9 out of 69 analyzed.

In the article, a triple comparative analysis was chosen, the determinants of which are: 27 real decision-making units, three DEA models and five years of business. Hence, this article is a new theoretical contribution to the application of the DEA method in the field of railway transport – (1) a new real sample: railway stations, transport of goods,

2018-22, (2) knowledge about efficiency, and (3) the possibility of corrective actions, to improve the company's operations and survival in the open market.

And the concrete challenge in the theoretical contribution is to know the individual practical contribution of each railway station to the functioning of the company. Accordingly, which stations should only be considered as role models, and which should be actively improved for the efficient operation of the company as a whole.

This article examines the efficiency of 27 railway stations in the RS in the function of transporting goods after the division of the ŽS company, in the five-year period of 2018-2022. More precisely, the efficiency of railway stations, in relation to the remaining stations in the set, and the remaining elements in the system and the model applied following the complex mathematical DEA system achieved/invested.

The next section deals with another example in the Republic of Serbia, a new non-monopoly company "Srbija Kargo" JSC, in the official places in the function of goods transportation: railway stations and the issue of efficiency.

Railway stations in the Republic of Serbia

In this article, the subject of research are concrete railway stations on the railway network of the Republic of Serbia, open for the transportation of goods. According to the latest data, there are 27 railway stations in the RS, in the function of transporting goods, most of which are supervisory for subordinate official places (transport forwarding and transport loading points) on the railway network of the RS.

Introductory analysis

Railway station, train station, Bahnhöfe, Les gares, Stazioni ferroviarie, Σιδηροδρομικοί σταθμοί, Vasútállomások, Železničné stanice, Železniške postaje, Железнодорожные станции, Järnvägsstationer, Estaciones de ferrocarril[2] - the words are different but they all mean the same: railway stations. In accordance with the system theory, they are part of the economic subsystem, part of the transportation subsystem, part of the transport subsystem, and here we analyze them as part of the railway, more precisely the railway transport subsystem.

[2] Respectively, in the languages: British English, American English, German, French, Italian, Greek, Hungarian, Slovak, Slovenian, Russian, Swedish and Spanish.

The subject of analysis – the railway stations (in the Republic of Serbia) – has been singled out for operational research theoreticians as well as traffic and transport practitioners. Since the first railway station until today, through decades of continuous innovation, the most modern stations have been built in developed European and world countries. In terms of such a tendency, the example that follows reflects a more recent state and is not a rounded whole, but open to new ideas, new examples, and future stations as the most valuable and prominent objects of the railway infrastructure, the beginning and the end of the transport service - loading and unloading stations in the process of transporting goods.

The main means of transporting goods are railway freight cars with different capacities (maximum amount of goods in tons). Hence, in the sample that follows, there are adequate inputs and outputs for each railway station:
- inputs: the number of executors and the number of received/dispatched freight cars from loading/unloading, and
- outputs: the quantity of transported goods (as a transport indicator) and the number of tariff kilometers traveled (as a traffic indicator).

As practitioners, we look for operational efficiency i.e., efficiency of functioning[3] where real empirical data is used, to find out the effects of disintegration. We look for the situation in the practice of rail transport of goods after the milestone in 2015 in order to identify target actions.

As an example of an activity where the creation of a service has several mutually competitive options, the activity of transport is given here, namely: (1) road transport, (2) rail transport, (3) air transport, (4) water transport, and (5) integral transport. Each of the listed transports has a passenger transport sub-option and a goods transport sub-option.

In practice, transport companies usually provide transport service exclusively in one way, e.g. rail transport service through railway transport technology. Further channeling of rail transport or disintegration into passenger transport and goods transport is a new practice in Serbia, understudied and insufficiently known. Hence, a challenge in the new period is to assess the situation after the disintegration in terms of the efficiency of each particular station in the years after the division.

[3] (Min & Jong Joo, 2006), (Andrejić, 2015)

Numerical pre-analysis

Merged into the rail transportation system, the passenger rail transport subsystem and the goods rail transport subsystem existed in the railway network of the Republic of Serbia until August 10, 2015, as the company Serbian Railways (ŽS). Since then, four separate companies have been operating: Srbija Kargo JSC (Joint Stock Company for Railway Transport of Goods), here the subject of research, Srbija Voz JSC (Joint Stock Company for Railway Passenger Transport), as well as ŽS Infrastructure (IŽS) and ŽS Holding.

In the sample that follows, the decision-making units are all 27 railway stations in the function of goods transportation (including their subordinate offices: TO and TT on the IŽS. The analyzed official places are terminuses, i.e., final official places of traffic routes in the RS (departure and/or end in the process of vehicle movement; departure or destination; entry and/or exit to/from the system[4]). The research includes: internal traffic (starting and ending places are at IŽS), import (ending places are at IŽS) and export (starting places are at IŽS).

How to divide one set (of 27 units) into two sets (a set of efficient units and a set of inefficient units)? Theoretically, this is possible to be achieved in 27 ways; therefore, there are 27 options, i.e., potential solutions, Table 2.

Table 2 – Potential solutions

Option	Efficient units		Inefficient units		Total units	Efficient /Total units
O_1	1		26		27	1/27
O_2	2		25		27	2/27
O_3	3		24		27	3/27
O_4	4		23		27	4/27
O_5	5		22		27	5/27
O_6	6		21		27	6/27
O_7	7		20		27	7/27
O_8	8		19		27	8/27
O_9	9		18		27	9/27
O_{10}	10		17		27	10/27
O_{11}	11		16		27	11/27
O_{12}	12		15		27	12/27
O_{13}	13		14		27	13/27
O_{14}	14	+	13	=	27	14/27
O_{15}	15		12		27	15/27
O_{16}	16		11		27	16/27
O_{17}	17		10		27	17/27

[4] An entry or an exit station is a place where goods enter or leave the selected transport system. (Filipović, 2013)

Option	Efficient units	Inefficient units	Total units	Efficient /Total units
O_{18}	18	9	27	18/27
O_{19}	19	8	27	19/27
O_{20}	20	7	27	20/27
O_{21}	21	6	27	21/27
O_{22}	22	5	27	22/27
O_{23}	23	4	27	23/27
O_{24}	24	3	27	24/27
O_{25}	25	2	27	25/27
O_{26}	26	1	27	26/27
O_{27}	27	0	27	27/27

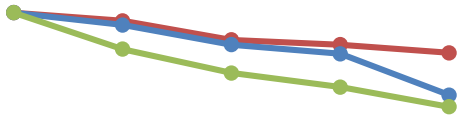
The optimal option is O_{27}, with all 27 efficient units, followed by option O_{26}, with 26 efficient units, then O_{25}, O_{24}… In the numerical sample, the efficiency is calculated for each of 27 decision-making units, a set of efficient units and a set of inefficient units are obtained, and a particular option is identified.

In the process of the movement of freight cars, the aim is to transport as many loaded cars as possible (Output1 maximum) and on the longest possible distance (Output2 maximum[5]). At the same time, it should be achieved with as few executors as possible and as few cars as possible – Input1 and Input2 should be minimal. Therefore, for calculating efficiency with classic DEA models, there are two inputs and two outputs here.

In general, various types of goods are transported by rail: articles of human nutrition, military equipment, containers, various types of oil, ores, coal, etc., in various series and types of cars, for various clients/shippers in import, export, domestic traffic, and transit. Empty cars also run, sent for loading or returning from unloading.

At the very beginning of the research, the business indicators are known – total results by year: tons of transported goods, the number of traffic cars (which generate income) and the number of active official places on the railway – which slightly decrease from year to year, according to data normalized between zero and one, Figure 3.

[5] When the income is received, i.e., so-called transportation fee.



	2018	2019	2020	2021	2022
tons of goods	1	0,9553	0,8496	0,8236	0,7780
freight cars	1	0,9326	0,8234	0,7727	0,5453
active official places	1	0,7984	0,6667	0,5891	0,4806

Figure 3 – Business indicators, 2018-22

In more detail, the percentage share of freight car traffic by year is divided by type of traffic, Table 3. A higher share of international traffic is observed, which is in line with growing globalization.

Table 3 – Freight car transportation, by year and type of traffic

Type of traffic	2018	2019	2020	2021	2022
Domestic	34	33	31	26	26
International	66	67	69	74	74
- import	23	24	23	25	29
- export	19	20	21	24	23
- transit	24	23	25	25	22
∑	100	100	100	100	100

The initial data (inputs and outputs) are real statistical data for the five-year period of 2018-22. Transit was not analyzed because there are no loading/unloading operations at the stations on the IŽS railway network (the final official places, loading or unloading, are abroad). The table of descriptive statistics of the initial data consists of (Aparicio & Zofio, 2021): minimum, median, average, maximum, and standard deviation. For the sample of the RS railway stations, descriptive statistics are given by year for the five-year period 2018-22, Table 4.

For a better trend, it is necessary to determine exactly which units of the organization are not functioning optimally. Hence, in the next section, the efficiency of each railway station is analysed, as follows: Effstation = f [Input1, Input2, Output1, Output2, $u1$, $u2$, $v1$, $v2$, model (1), (2), (3)]. At the same time, the dependence function is not known, and consequently, the non-parametric DEA method is applied.

Table 4 – Descriptive statistics of the initial data for 2018-22

Type	2018	2019	2020	2021	2022
			Minimun		
Input1	5	5	5	5	5
Input2	193	108	26	0	0
Output1	4,617	2,964	1,224	0	0
Output2	50,764	23,714	11,414	0	0
			Median		
Input1	19	21	21	21	21
Input2	11,809	8,214	7,840	5,058	3,189
Output1	266,382	247,441	249,238	192,106	136,539
Output2	2,212,381	1,486,651	1,636,987	918,934	559,322
			Average		
Input1	22	21	21	21	21
Input2	15,032	14,004	12,387	11,618	10,901
Output1	463,853	443,365	394,314	382,254	371,003
Output2	2,741,357	2,368,649	2,255,948	2,111,191	2,095,982
			Maximum		
Input1	55	53	53	53	53
Input2	115,084	120,416	84,054	90,766	90,807
Output1	4,100,475	4,209,062	2,938,645	3,240,929	3,261,823
Output2	15,247,532	14,410,170	10,088,444	10,782,367	11,594,050
			Standard deviation		
Input1	12	12	12	12	12
Input2	21,597	22,477	16,211	18,084	17,883
Output1	772,382	784,148	562,298	630,782	645,382
Output2	3,139,907	2,908,017	2,413,276	2,763,524	2,911,553

Source: (1) information: own research, (2) data: "Srbija Kargo" JSC, Traffic and Transport Sector, Center for Commercial Affairs, Center for Calculation and Control of Income.

Numerical DEA analysis

This subsection calculates the numerical value of the efficiency of 27 railway stations in the Republic of Serbia in the function of transporting goods after the 2015 division of the company Serbian Railways (ŽS) for the period of 2018-22.

The computational procedure was performed using the non-commercial software OSDEA-GUI (an acronym for Open Source Data Envelopment Analysis Graphical User Interface), version 0.2, more precisely, the CCR input and BCC input models (Open Source DEA, nd). For the specific sample of railway stations, where n=27, m=2, and s=2, a series of 27 linear programming (LP) problems is programmed. Each LP for each decision-making unit and each resulting unit efficiency, relative to the remaining DMUs. Inputs and outputs are the elements of the system, according to model (4), where N=5, namely: *N1=V, N2=TR, N3=T, N4=E and N5=OM.*

In order to have a broader overview, a three-way comparative analysis was performed with the above-mentioned, so-called classical[6] DEA models, Table 5.

Table 5 – Triple comparative analysis

Station	Year	Model			
			Acronym of	Orientation	Result
1 2 3 … … 27	2018 2019 2020 2021 2022	CCR	Charnes-Cooper-Rhodes	input	Technical efficiency TE
		BCC	Banker-Charnes-Cooper	input	Pure technical efficiency PTE
		SE	Scale Efficiency	input	TE/PTE

The result of the mentioned triple comparative analysis is the information on the efficiency (for station 1, year 2018, model CCR...), the average efficiency, as well as the number of the efficient units, Table 6.

Table 6 – Efficiency, input-oriented, stations-models-years

No.	DMU Name	CCR	BCC	SE	Average	No. efficient
			2018			
1	Beograd R.	0.4830	0.4878	0.9902	0.6537	
2	Bor Teretna	0.5736	0.5738	0.9997	0.7157	
3	Brasina	0.4352	0.5652	0.7700	0.5901	
4	Crveni Krst	0.8919	0.8942	0.9974	0.9278	
5	Dimitrovgrad	0.6500	0.6595	0.9856	0.7650	
6	Kragujevac	0.5986	0.6003	0.9972	0.7320	
7	Kraljevo	0.5583	0.6318	0.8837	0.6913	
8	Lapovo R.	0.9857	0.9977	0.9880	0.9905	
9	Niš R.	0.5129	0.5254	0.9762	0.6715	
10	Novi Sad R.	0.6484	0.6594	0.9833	0.7637	
11	Pančevo G.	1	1	1	1	1
12	Požega	0.9420	0.9591	0.9822	0.9611	
13	Prahovo P.	0.8725	0.8878	0.9828	0.9144	
14	Prijepolje T.	0.9867	1	0.9867	0.9911	
15	Radinac	1	1	1	1	2
16	Ristovac	1	1	1	1	3
17	Ruma	1	1	1	1	4
18	Sombor	1	1	1	1	5

[6] (Panwar et al, 2022)

No.	DMU Name	CCR	BCC	SE	Average	No. efficient
19	S. Mitrovica	0.5975	0.6351	0.9408	0.7245	
20	Subotica	0.5337	0.5404	0.9876	0.6872	
21	Surčin	0.6015	0.6317	0.9522	0.7285	
22	Šabac	1	1	1	1	6
23	Šid	0.7411	0.7606	0.9744	0.8254	
24	Vrbas	0.6558	0.7306	0.8976	0.7613	
25	Vreoci	0.9925	0.9946	0.9979	0.9950	
26	Vršac	1	1	1	1	7
27	Zrenjanin	0.9081	0.9117	0.9961	0.9386	
	Average	0.7840	0.8017	0.9729	0.8529	
			2019			
1	Beograd R.	0.3663	0.3693	0.9919	0.5758	
2	Bor Teretna	0.5946	0.6649	0.8943	0.7179	
3	Brasina	1	1	1	1	1
4	Crveni Krst	0.6935	0.7319	0.9475	0.7910	
5	Dimitrovgrad	0.1937	0.4312	0.4492	0.3580	
6	Kragujevac	0.6348	0.7199	0.8818	0.7455	
7	Kraljevo	0.4652	0.4924	0.9448	0.6341	
8	Lapovo R.	0.6842	0.8049	0.8500	0.7797	
9	Niš R.	0.3691	0.4059	0.9093	0.5614	
10	Novi Sad R.	0.4860	0.5076	0.9574	0.6503	
11	Pančevo G.	0.7895	0.9235	0.8549	0.8560	
12	Požega	0.5564	0.5747	0.9682	0.6998	
13	Prahovo P.	1	1	1	1	2
14	Prijepolje T.	0.4100	1	0.4100	0.6067	
15	Radinac	1	1	1	1	3
16	Ristovac	1	1	1	1	4
17	Ruma	0.7237	0.9737	0.7432	0.8135	
18	Sombor	1	1	1	1	5
19	S. Mitrovica	0.9508	0.9852	0.9651	0.9670	
20	Subotica	1	1	1	1	6
21	Surčin	0.3906	0.5484	0.7123	0.5504	
22	Šabac	1	1	1	1	7
23	Šid	0.4086	0.4277	0.9553	0.5972	
24	Vrbas	0.7972	1	0.7972	0.8648	
25	Vreoci	0.7706	0.8163	0.9440	0.8436	
26	Vršac	0.7651	0.9714	0.7876	0.8414	
27	Zrenjanin	0.6809	0.7047	0.9662	0.7839	
	Average	0.6937	0.7798	0.8863	0.7866	
			2020			
1	Beograd R.	0.2367	0.2445	0.9681	0.4831	
2	Bor Teretna	0.4944	0.6090	0.8118	0.6384	
3	Brasina	1	1	1	1	1
4	Crveni Krst	0.7125	1	0.7125	0.8083	
5	Dimitrovgrad	0.1405	0.3751	0.3746	0.2967	
6	Kragujevac	0.5815	0.6796	0.8557	0.7056	
7	Kraljevo	0.3513	0.3527	0.9960	0.5667	
8	Lapovo R.	0.4688	0.7162	0.6546	0.6132	
9	Niš R.	0.1608	0.3194	0.5034	0.3279	

No.	DMU Name	CCR	BCC	SE	Average	No. efficient
10	Novi Sad R.	0.3127	0.3616	0.8648	0.5130	
11	Pančevo G.	0.6754	0.9194	0.7346	0.7765	
12	Požega	0.3983	0.4148	0.9602	0.5911	
13	Prahovo P.	1	1	1	1	2
14	Prijepolje T.	1	1	1	1	3
15	Radinac	0.8494	1	0.8494	0.8996	
16	Ristovac	0.5316	0.5538	0.9599	0.6818	
17	Ruma	0.5267	0.7846	0.6713	0.6609	
18	Sombor	1	1	1	1	4
19	S. Mitrovica	1	1	1	1	5
20	Subotica	1	1	1	1	6
21	Surčin	0.4452	0.5416	0.8220	0.6029	
22	Šabac	1	1	1	1	7
23	Šid	0.2526	0.2851	0.8860	0.4746	
24	Vrbas	0.7520	1	0.7520	0.8347	
25	Vreoci	0.5365	0.5937	0.9037	0.6780	
26	Vršac	1	1	1	1	8
27	Zrenjanin	0.6109	0.6904	0.8848	0.7287	
	Average	0.6310	0.7201	0.8580	0.7364	
			2021			
1	Beograd R.	0.1695	0.1851	0.9157	0.4234	
2	Bor Teretna	0.6320	1	0.6320	0.7547	
3	Brasina	1	1	1	1	1
4	Crveni Krst	0.5436	0.7680	0.7078	0.6731	
5	Dimitrovgrad	0.1677	0.3481	0.4818	0.3325	
6	Kragujevac	0.6837	0.7330	0.9327	0.7831	
7	Kraljevo	0.2968	0.3158	0.9398	0.5175	
8	Lapovo R.	0.4073	0.4164	0.9781	0.6006	
9	Niš R.	0.2497	0.2867	0.8709	0.4691	
10	Novi Sad R.	0.3450	0.3501	0.9854	0.5602	
11	Pančevo G.	0.8091	0.9332	0.8670	0.8698	
12	Požega	0.3562	0.3567	0.9986	0.5705	
13	Prahovo P.	1	1	1	1	2
14	Prijepolje T.	0.4226	0.5556	0.7606	0.5796	
15	Radinac	0.9788	1	0.9788	0.9859	
16	Ristovac	0.0451	0.3846	0.1173	0.1823	
17	Ruma	0.4226	0.7225	0.5849	0.5767	
18	Sombor	1	1	1	1	3
19	S. Mitrovica	1	1	1	1	4
20	Subotica	1	1	1	1	5
21	Surčin	0.4043	0.5364	0.7537	0.5648	
22	Šabac	1	1	1	1	6
23	Šid	0.2789	0.2874	0.9704	0.5122	
24	Vrbas	0.6763	1	0.6763	0.7842	
25	Vreoci	0.3898	0.4029	0.9675	0.5867	
26	Vršac	0	0.8333	0	0.2778	
27	Zrenjanin	0.3464	0.4229	0.8191	0.5295	
	Average	0.5417	0.6607	0.8125	0.6716	
			2022			

No.	DMU Name	CCR	BCC	SE	Average	No. efficient
1	Beograd R.	0.4088	0.4109	0.9949	0.6049	
2	Bor Teretna	1	1	1	1	1
3	Brasina	1	1	1	1	2
4	Crveni Krst	0.8496	0.8602	0.9877	0.8992	
5	Dimitrovgrad	0.0052	0.3846	0.0135	0.1344	
6	Kragujevac	0.6518	0.7542	0.8642	0.7567	
7	Kraljevo	0.8999	0.9089	0.9901	0.9330	
8	Lapovo R.	1	1	1	1	3
9	Niš R.	0.2503	0.2618	0.9561	0.4894	
10	Novi Sad R.	0.7038	0.7111	0.9897	0.8015	
11	Pančevo G.	0.9031	0.9272	0.9740	0.9348	
12	Požega	0.9106	0.9141	0.9962	0.9403	
13	Prahovo P.	0.8898	0.8987	0.9901	0.9262	
14	Prijepolje T.	0.9049	0.9258	0.9774	0.9360	
15	Radinac	0.9484	1	0.9484	0.9656	
16	Ristovac	0.4508	0.4618	0.9762	0.6296	
17	Ruma	0.8351	0.8799	0.9491	0.8880	
18	Sombor	1	1	1	1	4
19	S. Mitrovica	0.7411	0.8125	0.9121	0.8219	
20	Subotica	0.5833	1	0.5833	0.7222	
21	Surčin	0.5091	0.5154	0.9878	0.6708	
22	Šabac	0.6873	0.8034	0.8555	0.7821	
23	Šid	0.3598	0.3746	0.9605	0.5650	
24	Vrbas	0.7970	1	0.7970	0.8647	
25	Vreoci	0.8822	0.8964	0.9842	0.9209	
26	Vršac	0	0.8333	0	0.2778	
27	Zrenjanin	0.6089	0.6172	0.9866	0.7376	
	Average	0.6956	0.7834	0.8768	0.7853	

As it can be seen from Table 6, "CCR efficiency score is always less and equal to the BCC efficiency score" (Panwar et al, 2022, p.5401). The average efficiency from the average efficiencies by model, year and station is the final efficiency which is 0.7666, Tables 7 and 8.

The integration of multiple models can be important in determining corrective actions in order to achieve efficiency. For inefficient units, target actions? They are those that affect the complex input-output connection, to which the stations are differently sensitive, and the actions are smaller or larger. Also, actions are smaller or larger depending on the applied model. Opting for multiple models, this can be understood as a phased (gradual) increase in efficiency, from smaller to larger changes. Hence, for each inefficient station, the best target actions are determined post-DEA by Sensitivity Analysis. This results in a decrease in input and/or an increase in output, with which the inefficient station achieves its efficiency.

Table 7 – Efficiency, input, stations – average models – years

DMU No.	Average model 2018	2019	2020	2021	2022	Average Figure 4
1	0.6537	0.5758	0.4831	0.4234	0.6049	0.5482
2	0.7157	0.7179	0.6384	0.7547	1	0.7653
3	0.5901	1	1	1	1	0.9180
4	0.9278	0.7910	0.8083	0.6731	0.8992	0.8199
5	0.7650	0.3580	0.2967	0.3325	0.1344	0.3773
6	0.7320	0.7455	0.7056	0.7831	0.7567	0.7446
7	0.6913	0.6341	0.5667	0.5175	0.9330	0.6685
8	0.9905	0.7797	0.6132	0.6006	1	0.7968
9	0.6715	0.5614	0.3279	0.4691	0.4894	0.5039
10	0.7637	0.6503	0.5130	0.5602	0.8015	0.6577
11	1	0.8560	0.7765	0.8698	0.9348	0.8874
12	0.9611	0.6998	0.5911	0.5705	0.9403	0.7526
13	0.9144	1	1	1	0.9262	0.9681
14	0.9911	0.6067	1	0.5796	0.9360	0.8227
15	1	1	0.8996	0.9859	0.9656	0.9702
16	1	1	0.6818	0.1823	0.6296	0.6987
17	1	0.8135	0.6609	0.5767	0.8880	0.7878
18	1	1	1	1	1	1
19	0.7245	0.9670	1	1	0.8219	0.9027
20	0.6872	1	1	1	0.7222	0.8819
21	0.7285	0.5504	0.6029	0.5648	0.6708	0.6235
22	1	1	1	1	0.7821	0.9564
23	0.8254	0.5972	0.4746	0.5122	0.5650	0.5949
24	0.7613	0.8648	0.8347	0.7842	0.8647	0.8219
25	0.9950	0.8436	0.6780	0.5867	0.9209	0.8048
26	1	0.8414	1	0.2778	0.2778	0.6794
27	0.9386	0.7839	0.7287	0.5295	0.7376	0.7437
Average	0.8529	0.7866	0.7364	0.6716	0.7853	0.7666

Table 8 – Efficiency, input, average, years-models

Model / Year	CCR	BCC	SE	Average Figure 5
2018	0.7840	0.8017	0.9729	0.8529
2019	0.6937	0.7798	0.8863	0.7866
2020	0.6310	0.7201	0.8580	0.7364
2021	0.5417	0.6607	0.8125	0.6716
2022	0.6956	0.7834	0.8768	0.7853
Average	0.6692	0.7491	0.8813	0.7666

Based on Tables 7 and 8, for each station, the average efficiency per station and the average efficiency per year of the analyzed period are shown graphically, Figures 4 and 5, respectively. The research showed

that the analyzed period of 2018-22 is characterized by an annual change in the number of efficient units in the set of railway stations as decision-making units. The result is a relatively small number of efficient units (7, 7, 8, 6 and 4, respectively, out of 27 units) in an open, dynamic market, where the number of licensed/active freight operators is growing year by year (14 licensed / 5 active in 2018, 14/6, 15/9, 16/10 and 19/13 of the operators in 2022). (Directorate for Railways, 2019; 2020; 2021; 2022; 2023). Efficiency was decreasing by year until 2021, and then it increased slightly. If the result is connected with the pandemic, then a return of the average annual efficiency to the pre-pandemic level can be noticed for the year 2022.

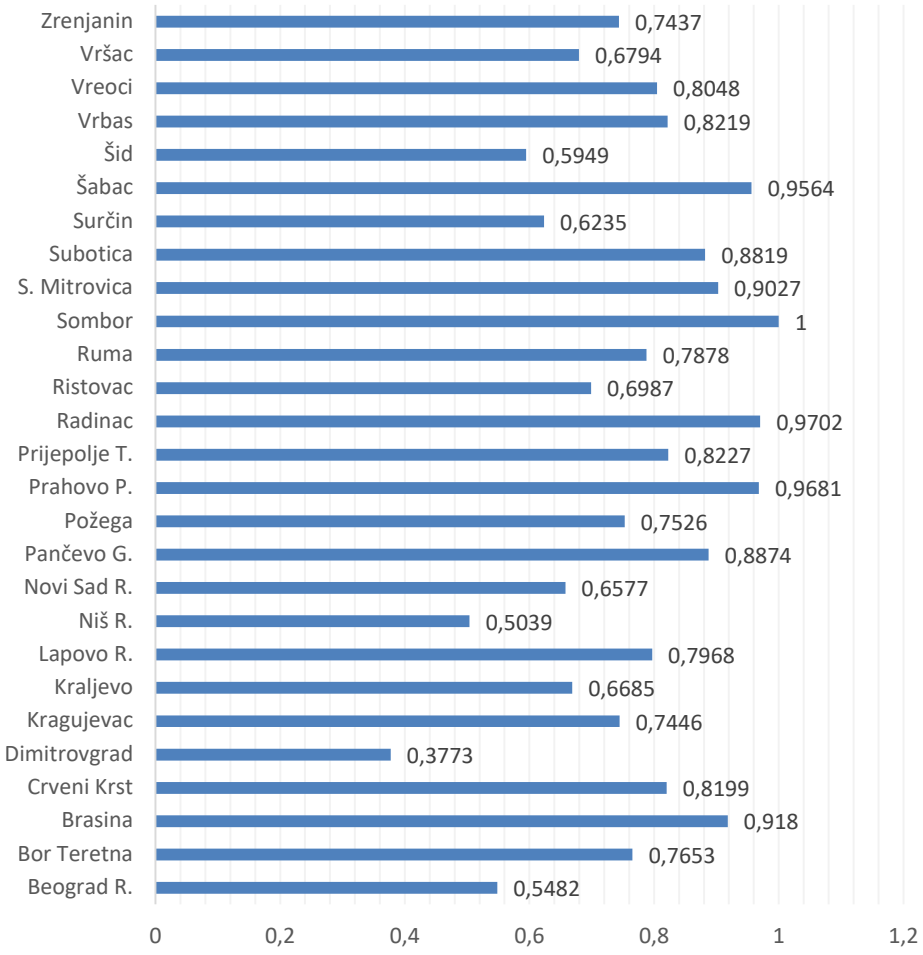


Figure 4 – Efficiency by station, average, 2018-22, model (1)-(3)

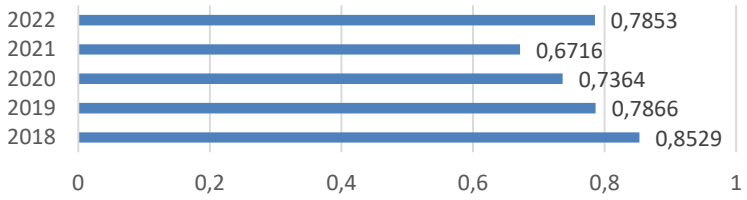


Figure 5 – Efficiency by year, average, DMU 1-27, model (1)-(3)

Finally, the obtained information on efficiency is also relative to the assigned weight coefficients of the input-output parameters, Table 9. For the analyzed years and from the aspect of particular stations, the most important is the number of freight cars loaded or unloaded at respective stations, and the least important is the number of kilometers traveled by car. This means that with such assigned input-output weights, the efficiency is maximal. For further improvement of efficiency (up to the value "1", in the case of inefficient units) a change of the initial (input/output) data is required, i.e., a change in business practices.

Table 9 – Weights of the input-output parameters

Year	Model	u_1	u_2	v_1	v_2
		staff	cars	tons	km
2018	CCR	0.4637	2.6454	0.0559	0.0078
2019		0.6902	2.9984	0.0299	0.0192
2020		1.0638	6.4583	0.0339	0.0210
2021		1.1511	1.3942	0.0173	0.0187
2022		0.3510	7.9415	0.1800	0.0053
	∑	3.7198	21.4378	0.3170	0.0720
2018	BCC	0.6612	1.4292	0.0269	0.0140
2019		0.7828	1.9940	0.0198	0.0045
2020		0.9163	5.9992	0.0307	0.0183
2021		1.1181	1.4230	0.0141	0.0098
2022		0.6540	3.8519	0.0795	0.0103
	∑	4.1324	14.6973	0.1710	0.0569

This can be seen in Figures 4 and 5, where the efficiency as a indicator of the business practice of the railway station – as a decision--making unit, as a set and as a system – can be further improved, up to the value of "1". From a transport functional to an efficiently functional unit, assembly and system, it is necessary to balance the input-output connection.

However, while the required information for several years has been obtained by applying different DEA models and while corrective actions

are part of the results of the used program, DEA still does not solve the question: how to practically implement the measures? "While DEA can be used to set targets for improvement of desired outputs, it does not instruct the user on how to reach those targets." (Avkiran, 2001, p.74)

Conclusion

In the newly opened free transport market, operators need to function efficiently in order to better serve, attract, and retain clients.

The purpose of this article is to calculate the efficiency of the decision-making units in relation to the remaining elements of the set, the selected elements of the system and the applied DEA models. Specifically, the aim is the set-system-model DEA analysis of a set of 27 railway stations in the RS, in the function of transporting goods, including subordinate official places, on the five-year path after the reorganization, from 2018 to 2022. Each railway station was observed threefold, namely, as:

1. An element of the set of IŽS stations, in the function of transporting goods (set analysis);
2. An element of the RS railway transportation system (system analysis); and
3. A DMU efficiency decision-making unit (mathematical DEA analysis).

Such a demanding goal was achieved by obtaining triple-relative efficiency which comes to the fore through the application of 27 decision--making units, four input-output parameters and three mathematical models.

The initial data (inputs and outputs) with which the efficiency is calculated, are the reflection of the state in the set, in the system and outside the system. Specifically, the inputs are the number of executors and the number of freight cars (for which the respective station is loading/unloading). The outputs are transport and traffic services: tons of goods loaded/unloaded and tariff kilometers traveled per car. The data on inputs and outputs are at the 2018-22 annual level.

The mathematical models (CCR/BCC/SE), used to calculate the efficiency based on the initial data, express an average technical/pure-technical/scale efficiency of 0.6692, 0.7491, and 0.8813, respectively.

At the very end of the research, by applying the set-system-model DEA analysis, as a result of the overall situation in practice, the following is obtained: (1) final efficiency value of 0.7666 as an average of 27 DMU, five analyzed years of operation, and three DEA models (2) total weights

of the initial data, where the number of cars has the highest weight, and the number of kilometers has the lowest.

For full efficiency (27/27), a new business practice and additional, corrective, target actions are advised as a proposal for future research.

The target actions are the amount (reduction and/or addition) of the same considered activities (inputs or outputs) with which inefficient decision-making units become efficient; thus re-efficiency or regained efficiency is obtained, which is now equal to the one, and railway stations in the function of transporting goods by traffic and transport function efficiently. However, there is no unique efficiency. It is always an assessment, relative to the analyzed set of similar decision-making units, the analyzed multi-component system of various elements and the applied Data Envelopment Analysis model.

An extension of the sample, in addition to the implemented set-system-model DEA analysis of railway stations, is a step forward that considers the railway (1) against other, competitive modes of transport, such as road, water and air transport, and (2) together with other, complementary modes, such as combined, multimodal transport, primarily rail-road and rail-water, with a multifaceted advantage.

"For both passenger and freight movements, portal-to-portal transportation should be considered that may include various modes and interfaces. This is particularly crucial for freight, domestic as well as international." (Sinha, 2007, p.12)

The final and common conclusion is that in order to work successfully, strengthen efficiency and increase competitiveness, as well as after the implemented measures, it is necessary to monitor business parameters over and over again, refresh information, and innovate efficiency measures.

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Estaciones de ferrocarril en la República de Serbia en la función de transporte de mercancías: eficiencia según el sistema DEA

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CAMPO: matemáticas
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/propósito: El Análisis Envolvente de Datos (DEA - por sus siglas en inglés) es comúnmente utilizado para calcular la eficiencia de Unidades de Toma de Decisiones similares (DMU - por sus siglas en inglés), que como tales son elementos de un conjunto. En el artículo, se considera que cada elemento de un conjunto (de elementos similares) es al mismo tiempo un elemento de un sistema (de varios elementos). Un ejemplo de DMU son 27 estaciones de ferrocarril en la República de Serbia (RS) como elemento de un conjunto de estaciones de ferrocarril y como elemento del sistema de transporte ferroviario, en función de transporte de mercancías, tras la división de la empresa Serbian Railways (en pasajeros y mercancías). Por el bien de un mejor servicio, atracción y retención de clientes, en el nuevo, libre, mercado del transporte, el propósito de este artículo es encontrar la eficiencia de las estaciones de la RS en el periodo 2018-2022.

Métodos: Análisis DEA comparativo de modelos sistémicos de sistemas ferroviarios. estaciones como DMU. Una unidad es un elemento del conjunto, la unidad es un elemento del sistema, y una unidad es el tema de la matemática. Modelo DEA-CCR/BCC/SE. Análisis DEA comparativo de modelos sistémicos de sistemas de estaciones ferroviarias como DMU. Una unidad es un elemento del conjunto, la unidad es un elemento del sistema y una unidad es el tema del modelo matemático DEA-CCR/BCC/SE.

Resultados: La eficiencia final, el promedio de todos los valores medios, es 0.7666, como resultado de un triple análisis comparativo de la DEA: 27 DMU, tres modelos DEA y cinco años de funcionamiento.

Conclusión: Las estaciones son funcionalmente diferentes en términos de eficiencia, y cada estación difiere funcionalmente, por años y por modelo. El objetivo final es lograr un equilibrio entrada - salida y la Opción 27/27 que se logra con acciones correctivas de reducción/adición, entrada o salida.

Palabras clave: eficiencia, DEA-CCR/BCC/SE, estaciones ferroviarias, sistema de configuración, transporte de mercancías.

Железнодорожные станции в Республике Сербия в функции грузоперевозок: эффективность по системе DEA

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РУБРИКА ГРНТИ: 27.47.19 Исследование операций
28.29.00 Системный анализ
73.29.21 Железнодорожные станции и узлы. Вокзалы,
73.29.51 Грузовое хозяйство железнодорожного транспорта
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Анализ охвата данных (DEA) обычно используется для расчета эффективности аналогичных подразделений по принятию решений (DMU), которые как таковые являются элементами одного множества. В данной статье такие элементы рассматриваются как часть множества (из сходных элементов), но одновременно и как часть системы (из различных элементов).

Примером DMU в данной статье являются 27 железнодорожных станций в Республике Сербия в качестве элемента множества железнодорожных станций, а также в качестве элемента системы железнодорожного транспорта, которая выполняет функцию грузоперевозок, после разделения компании «Сербские железные дороги» (на «пассажирские» и «товарные»). Целью данной статьи является определение эффективности работы станций Сербских железных дорог в период с 2018 по 2022 год для улучшения обслуживания, привлечения и удержания клиентов на недавно открывшемся свободном транспортном рынке.

Методы: В ходе исследования проведен сравнительный DEA-анализ групповых системных моделей железнодорожных станций как DMU. Причем, единица − это элемент множества, единица − это

элемент системы, и единица − это объект математической модели DEA-CCR/BCC/SE.

Результаты: В результате тройного сравнительного анализа DEA: 27 железнодорожных станций, трех моделей DEA в течение пяти лет работы получена итоговая эффективность, выраженная средним значением всех средних значений, которое составляет 0,7666.

Заключение: Станции функционально различаются с точки зрения эффективности. Каждая станция функционально отличается в зависимости от года и модели. Конечной целью является баланс доходов и расходов и опция 27/27, которая достигается корректирующими действиями: уменьшением/увеличением, доходов и расходов.

Ключевые слова: эффективность, DEA-CCR/BCC/SE, железнодорожные станции, система множеств, грузоперевозки.

Железничке станице у Републици Србији у функцији превоза робе: ефикасност по систему DEA

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Београд, Република Србија

ОБЛАСТ: математика
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Data Envelopment Analysis (DEA) уобичајено се користи за израчунавање ефикасности истоврсних јединица одлучивања (DMU), које су елементи једног скупа. У раду се сматра да је сваки такав скуп (истоврсних елемената) уједно и елемент система (разноврсних елемената). Пример DMU представља 27 железничких станица у Републици Србији (РС), као елемент скупа железничких станица и као елемент система железничког транспорта, у функцији превоза робе после поделе предузећа Железнице Србије (ЖС) (одвојено „путници" и „роба"). Ради квалитетнијег опслуживања, привлачења и задржавања комитената на новоотвореном, слободном и транспортном тржишту, циљ овог рада био је налажење ефикасности станица РС, у периоду 2018–2022. година.

Методе: У раду је примењена скуповно-системска моделна компаративна DEA анализа железничких станица као DMU. Јединица је елемент скупа, елемент система и предмет математичког DEA-CCR/BCC/SE модела.

Резултати: Коначна ефикасност, просек свих просека, износи 0,7666, као резултат тројне компаративне DEA анализе: 27 железничких станица, три DEA модела и пет година пословања.

Закључак: Станице су различито функционалне по питању ефикасности; једна иста станица је различито функционална по годинама и по моделу. Крајњи циљ је баланс улаз-излаз и опција 27/27 која се постиже уз корективне акције – смањење/повећање улаза, односно излаза.

Кључне речи: ефикасност, DEA-CCR/BCC/SE, железничке станице, скуп-систем, превоз робе.

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Bending examination of advanced generation of composite structures with specific properties exposed to different loads

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Abstract:

Introduction/purpose: This article presents the bending examination of advanced-generation composite structures with specific properties exposed to different loads.

Methods: This paper thus proposes and introduces a new generalized five-variable shear strain theory for calculating the static response of functionally graded rectangular plates made of ceramic and metal. Notably, our theory eliminates the need for a shear correction factor and ensures zero-shear stress conditions on both the upper and lower surfaces. Numerical investigations are introduced to interpret the influences of loading conditions and variations of power of functionally graded material, modulus ratio, aspect ratio, and thickness ratio on the bending behavior of FGPs. These analyzes are then compared to the results available in the literature.

Results: Preliminary results include a comparative analysis with standard higher-order shear deformation theories (PSDPT, ESDPT, SSDPT), as well as Mindlin and Kirchhoff theories (FSDPT and CPT).

Conclusion: Our theory contributes alongside established theories in the field, providing valuable insights into the static thermomechanical response of functionally graded rectangular plates. This encompasses the influence of volume fraction exponent values on nondimensional displacements and stresses, the impact of aspect ratios on deflection, and the effects of the thermal field on deflection and stresses. Numerical examples of the bending examination of advanced-generation composite structures with specific properties exposed to different loads demonstrate the accuracy of the present theory.

Key words: functionally graded materials, bending, higher-order shear deformation theories, thermomechanical.

Introduction

Composites are materials formed by combining two or more constituent materials to create superior properties, defying traditional material constraints.

They are commonly used in aerospace, automotive, construction, and many other industries due to their exceptional strength-to-weight ratio (where the quest for ever-lighter and stronger materials is a perpetual challenge) as well as good performance.

Despite these good properties, however, there is a negative aspect that worries industrialists and researchers; it is the failure in difficult operational environments. It shows signs of failure and disintegration.

Composite materials, while versatile, can deteriorate over time due to weakening interfaces between their layers (Pindera et al, 1998; Boggarapu et al, 2021), leading to performance issues and failures. In response to these challenges, functionally graded materials (FGMs) have emerged as a progressive development in material science.

Functionally graded materials (FGMs) indeed represent an innovative and sophisticated approach to addressing some of the challenges associated with conventional composite materials. FGMs are designed to provide tailored material properties by gradually changing, or grading, the composition, structure, and properties of the material in a specific direction. This gradient-based approach offers several advantages for various engineering and industrial applications.

In 1984, a group of researchers in Sendai, Japan (Koizumi, 1993; Koizumi & Niino, 1995; Koizumi, 1997), introduced the concept of Functionally Graded Materials (FGMs). These materials are characterized

by their uninterrupted variation in properties, distinguishing them from conventional materials.

Functionally graded materials (FGMs) find application across diverse industries (Kieback et al, 2003), and recent research illuminates their behavior under thermal and mechanical loads. Classical plate theories, like CPT, lack accuracy for thicker structures (Bouazza et al, 2011). The First-Order Shear Deformation Theory (FSDT) (Reissner, 1945; Mindlin, 1951; Timoshenko & Woinowsky-Krieger, 1959) addressed this but needs a corrective factor. Higher-order shear deformation theories (HSDT) excel, showing improved accuracy without requiring a correction factor, unlike previous models.

In this context, Reddy (2000) studied the static behavior of FGM plates using the third-order shear deformation theory. Zenkour & Alghamdi (2010) explored the bending behavior of sandwich plates, investigating the impacts of thermomechanical loads on stresses and deflections. Additionally, Bouderba & Benyamina (2018) introduced a model for analyzing the thermal-mechanical behavior of thick metal/ceramic FGM plates.

Li et al. (2020) introduced a new five-variable shear deformation theory for predicting the static response of functionally graded plates. Daikh et al. (2020) studied the thermomechanical bending behavior of functionally graded sandwich plates under varied temperatures. Brischetto & Carrera (2010) proposed enhanced mixed theories, while Benyamina et al (2018) examined composite material plates in thermal settings, contributing to a deeper understanding of their performance.

Bouderba et al. (2016) used a simple shear deformation theory to examine the thermal stability of FGM sandwich plates. Shinde et al. (2015) introduced a refined trigonometric shear deformation theory for the analysis of bending in both isotropic and orthotropic plates under a variety of loading conditions. In a related vein, Bouderba & Berrabah (2022) delved into the bending response of porous advanced composite functionally graded material (FGM) plates subjected to thermomechanical loads.

Zenkour & Hafed (2020) conducted a study on the bending analysis of functionally graded piezoelectric (FGP) material plates under simply supported edge conditions. They employed a simple quasi-3D sinusoidal shear deformation theory for their analysis. In another study, Brischetto et al (2008) examined the deformations of a simply supported rectangular plate composed of functionally graded material (FG) subjected to both thermal and mechanical loads.

On the other hand, Berrabah & Bouderba (2023) employed an accurate shear deformation theory to investigate the mechanical buckling behavior of FG plates. Furthermore, higher-order plate theories have been introduced in the literature to address the mechanical and thermal buckling of FG plates, with the Carrera unified formulation being utilized (Farrokh et al, 2021; Farrokh et al, 2022).

This paper aims to comprehensively examine advanced composite structures under varied loads, focusing specifically on a rectangular plate made of functionally graded material (FGM) subjected to mechanical and thermal stress. Using the novel CSDPT theory with five unknown variables, the study derives and solves the equations of motion through Navier's procedure. Validation occurs through comparative analyses with standard higher-order theories like PSDPT, SSDPT, and ESDPT. The study's outcomes illuminate the impact of the power index on non-dimensional displacement and stresses, addressing the thermal field's influence on deflection and stresses in the FGM plate. This examination significantly contributes to understanding the behavior of these structures under different load conditions, advancing the field of mechanical construction.

Essential formulation

Structure geometry and material gradient

Geometry of the structure of the FGM (in the context of the plate)

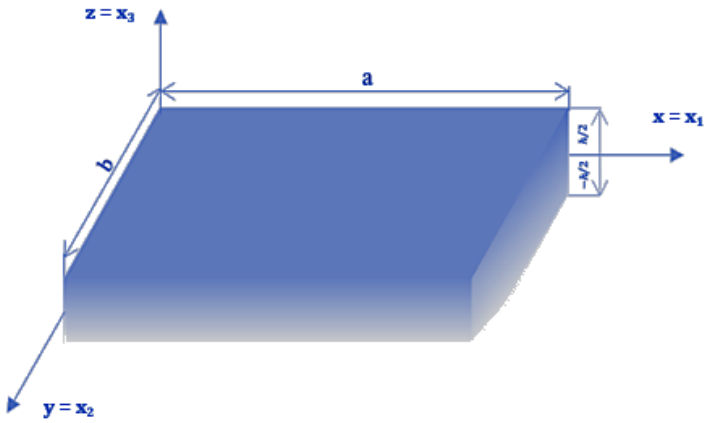

Figure 1 – Geometry and the coordinate system of the FGM

In the context of our research on advanced composite structures, the geometric characteristics of the rectangular plate made of functionally graded material (FGM) play a pivotal role. This plate, as depicted in Figure1, exhibits specific material properties that transition gradually from the bottom to the top surface.

Table 1 – Geometric properties of the functionally graded plate.

Characte-ristics	Structure geometry	Thickness	Length	Width	Aspect ratio	Material coordinate origin (x_3)
Symbol	-	h	a	B	a/b	x_3
Description	Rectangular plate	Plate thickness (x_3-axis)	Plate length (x_1-axis)	Plate width (x_2-axis)	Aspect ratio of the plate	Middle of the plate thickness ($x_3 = \pm h / 2$)

Material gradient in the FGM plate

In the context of functionally graded material (FGM) plates, material attributes, including Young modulus (E), Poisson's ratio (v), and thermal dilation coefficient (α), are defined by applying the mixing rule (1) (Reddy, 2000) and utilizing the Power-Law function (2).

$$P(x_3) = (P_c - P_m)V\left(x_3\right) + P_m \quad (1)$$

$$V\left(x_3\right)=(1/2+x_3/h)^n \quad (2)$$

Material properties can be described by the following equation:

$$E(x_3) = (E_c - E_m)(1/2 + x_3 / h)^n + E_m \quad (3)$$

The gradient law for Young's modulus (E) (3), applies to Poisson's ratio (v) and the coefficient of thermal expansion (α) as well.

Here, x_3 signifies the position along the plate's thickness, h is the total thickness, and n is a material parameter influencing the composition gradation.

The material properties (E_m, ν_m, α_m) and (E_c, ν_c, α_c) are associated with the metallic and ceramic phases, respectively.

Table 2 – Transverse shear strain functions for the FGM plate.

Theories, the author	**Form of function f(z)**
Parabolic deformation theory of plates, (Reissner, 1945)	$5z/4(1-(4/3)(z/h)^2)$
Parabolic shear deformation theory (PSDPT), (Reddy, 1984)	$z(1-(4/3)(z/h)^2)$
Trigonometric deformation theory of plates (SSDPT), (Touratier, 1991)	$(h/\pi)\sin(\pi z/h)$
The exponential shear deformation plate theory (ESDPT), (Karama et al, 2003)	$ze^{-2(z/h)^2}$
Hyperbolic deformation theory of plates, (Soldatos, 1992)	$z\cosh(1/2)-h\sinh(z/h)$
Combination functions(CSDPT), Present	$\frac{(e^2+1)\arctan(e^{2z/h})}{(e-1)^2}-\frac{2ez}{h(e-1)^2}-\frac{\pi(e^2+1)}{4(e-1)^2}$

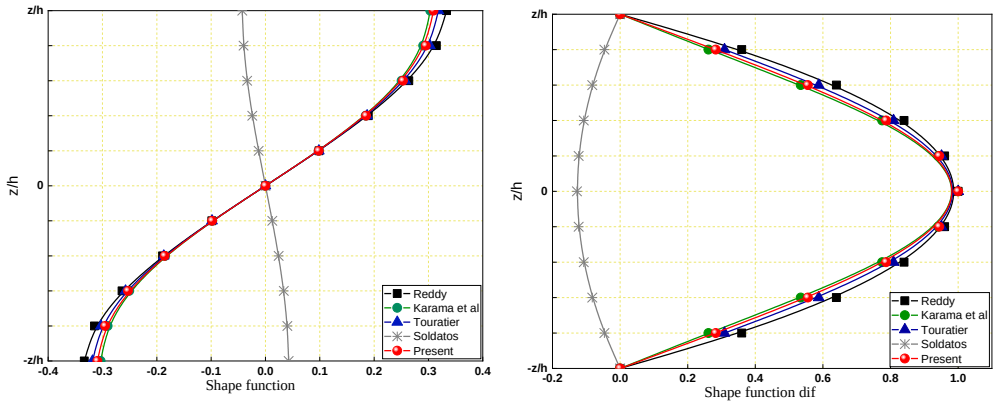

Figure 2 – Distribution of the functions f (z):
(a)shape function f(z),
(b) differentiation f´(z)

Figure 2 provides a comparison of how the shape function and its derivatives vary across different shear deformation theories, denoted as f(z) and its derivative f'(z).

Table 3 – Material properties - metal and ceramic materials, see (Bao & Wang, 1995; Bouderba & Berrabah, 2022)

Property	Young's modulus		Poisson's ratio		Thermal expansion coefficient		Density	
Symbol	E_{metal}	$E_{ceramic}$	ν_{metal}	$\nu_{ceramic}$	α_{metal}	$\alpha_{ceramic}$	ρ_{metal}	$\rho_{ceramic}$
Value	70	151	0.3	0.3	23	10	7.8	7.8
Descrip-tion	Elastic modulus of the material in GPa		Poisson's ratio of the material		Linear coefficient of thermal expansion ($x10^{-6}$/°C)		Density of the material in g/cm³	

Theoretical formulation

Formulating the displacement field

In the context of thick functionally graded material (FGM) plates, the displacement of a material point at the coordinates (x_1, x_2, x_3) could be expressed as follows:

$$U(x_1,x_2,x_3)=u_0(x_1,x_2)-x_3\frac{\partial w_0}{\partial x_1}+\Phi(x_3)\Theta_{x_1}$$

$$V(x_1,x_2,x_3)=v_0(x_1,x_2)-x_3\frac{\partial w_0}{\partial x_2}-\Phi(x_3)\Theta_{x_2} \quad (4)$$

$$W(x_1,x_2,x_3)=w_0(x_1,x_2)$$

The mid surface of the structure is characterized by five unknown displacement functions, namely u_0, v_0, w_0, and $\Theta_{x_1}, \Theta_{x_2}$.

Based on the equations describing the displacement within the field and the relationships governing strain-displacement, we deduce expressions for the strain elements derived from the displacement elements.

$$\begin{Bmatrix}\varepsilon_{11}\\ \varepsilon_{22}\\ \gamma_{12}\end{Bmatrix}=\begin{Bmatrix}\dfrac{\partial u_0}{\partial x_1}-x_3\dfrac{\partial^2 w_0}{\partial {x_1}^2}+\Phi(x_3)\dfrac{\partial\Theta_{x_1}}{\partial x_1}\\ \dfrac{\partial v_0}{\partial x_2}-x_3\dfrac{\partial^2 w_0}{\partial {x_2}^2}+\Phi(x_3)\dfrac{\partial\Theta_{x_2}}{\partial x_2}\\ \left(\dfrac{\partial v_0}{\partial x_1}+\dfrac{\partial u_0}{\partial x_2}\right)-x_3\dfrac{2\partial^2 w_0}{\partial x_1\partial x_2}+\Phi(x_3)\left(\dfrac{\partial\Theta_{x_2}}{\partial x_1}+\dfrac{\partial\Theta_{x_1}}{\partial x_2}\right)\end{Bmatrix} \quad (5a)$$

$$\gamma_{23} = \frac{d\Phi(x_3)}{dx_3}.\Theta_{x_2}, \gamma_{13} = \frac{d\Phi(x_3)}{dx_3}.\Theta_{x_1} \qquad \text{(5b, 5b')}$$

where $\varepsilon_{11}, \varepsilon_{22}, \gamma_{12}, \gamma_{23}$ and γ_{13} are the strain and shear components, respectively.

Equations (5a) and (5b, 5b') can be expressed like this:

$$\begin{Bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \gamma_{12} \end{Bmatrix} = \begin{Bmatrix} \varepsilon_{11}^0 \\ \varepsilon_{22}^0 \\ \gamma_{12}^0 \end{Bmatrix} + x_3 \begin{Bmatrix} k_{11}^0 \\ k_{22}^0 \\ k_{12}^0 \end{Bmatrix} + \Phi(z) \begin{Bmatrix} k_{11}^1 \\ k_{22}^1 \\ k_{12}^1 \end{Bmatrix}, \qquad (6)$$

$$\gamma_{23} = \Phi'(x_3).\gamma_{23}^0, \gamma_{13} = \Phi'(x_3).\gamma_{13}^0, \gamma_{33} = 0.$$

The stress-strain relationships can be concisely expressed with the following equation:

$$\begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \tau_{12} \\ \tau_{23} \\ \tau_{13} \end{Bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & Q_{13} & 0 & 0 & 0 \\ Q_{12} & Q_{22} & Q_{23} & 0 & 0 & 0 \\ Q_{13} & Q_{23} & Q_{33} & 0 & 0 & 0 \\ & & & Q_{66} & 0 & 0 \\ & & & & Q_{44} & 0 \\ Sym & & & & & Q_{55} \end{bmatrix} \begin{Bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \\ \gamma_{12} \\ \gamma_{23} \\ \gamma_{13} \end{Bmatrix} \qquad (7)$$

The following equation considers the influence of thermal effects:

$$\begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \tau_{12} \end{Bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ & Q_{22} & 0 \\ Sym & & Q_{66} \end{bmatrix} \left(\begin{Bmatrix} \varepsilon_{11} \\ \varepsilon_{12} \\ \gamma_{12} \end{Bmatrix} - \begin{Bmatrix} \alpha(x_3)\,\Delta T \\ \alpha(x_3)\,\Delta T \\ 0 \end{Bmatrix} \right) \qquad \text{(8a)}$$

$$\begin{Bmatrix} \tau_{23} \\ \tau_{13} \end{Bmatrix} = \begin{bmatrix} Q_{44} & 0 \\ Sym & Q_{55} \end{bmatrix} \begin{Bmatrix} \gamma_{23} \\ \gamma_{13} \end{Bmatrix} \qquad \text{(8b)}$$

The parameters $(\sigma_{11}, \sigma_{22}, \tau_{12}, \tau_{23}, \tau_{13})$ and $(\varepsilon_{11}, \varepsilon_{22}, \gamma_{12}, \gamma_{23}, \gamma_{13})$ represent the stress and deformation components, respectively.

The mathematical formulation of the stiffness coefficients Q_{ij} is as follows:

$$Q_{11} = Q_{22} = Q_{33} = \frac{E(x_3)}{1-\nu^2}, \quad Q_{12} = \frac{\nu\, E(x_3)}{1-\nu^2}, Q_{44} = Q_{55} = Q_{66} = \frac{E(x_3)}{2(1+\nu)} \qquad \text{(9a, 9b, 9c)}$$

The temperature distribution $T(x_1, x_2, x_3)$ through thickness is assumed as Bouderba et al. (2013).

The following equation describes how temperature varies through the thickness of the plate:

$$T(x_1, x_2, x_3) = T_1(x_1, x_2) + \frac{x_3}{h} T_2(x_1, x_2) + \bar{\Phi}(x_3) T_3(x_1, x_2) \qquad (10)$$

In this study, we focused on employing the sinusoidal temperature distribution to conduct our analysis $\bar{\Phi}(x_3) = \frac{1}{\pi}\sin(x_3 \frac{\pi}{h})$.

Governing equations

Formulating the equilibrium governing equations involves applying the principle of virtual work, which can be articulated in the following manner in this context:

$$\begin{aligned}
&\partial N_{11}/\partial x_1 + \partial N_{12}/\partial x_2 = 0 \\
&\partial N_{22}/\partial x_2 + \partial N_{12}/\partial x_1 = 0 \\
&\partial^2 M_{11}/\partial {x_1}^2 + 2\partial^2 M_{12}/\partial x_1 \partial x_2 + \partial^2 M_{22}/\partial {x_2}^2 + q = 0 \qquad (11) \\
&\partial S_{11}/\partial x_1 + \partial S_{12}/\partial x_2 - Q_{13} = 0 \\
&\partial S_{22}/\partial x_2 + \partial S_{12}/\partial x_1 - Q_{23} = 0
\end{aligned}$$

N, M, and S are the quantities that represent the force and moment resultants, and their definitions are as follows:

$$\begin{Bmatrix} N_{11} & N_{22} & N_{12} \\ M_{11} & M_{22} & M_{12} \\ S_{11} & S_{22} & S_{12} \end{Bmatrix} = \int_{h_1}^{h_2} (\sigma_{11}, \sigma_{22}, \sigma_{12}) \begin{Bmatrix} 1 \\ x_3 \\ \Phi(x_3) \end{Bmatrix} dx_3, \qquad \text{(12a)}$$

$$(Q_{13}, Q_{23}) = \int_{h_1}^{h_2} (\tau_{13}, \tau_{23}) \Phi'(x_3) dx_3, \qquad \text{(12b)}$$

The interval limits for simplification: $-h/2 = h_1$, $h/2 = h_2$,

$$\begin{Bmatrix} N \\ M \\ S \end{Bmatrix} = \begin{bmatrix} A & B & B^a \\ & D & D^a \\ Sym & & F^a \end{bmatrix} \begin{Bmatrix} \varepsilon^0 \\ k^0 \\ k^1 \end{Bmatrix} - \begin{Bmatrix} N^T \\ M^T \\ S^T \end{Bmatrix}, \tag{13a}$$

$$Q_{23} = A_{44}^a \gamma_{23}, Q_{13} = A_{55}^a \gamma_{13}. \tag{13b}$$

$$N = \{N_{11}, N_{22}, N_{12}\}^t, M = \{M_{11}, M_{22}, M_{12}\}^t, S = \{S_{11}, S_{22}, S_{12}\}^t,$$

$$N^T = \{N_{11}^T, N_{22}^T, 0\}^t, M^T = \{M_{11}^T, M_{22}^T, 0\}^t, S^T = \{S_{11}^T, S_{22}^T, 0\}^t, \tag{13c}$$

$$\varepsilon^0 = \{\varepsilon_{11}^0, \varepsilon_{22}^0, \gamma_{12}^0\}^t, k^0 = \{k_{11}^0, k_{22}^0, k_{12}^0\}^t, k^1 = \{k_{11}^1, k_{22}^1, k_{12}^1\}^t,$$

The following can be deduced:

$$A = \begin{bmatrix} A_{11} & A_{12} & 0 \\ & A_{22} & 0 \\ Sym & & A_{66} \end{bmatrix}, B = \begin{bmatrix} B_{11} & B_{12} & 0 \\ & B_{22} & 0 \\ Sym & & B_{66} \end{bmatrix}, B^a = \begin{bmatrix} B_{11}^a & B_{11}^a & 0 \\ & B_{11}^a & 0 \\ Sym & & B_{66}^a \end{bmatrix},$$

$$D = \begin{bmatrix} D_{11} & D_{12} & 0 \\ & D_{22} & 0 \\ Sym & & D_{66} \end{bmatrix}, D^a = \begin{bmatrix} D_{11}^a & D_{12}^a & 0 \\ & D_{22}^a & 0 \\ Sym & & D_{66}^a \end{bmatrix}, F^a = \begin{bmatrix} F_{11}^a & F_{12}^a & 0 \\ & F_{22}^a & 0 \\ Sym & & F_{66}^a \end{bmatrix} \tag{14a}$$

$$Q = \{Q_{23}, Q_{13}\}^t, \gamma = \{A_{23}^0, A_{13}^0\}^t, A^a = \begin{bmatrix} A_{44}^a & 0 \\ 0 & A_{55}^a \end{bmatrix} \tag{14b}$$

The stiffness coefficients, denoted as A_{ij}, B_{ij}, are defined as follows:

(15a)

$$\begin{Bmatrix} A_{11} & B_{11} & D_{11} & B_{11}^a & D_{11}^a & F_{11}^a \\ A_{12} & B_{12} & D_{12} & B_{12}^a & D_{12}^a & F_{12}^a \\ A_{66} & B_{66} & D_{66} & B_{66}^a & D_{66}^a & F_{66}^a \end{Bmatrix} = \int_{h_1}^{h_2} Q_{11} \left(1, x_3, x_3^2, \Phi(x_3), x_3\ \Phi(x_3), \Phi^2(x_3)\right) \begin{Bmatrix} 1 \\ \nu \\ \frac{1-\nu}{2} \end{Bmatrix} dx_3,$$

$$\left(A_{22}, B_{22}, D_{22}, B_{22}^a, D_{22}^a, F_{22}^a\right) = \left(A_{11}, B_{11}, D_{11}, B_{11}^a, D_{11}^a, F_{11}^a\right),$$

$$A_{ii}^a = \int_{h_1}^{h_2} \frac{E(x_3)}{2(1+\nu)} \left[\Phi'(x_3)\right]^2 dx_3, (i = 4, 5) \tag{15b}$$

The stress and moment resultants on a plate element $N_{11}^T = N_{22}^T, M_{11}^T = M_{22}^T, S_{11}^T = S_{22}^T$, due to thermal loads are defined respectively by:

$$\begin{Bmatrix} N_{ii}^T \\ M_{ii}^T \\ S_{ii}^T \end{Bmatrix} = \int_{h_1}^{h_2} \frac{E(x_3)}{(1-\nu)} \alpha(x_3) T \begin{Bmatrix} 1 \\ x_3 \\ \Phi(x_3) \end{Bmatrix} dx_3, (i=1) \tag{16}$$

Substituting Eq. (13a, 13b) into Eq. (11), we obtain the following equations:

$$(A_{66}d_{22} + A_{11}d_{11})u_0 + (A_{66} + A_{12})d_{12}v_0 - (2B_{66} + B_{12})d_{122}w_0$$
$$-B_{11}d_{111}w_0 + (B_{66}^a d_{22} + B_{11}^a d_{11})\Theta_{x_1} + (B_{66}^a + B_{12}^a)d_{12}\Theta_{x_2} = p_1, \tag{17a}$$

$$(A_{66} + A_{12})d_{12}u_0 + (A_{22}d_{22} + A_{66}d_{11})v_0 - (2B_{66} + B_{12})d_{112}w_0$$
$$-B_{22}d_{222}w_0 + (B_{66}^a + B_{12}^a)d_{12}\Theta_{x_1} + (B_{22}^a d_{22} + B_{66}^a d_{11})\Theta_{x_2} = p_2, \tag{17b}$$

$$-(B_{12} + 2B_{66})d_{122}u_0 - B_{11}d_{111}u_0 - (B_{12} + 2B_{66})d_{112}v_0 - B_{22}d_{222}v_0$$
$$+(D_{11}d_{1111} + D_{22}d_{2222})w_0 + 2(D_{12} + 2D_{66})d_{1122}w_0 - (D_{12}^a + 2D_{66}^a)d_{122}\Theta_{x_1}$$
$$-D_{11}^a d_{111}\Theta_{x_1} - (D_{12}^a + 2D_{66}^a)d_{112}\Theta_{x_2} - D_{22}^a d_{222}\Theta_{x_2} = p3, \tag{17c}$$

$$(B_{66}^a d_{22} + B_{11}^a d_{11})u_0 + (B_{66}^a + B_{12}^a)d_{12}v_0 - D_{11}^a d_{111}w_0$$
$$-(D_{12}^a + 2D_{66}^a)d_{122}w_0 + (F_{11}^a d_{11} + F_{66}^a d_{22} - A_{44}^a)\Theta_{x_1} + (F_{12}^a + F_{66}^a)d_{12}\Theta_{x_2} = p4, \tag{17d}$$

$$(B_{66}^a + B_{12}^a)d_{12}u_0 + (B_{66}^a d_{11} + B_{22}^a d_{22})v_0 - D_{22}^a d_{222}w_0$$
$$-(D_{12}^a + 2D_{66}^a)d_{112}w_0 - (F_{12}^a + F_{66}^a)d_{12}\Theta_{x_1} + (F_{22}^a d_{22} + F_{66}^a d_{11} - A_{55}^a)d_{12}\Theta_{x_2} = p5, \tag{17e}$$

In this context, $\{p\} = \{p_1, p_2, p_3, p_4, p_5\}^t$ is a force vector, d_{ij}, d_{ijl} and d_{ijlm} are the following differential operators:

$$d_{ij} = \frac{\partial^2}{\partial x_{1_i} \partial x_{1_j}}, d_{ijl} = \frac{\partial^3}{\partial x_{1_i} \partial x_{1_j} \partial x_{1_l}}, d_{ijlm} = \frac{\partial^4}{\partial x_{1_i} \partial x_{1_j} \partial x_{1_l} \partial x_{1_m}}, \tag{18}$$
$$d_i = \frac{\partial}{\partial x_{1_i}}, (i, j, l, m = 1, 2), (x_{1_i} = x_1; x_{1_j} = x_2),$$

The components of the generalized force vector $\{p\}$ are defined as follows:

$$p_1 = \frac{\partial N_{11}^T}{\partial x_1}, p_2 = \frac{\partial N_{22}^T}{\partial x_2}, p_3 = q - \frac{\partial^2 M_{11}^T}{\partial x_1^2} - \frac{\partial^2 M_{22}^T}{\partial x_2^2}, p_4 = q - \frac{\partial^2 S_{11}^T}{\partial x_1^2} - \frac{\partial^2 S_{22}^T}{\partial x_2^2}, \tag{19}$$

Determining exact solutions for functionally graded plate structures

Rectangular plates are typically categorized based on the nature of their support systems. In this context, we are concerned with the specific boundary conditions associated with a simple support configuration.

$$\begin{aligned} v_0 &= w_0 = \Theta_{x_2} = N_{11} = M_{11} = S_{11} = 0 \ \ at\, x_1 = 0, a, \\ u_0 &= w_0 = \Theta_{x_1} = N_{22} = M_{22} = S_{22} = 0 \ \ at\, x_2 = 0, b, \end{aligned} \tag{20}$$

The displacement functions q_i and T_i can be expanded in the following manner, aligning them with both the boundary conditions and the governing equations. This expansion is characterized by the use of a double Fourier series.

$$\begin{Bmatrix} q \\ T_k \end{Bmatrix} = \begin{Bmatrix} q_0 \\ t_k \end{Bmatrix} \sin(i\, x_1)\sin(j\, x_2), (k = 1,\ 2,\ 3) \tag{21}$$

where $i = \pi / a$, $j = \pi / b$, q_0 and t_k are constants.

Following the procedure of the Navier solution, we assume the following solution:

$$\begin{Bmatrix} u_0 \\ v_0 \\ w_0 \\ \Theta_{x_1} \\ \Theta_{x_2} \end{Bmatrix} = \begin{Bmatrix} U\cos(i\, x_1)\sin(j\, x_2) \\ V\sin(i\, x_1)\cos(j\, x_2) \\ W\sin(i\, x_1)\sin(j\, x_2) \\ X\cos(i\, x_1)\sin(j\, x_2) \\ Y\sin(i\, x_1)\cos(j\, x_2) \end{Bmatrix}, \tag{22}$$

where the arbitrary parameters U, V, W, X and Y are used to determine the conditions in which the solution of equation (22) satisfies equilibrium equations (17). The following operator's equation is obtained:

$$\{\Delta\}[\Omega] = \{P\}, \tag{23}$$

$\{\Delta\}=\{U,V,W,X,Y\}^t$ and $[\Omega]$ is the symmetrical matrix, in which:

$$\begin{aligned}
&\Omega_{11}=-\left(A_{11}i^2+A_{66}j^2\right),\Omega_{12}=-i\,j\,\left(A_{12}+A_{66}\right),\Omega_{13}=i\,[B_{11}i^2+(B_{12}+2B_{66})\,j^2],\\
&\Omega_{14}=-\left(B^a_{11}i^2+B^a_{66}j^2\right),\Omega_{15}=-i\,j\,\left(B^a_{12}+B^a_{66}\right),\Omega_{22}=-\left(A_{66}i^2+A_{22}j^2\right),\\
&\Omega_{23}=j\,[B_{12}i^2+2B_{66}i^2+B_{22}j^2],\Omega_{24}=-i\,j\,\left(B^a_{12}+B^a_{66}\right),\Omega_{25}=-\left(B^a_{66}i^2+B^a_{22}j^2\right),\\
&\Omega_{33}=-\,[D_{11}i^4+2D_{12}i^2j^2+4D_{66}i^2j^2+D_{22}j^4],\\
&\Omega_{34}=i\,[D^a_{11}i^2+D^a_{12}j^2+2D^a_{66}j^2],\Omega_{35}=j\,[D^a_{12}i^2+2D^a_{66}i^2+E_{22}j^2],\\
&\Omega_{44}=-\,[F^a_{11}i^2+F^a_{66}j^2+A^a_{44}],\Omega_{45}=-i\,j\,\left(F^a_{12}+F^a_{66}\right),\Omega_{55}=-\,[F^a_{66}i^2+F^a_{22}j^2+A^a_{55}],
\end{aligned}\tag{24}$$

The components of the generalized forces vector are given by:

$$\begin{aligned}
&P_1=i\left(A^Tt_1+B^Tt_2+B^T_at_3\right),P_2=j\left(A^Tt_1+B^Tt_2+B^T_at_3\right),\\
&P_3=-q_0-h\left(i^2+j^2\right)\left(B^Tt_1+D^Tt_2+D^T_at_3\right),\\
&P_4=ih\left(B^T_at_1+D^T_at_2+F^T_at_3\right),P_5=jh\left(B^T_at+D^T_at_2+F^T_at_3\right),
\end{aligned}\tag{25}$$

$$\left\{A^T,B^T,D^T\right\}=\int_{h_1}^{h_2}\frac{E(x_3)}{1-\nu}\alpha(x_3)\left\{1,\bar{x}_3,\bar{x}_3^2\right\}dx_3,\tag{26}$$

$$\left\{B^T_a,D^T_a,F^T_a\right\}=\int_{h_1}^{h_2}\frac{E(x_3)}{1-\nu}\alpha(x_3)\bar{\Phi}(x_3)\left\{1,\bar{x}_3,\bar{\Phi}(x_3)\right\}dx_3,\tag{27}$$

It is important to note $\bar{x}_3=x_3/h,\bar{\Phi}(x_3)=\Phi(x_3)/h$.

Analytical validation and numerical results

This section examines how materials respond to bending under thermal and mechanical loads. It aims to verify the accuracy of the theory and explore the effects of the parameters on bending, using the following non-dimensional parameters in the calculations:

The central deflection $\bar{w}=\frac{10^2D}{a^4q_0}w\left(\frac{a}{2},\frac{b}{2}\right)$, axial stress $\bar{\sigma}_{11}=\frac{1}{10^2q_0}\sigma_{11}\left(\frac{a}{2},\frac{b}{2},\frac{h}{2}\right)$,

The longitudinal shear stress $\bar{\tau}_{12}=\frac{1}{10q_0}\tau_{12}\left(0,0,-h/3\right)$,

Transverse shear stress $\bar{\tau}_{13}=-\frac{1}{10q_0}\tau_{13}\left(0,b/2,0\right)$,

The coordinate thickness $\bar{x}_3 = x_3 / h$, $D=\frac{h^3 E_C}{12\left(1-\nu^2\right)}$

In this section, we validate the proposed composite shear deformation plate theory (CSDPT) using numerical results. We compare it with various standard high-order shear deformation theories (PSDPT, SSDPT, ESDPT), as well as with the first-order FSDPT and the classical plate theory CPT, as referenced in Mindlin (1951), Timoshenko & Woinowsky-Krieger (1959), Reddy (1984), Touratier (1991) and Karama et al. (2003).

Table 5 presents a comparison of dimensionless deviations between the 'present theory' and the 'standard theories,' indicating minor differences across all theories.

Figures 6 and 7 compellingly demonstrate the robust agreement between the present theory and the established standard theories.

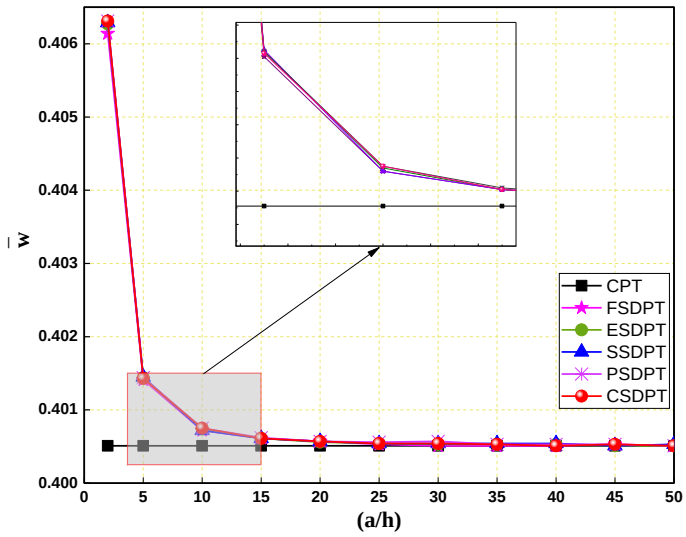

Figure 3 – Dimensionless deflection ($\bar{w}$) across the thickness of a square FGM plate (with n=2) under varied (a/h) ratios, subject to specific conditions (q_0=100, t_i=0)

Table 5 – Comparison of the volume fraction exponent (n) effects on the dimensionless displacements and stresses between the present theory and the established theories.

Deflection	Theory	n = 0	n = 1	n = 2	n = 5	n = 10
$\bar{w}$	CPT	0.83156	1.1896	1.2976	1.3983	1.4878
	FSDT (*)	0.85761	1.2252	1.3382	1.4453	1.5386
	ESDT (*)	0.85743	1.2250	1.3392	1.4482	1.5407
	SSDT (*)	0.85756	1.2251	1.3394	1.4483	1.5410
	TSDT (*)	0.85760	1.2252	1.3394	1.4483	1.5410
	Present	0.85761	1.2252	1.3394	1.4482	1.5410
$\bar{\sigma}_{11}$	CPT	0.50880	0.63901	0.68352	0.75682	0.83819
	FSDT (*)	0.50880	0.63903	0.68355	0.75682	0.83819
	ESDT (*)	0.51180	0.64307	0.68821	0.76210	0.84369
	SSDT (*)	0.51166	0.64286	0.68797	0.76182	0.84343
	TSDT (*)	0.51147	0.64261	0.68769	0.76157	0.84310
	Present	0.51174	0.64298	0.68814	0.76200	0.84357
$\bar{\tau}_{12}$	CPT	0.76599	0.71701	0.69135	0.70066	0.71089
	FSDT (*)	0.76599	0.71701	0.69135	0.70059	0.71093
	ESDT (*)	0.76424	0.71574	0.68985	0.69884	0.70904
	SSDT (*)	0.76437	0.71578	0.68993	0.69893	0.70912
	TSDT (*)	0.76444	0.71582	0.69001	0.69905	0.70920
	Present	0.76430	0.71570	0.68992	0.69890	0.70905
$\bar{\tau}_{13}$	CPT	/	/	/	/	/
	FSDT (*)	-	-	-	-	-
	ESDT (*)	0.34378	0.34378	0.31986	0.29862	0.31141
	SSDT (*)	-	-	-	-	-
	TSDT (*)	0.45704	0.45704	0.44189	0.43013	0.44157
	Present	-	-	-	-	-
		0.44329	0.44329	0.42779	0.41568	0.42766
		-	-	-	-	-
		0.42956	0.42957	0.41372	0.40126	0.41370
		-	-	-	-	-
		0.45200	0.45194	0.43664	0.42471	0.43641

(*) Taken by Bouderba & Berrabah (2022)

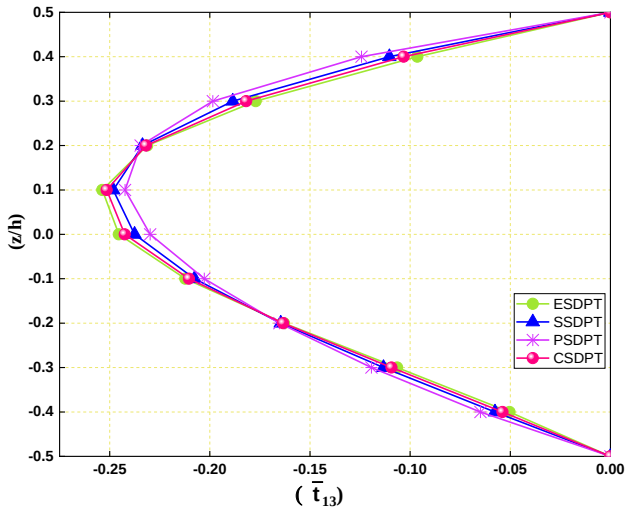

Figure 4 – Variation of ($\bar{\tau}_{13}$) across the thickness of a square FGM plate (with n=2) under varied (a/h) ratios, subject to specific conditions (q_0=100, t_i=0)

The following figures highlight and reveal the influence of the aspect ratios on the stress distribution within functionally graded material plates. A higher a/h (e.g., a/h = 20) results in elevated stress levels, while a lower a/h (e.g., a/h = 2) leads to minimized stress levels, particularly suitable for low-stress-tolerance applications. These findings underscore the pivotal role of aspect ratios in tailoring FGM plate designs to meet diverse stress requirements.

Simultaneously, varying thermal conditions (T_1, T_2, T_3) significantly shapes stress distribution across all aspect ratios, highlighting the pronounced influence of the thermal.

T_3 uniquely impacts the stress gradient through the plate's thickness, highlighting its distinct role in stress distribution.

Material property gradients (n values) play a vital role in shaping stress distribution.

Illustrating the relationship between a/h and n, along with the impact of the thermal field, these factors can be adjusted to meet precise design criteria.

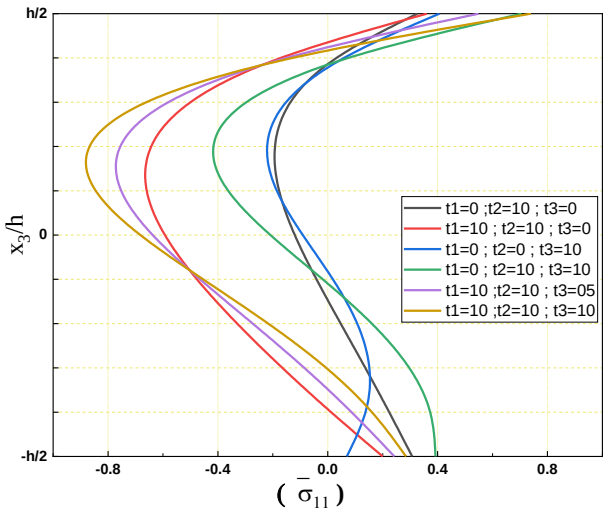

*Figure 5 – Effect of the thermal field on the($\bar{\sigma}_{11}$) through-the-thickness of a rectangular FGM plate with (n = 2, q_0 = 100, b = 2a). a=02*h*

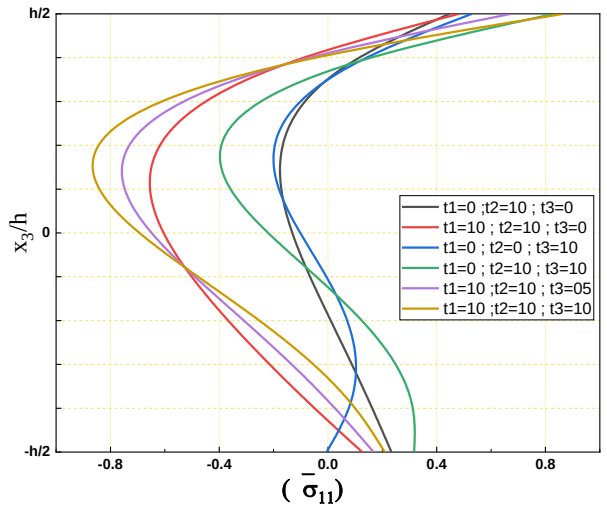

*Figure 6 – Effect of the thermal field on the($\bar{\sigma}_{11}$) through-the-thickness of a rectangular FGM plate with(n = 2, q_0 = 100, b = 2a). a=05*h.*

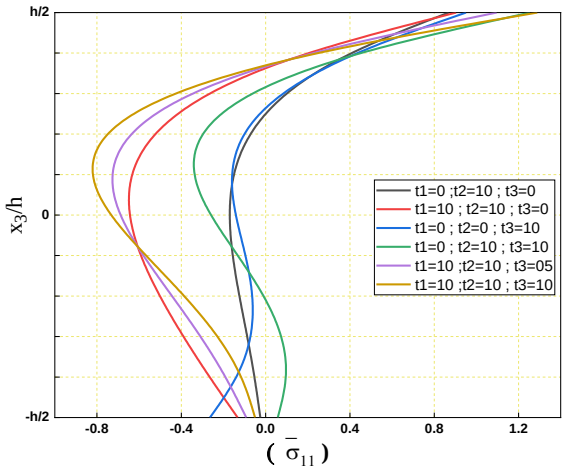

*Figure 7 – Effect of the thermal field on the($\bar{\sigma}_{11}$) through-the-thickness of a rectangular FGM plate with(n = 2, q_0 = 100, b = 2a). a=10*h.*

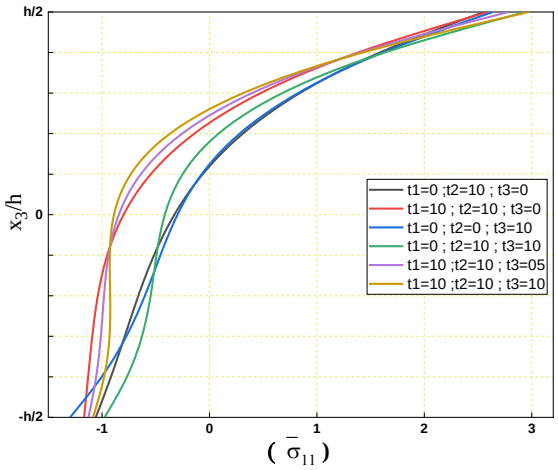

*Figure 8 – Effect of the thermal field on the($\bar{\sigma}_{11}$) through-the-thickness of a rectangular FGM plate with(n = 2, q_0 = 100, b = 2a). a=20*h.*

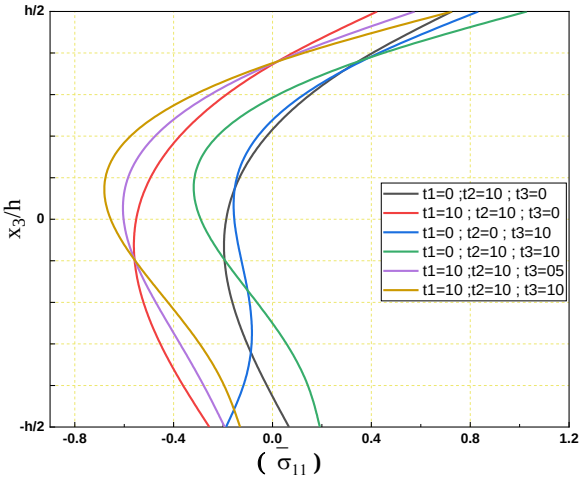

*Figure 9 – Effect of the thermal field on the($\bar{\sigma}_{11}$) through-the-thickness of a rectangular FGM plate with(n = 1, q_0 = 100, b = 2a). a=10*h.*

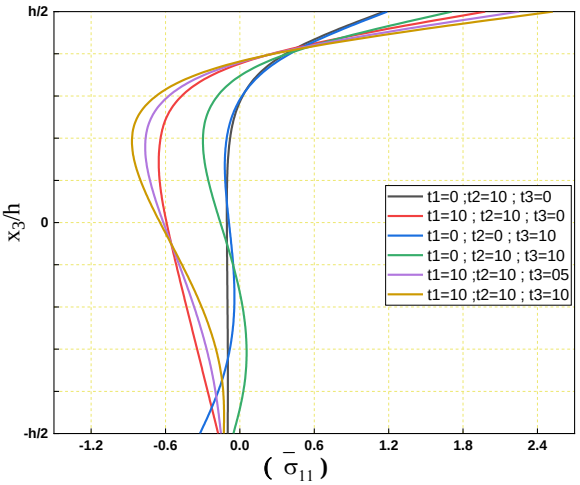

*Figure10 – Effect of the thermal field on the($\bar{\sigma}_{11}$) through-the-thickness of a rectangular FGM plate with(n = 6, q_0 = 100, b = 2a). a=10*h.*

Conclusions

This study thoroughly examined how advanced composite structures respond to various loads - mechanical and thermal - using a new CSDPT theory that eliminates the need for shear correction factors. By comparing the results with the standard established theories, it showed strong consistency being particularly aligned, particularly pertinent when taking into account SSSS boundary conditions. The research explored how changing volume fraction exponents and side-to-thickness ratios impact the displacements and stresses of functionally graded rectangular plates under distributed loading, highlighting the significant influence of material property gradients on their response. It also emphasized how different loads affect stresses within the plates, emphasizing the intricate relationship between these loads and stress distribution. Ultimately, this theory proves to be precise and suitable for analyzing the thermo-mechanical bending response of thick functionally graded plates, contributing valuable insights for practical applications and enhancing our understanding of advanced composite materials.

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Examen de flexión de estructuras compuestas de generación avanzada con propiedades específicas expuestas a diferentes cargas

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CAMPO: mecánica
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: Este artículo presenta el examen de flexión de estructuras compuestas de generación avanzada con propiedades específicas expuestas a diferentes cargas.

Métodos: Este artículo propone e introduce una nueva teoría generalizada de la deformación cortante de cinco variables para calcular la respuesta estática de placas rectangulares funcionalmente graduadas hechas de cerámica y metal. Notablemente, nuestra teoría elimina la necesidad de un factor de corrección de corte y garantiza condiciones de tensión de corte cero en las superficies superior e inferior. Se introducen investigaciones numéricas para interpretar las influencias de las condiciones de carga y las variaciones de potencia del material clasificado funcionalmente, la proporción de módulo, la proporción de aspecto y la proporción de espesor en el comportamiento de flexión de los FGP. Estos análisis luego se comparan con los resultados disponibles en los textos.

Resultados: Los resultados preliminares incluyen un análisis comparativo con las teorías estándar de deformación por corte de orden superior (PSDPT, ESDPT, SSDPT), así como con las teorías de Mindlin y Kirchhoff (FSDPT y CPT).

Conclusión: Nuestra teoría contribuye junto con las teorías establecidas en el campo, proporcionando información valiosa sobre la respuesta termomecánica estática de placas rectangulares funcionalmente graduadas. Esto abarca la influencia de los valores del exponente de la fracción de volumen en los desplazamientos y tensiones adimensionales, el impacto de las relaciones de aspecto en la deflexión y los efectos del campo térmico en la deflexión y las tensiones. Ejemplos numéricos del examen de flexión de estructuras compuestas de generación avanzada

con propiedades específicas expuestas a diferentes cargas demuestran la precisión de la presente teoría.

Palabras claves: materiales funcionalmente graduados, flexión, teorías de deformación por corte de orden superior, termomecánica.

Исследование на изгиб усовершенствованного поколения композитных конструкций со специфическими свойствами, подверженных различным нагрузкам

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РУБРИКА ГРНТИ: 55.09.43 Композиционные материалы
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В данной статье представлено исследование на изгиб композитных конструкций нового поколения со специфическими свойствами, подверженных различным нагрузкам.

Методы: В данной статье представлена новая обобщенная теория деформации сдвига с пятью переменными для расчета статического отклика функционально градуированных прямоугольных пластин, изготовленных из керамики и металла. Данная теория исключает необходимость использования поправочного коэффициента сдвига и обеспечивает отсутствие условий деформации сдвига как на верхней, так и на нижней поверхности пластины. Введено численное испытание при интерпретации влияния условий нагрузки и изменений прочности функционально градуированного материала, а также коэффициентов модуля, аспекта и толщины на поведение функционально градуированных пластин при изгибе. Результаты анализа были сопоставлены с результатами, доступными в литературе.

Результаты: Предварительные результаты включают сравнительный анализ со стандартными теориями сдвиговой

деформации высшего порядка (PSDPT, ESDPT, SSDPT), а также теориями Миндлина и Кирхгофа (FSDPT и CPT).

Выводы: Наряду с ранее подтвержденными теориями в этой области, данная теория вносит вклад, предоставляя ценную информацию о статическом термомеханическом отклике функционально градуированных прямоугольных пластин. Он охватывает влияние значений показателя объемной доли на безразмерные смещения и напряжения, влияние коэффициентов аспекта на дефлексию, а также влияние теплового поля на дефлексию и напряжения. Численные примеры испытаний на изгиб усовершенствованного поколения композитных структур со специфическими свойствами, испытанных различными нагрузками, подтверждают точность представленной теории.

Ключевые слова: функционально-сортированные материалы, изгиб, теории сдвиговой деформации высшего порядка, термомеханический.

Испитивање вршено савијањем напредне генерације композитних структура са специфичним својствима изложених различитим оптерећењима

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ОБЛАСТ: механика
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: У раду је представљено испитивање савијањем напредне генерације композитних структура са специфичним својствима изложених различитим оптерећењима.

Методе: Предлаже се и уводи нова генерализована теорија смицања са пет варијабли ради израчунавања статичког одговора четвртастих функционално градираних керамичко-металних плоча. Теорија елиминише потребу за коришћењем корективног фактора смицања и обезбеђује одсуство услова за деформацију смицањем и на горњој и на доњој површини плоче. Уводи се

нумеричко испитивање за тумачење утицаја услова оптерећења и варијација снаге функционално градираног материјала, као и коефицијената модула, аспекта и дебљине на понашање функционално градираних плоча при савијању. Резултати ових анализа упоређени су са резултатима доступним у литератури.

Резултати: Прелиминарни резултати обухватају компаративну анализу са стандардним теоријама смицања вишег реда (PSDPT, ESDPT, SSDPT), као и са теоријама Миндлина (FSDPT) и Кирхофа (CPT).

Закључак: Заједно са већ потврђеним теоријама у овој области, представљена теорија пружа допринос увидом у статички термомеханички одговор функционално градираних плоча. Он обухвата утицај вредности експонента запреминског удела на недимензионална померања и напоне, утицај коефицијената аспекта на дефлексију, као и ефекте термалног поља на дефлексију и напоне. Нумерички примери испитивања вршеног савијањем напредне генерације композитних структура са специфичним својствима изложених различитим оптерећењима потврђују тачност представљене теорије.

Кључне речи: функционално градирани материјали, савијање, теорије смицања вишег реда, термомеханички.

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Desktop application for crypto-protected voice communication

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FIELD: computer sciences, telecommunications, IT, cryptography
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Abstract:

Introduction/purpose: All data exchanged over the Internet as well as other computer networks should be considered exposed to various types of security threats. In light of this, the transmission of voice over applications that do not use any type of crypto-protection allows anyone to discern the content of communication. Since voice transmission requires as little delay as possible, various protocols are used to enable crypto protected real-time communication. This paper presents one solution in a desktop application variant.

Methods: The essence in voice exchange systems as well as in other systems where real-time communication is necessary is the establishment of a crypto-protected session which is a virtual secure channel for

communication to which only the communicating parties have access. Voice sessions in the application are established with the SIP (Session Initiation Protocol) protocol. The sessions are further protected using the ZRTP (Zimmerman Real-time Transport Protocol) protocol. FusionPBX was used as the SIP server (registrar) for testing purpouses. The application is developed in C++ language using the Qt framework.

Results: The final version of the application demostrates that ZRTP and SIP protocols are well suited for establishing crypto protected voice communications with low delay.

Conclusion: This solution provides cryptographic functions for data secrecy and the management of cryptographic keys. Improving the solution with digital signatures and certificates will result in additional cryptographic functions: data integrity and personal identification. With this improvement, this solution will be able to withstand modern security threats with low delay.

Key words: crypto protected sessions, real-time communication, voice sessions, SIP protocol, ZRTP protocol, communications.

Introduction

The quality and speed of information exchange has grown with the technological development of mankind. Having the right information at the right time puts an individual or a group at a significant advantage over other entities, whether they are business competitors or the enemy in military conflicts. The telephone, one of important inventions of the modern age, enabled the transmission of voice to remote locations, which made business processes easier and faster. The importance of this invention is reflected in the rapid expansion of the use of telephones in the business sphere, as well as the continuous construction of telephone lines. The development of computer networks was much faster and more far-reaching compared to the development of telephone lines due to the fact that they enabled not only the transmission of voice but also other types of data. All this resulted in the development of VoIP (Voice over IP) technology, which enabled voice transmission using the infrastructure of an already existing computer network. This technology made it possible to exchange voice using devices of different standards as well as computers.

As in any system where data is exchanged, it is necessary to protect the integrity and authenticity of the data. The first use of classic telephones in war led to the development of various eavesdropping techniques in order to gain an advantage over enemies. In order to protect themselves from enemy eavesdropping, armies developed various encryption principles. As the systems became more complex, the attack techniques also became more complicated and multiplied, which was accompanied

by the development of defense techniques. The development of computers drastically accelerated data processing, which led to a revolutionary change in the field of cryptography. Voice is nothing but a type of data that can be transmitted over a computer network. The protection of voice transmission is therefore not much different from the protection of any other type of data, except that it requires low latency like other forms of real-time communication. In order to achieve this, various software tools and libraries have been developed to work with cryptographic algorithms and data protection techniques. In combination with the existing communication protocols and modern frameworks for the development of applications for different platforms, modern intuitive but also cryptographically protected applications can be implemented. This paper presents a proposal for an application solution for the cryptoprotection of speech in an IP environment.

Protocol suite

In order to provide the desired services for crypto-protected voice exchange, the implementation proposed in this paper implies the use of the SIP (Session Initiation Protocol) protocol to establish a session for voice transmission. The voice in the test application is transmitted using the ZRTP (Zimmermann Real-Time Transport Protocol) protocol that encrypts the data symmetrically, using the AES algorithm with a key exchanged using the Diffie-Hellman algorithm (Abdallah & Meshoul, 2023).

SIP protocol

SIP (Session Initiation Protocol) is an application-level protocol used to control, establish and terminate sessions. Its most common application is establishing communication in IP telephony (VoIP systems).

After establishing a session between two "agents", as all types of end points in communication are called in SIP (they consist of a client agent which generates requests, and a server agent which generates responses to requests), further data transmission is taken over by one of protocols responsible for the transmission of a given media type (video or sound).

The most commonly used protocol for VoIP in combination with SIP is RTP (Realtime Transport Protocol) (Merit & Ouamri, 2012).

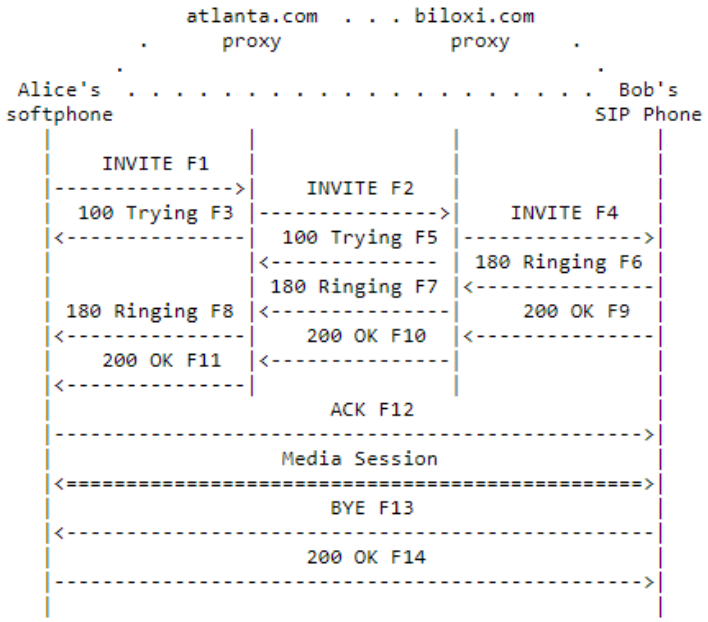

Figure 1 – An example of SIP messages exchange for establishing the session

The syntax of SIP is similar to other protocols that use a request/response system such as HTTP. SIP requests must start with a line containing the name of the method used, the URI to which the request is directed, the name, and the version of the protocol.

The basic methods supported by SIP requests are as follows:

– REGISTER - serves to log a certain agent to the server so that it is generally visible and available for establishing sessions,
– INVITE - a request to send an invitation to a specific address to establish a session.
– ACK - serves as a signal to the requested party that its confirmation has been received and that the session can begin,
– CANCEL – a request to cancel the session,
– BYE – a request to terminate the current session, and
– OPTIONS – a request sent to the SIP server to inquire about its capabilities.

Here is a example of an SIP message with the INVITE method:

```
INVITE sip:bj@bjsip.com SIP/2.0
Via: SIP/2.0/UDP pc33.atlanta.com;branch=z9hG4bK776asdhds
Max-Forwards: 70
To: Bob <sip:bj@bjsip.com>
From: Alice <sip:alice@atlanta.com>;tag=1928301774
Call-ID: a84b4c76e66710@pc33.atlanta.com
CSeq: 314159 INVITE
Contact: <sip:alice@pc33.atlanta.com>
Content-Type: application/sdp
Content-Length: 142
```

In the SIP response, the first line represents the status line which contains the status code. A status code is a three-digit integer value that indicates the result of an attempt by the requested party to understand and respond to the request. Similar to HTTP, the first digit of the status code divides the codes into classes. Unlike the HTTP protocol which has 5 code classes, the SIP protocol has an additional 6th class which represents Global failures statuses (Boruchinkin, 2015).

ZRTP protocol

ZRTP (Zimmerman Real-time Transport Protocol) is a protected version of the RTP (Real-time Transport Protocol) protocol, which is a transport layer protocol intended for real-time communication, usually visual and voice communication. It uses the Diffie-Hellman algorithm for key exchange, which builds on SRTP (Secure Real-time Transport Protocol) which uses the AES algorithm to maintain an encrypted session (Boruchinkin, 2015). The protocol implements the negotiation of security parameters through small time windows where participants agree on algorithms and cryptographic settings. During this process, a Short Authentication String (SAS) code is generated and can be used to verify the user's identity (Qi et al, 2018).

ZRTP is used to protect against a variety of attacks, including Man-in-the-Middle attacks, where someone tries to intercept and manipulate communications. During parameter exchange, users can compare the

SAS code over a secure channel, such as face-to-face with a contact or through another communication channel. Data is encrypted using a symmetric cryptosystem, such as AES, which provides efficient and strong encryption. There is also the possibility of using user keys for additional security. Taking into account these technical aspects, ZRTP contributes to the creation of secure and confidential communication channels on the Internet, ensuring data integrity and privacy during information exchange (Eltengy, 2021).

Development tools

The test application was implemented in the C++ programming language using the Qt framework, specifically the QtQuick approach for developing graphical interfaces. QtCreator was used as the development environment. The basic principles of object-oriented programming as well as the functionalities provided by the programming languages C++, JavaScript and QML were used.

Qt framework

Qt is a cross-platform, open-source software development framework that enables the creation of applications for a wide variety of operating systems. It is developed by the Qt Company and is one of the most popular GUI development frameworks in the world of programming. The advantages of using Qt are: independence from the platform, having various tools for developing graphical user interfaces and a large number of classes for working with files, databases, network, multimedia, etc. Qt has its own integrated environment for developing applications called Qt Creator. Qt Creator offers a wide choice of types of projects when developing applications, where there are two main types for applications with a graphical user interface: Qt Widgets and Qt Quick. Other project types are variations of these two types (Mondal & Sharma, 2019).

The test application was developed using QT Quick approach to create graphical interfaces. QT Quick is a newer approach to creating user interfaces in QT, based on declarative graphical programming (QML) and imperative graphical programming (JavaScript). QML (Qt Modeling Language) is a declarative language used in the Qt Quick environment for creating user interfaces. QML allows the declarative definition of the user interface using simple scripts, which describe the appearance and behavior of elements. QML supports a component approach which means that reusable components can be created and embedded in different parts of the user interface making it easier to structure and maintain the code.

This makes UI development faster and more efficient, as it requires fewer lines of code compared to QT Widgets (Krasnowski & Lebrun, 2022).

Each user-defined component is defined in separate files. The syntax of the QML language resembles JSON (JavaScript Object Notation), where objects are graphic components, and object key-value pairs represent the attributes of that graphic object. In the example, the flexibility of the QML language can be observed, because attribute values can be bound to the values of other attributes or to the values of JavaScript expressions. Comparing QML with HTML, it is found that QML is more readable and more flexible, it reduces code repetition with a component approach and offers wider possibilities for customization of components (Mondal & Sharma, 2019). Below is an example of a user-defined QML component from a test application, specifically a user-defined button:

```
import QtQuick
import "/scripts/Utils/changeBrightness.js" as ColorJs
Rectangle {
    property var onClick
    property alias text: textBox.text
    property string textColor: theme.textColor
    property string col
    height: 30
    radius: height / 4
    scale: mouseArea.containsMouse ? 1.02 : 1
    color: mouseArea.containsMouse ? ColorJs.changeBrightness(col, -0.05) :
col
    Text{
        //warning
        font.pointSize: Math.ceil(height * 0.7)
        id: textBox
        color: textColor
        font.family: globalFont
        anchors.centerIn: parent
    }
    MouseArea{
        id: mouseArea
        anchors.fill: parent
        cursorShape: Qt.PointingHandCursor
        onClicked: () =>{
            onClick()
        }
        hoverEnabled: true
    }
}
```

The main idea of the Qt Quick approach in the development of graphic interfaces is to define graphic components declaratively through QML, changing the appearance of graphic components imperatively through the JavaScript language, while more complex programming logic is performed in C++. This development pattern resembles the MVC (Model View Controller) pattern with the fact that only the more complex controller logic is implemented in the C++ programming language. In this way, the components of the MVC pattern are sufficiently separated as entities, while Qt provides several APIs to easily connect MVC components (Kara et al, 2023).

PJSIP library

PJSIP is a free, open-source multimedia communication library written in C that implements standard protocols such as SIP, SDP, RTP, STUN, TURN, and ICE. It combines the Signaling Protocol (SIP) with a rich multimedia framework and NAT traversal functionality in a high-level API that is portable and suitable for almost all types of systems ranging from desktop computers through dedicated systems to mobile phones. PJSIP is both compact and feature-rich. It supports audio, video, presence subscription and instant messaging and has extensive documentation. On mobile devices, it abstracts system-dependent functions and in many cases can use the device's native multimedia capabilities. The library makes it possible to implement softphone applications of very small size (up to 150KB) using lower-level APIs, while using higher-level functionality, applications can be "packaged" into footprints of only a few hundred kilobytes (Ntantogian et al, 2019).

In order to facilitate access and work with the library, higher-level programming interfaces have been implemented. The first API is the PJSUA high-level API for the C language that defines types, structures, macros, enumerations, and functions to facilitate operation and calling of library procedures. The next level of abstraction is PJSUA2, an object-oriented API that makes it even easier to call the PJSIP library from object-oriented languages. It was initially implemented for the C++ programming language, but it can be used through various interfaces and called from other higher programming languages such as C#, Python and Java (Merit & Ouamri, 2012).

The PJSUA2 API is implemented through various classes that represent the abstraction of various functions of the base library. The classes through which access to the main functionalities of PJSIP is enabled are:

– Endpoint - represents an abstraction of the endpoint in SIP communication; it is necessary to create exactly one instance of this class in each application because further initialization and settings of the library are performed through,
– Media - abstract base class that represents the media element of the system that can record/play media content; this class is inherited by classes like the AudioMedia class which in turn is inherited by the AudioMediaRecorder and AudioMediaRecorder classes,
– Call - serves to abstract the establishment of calls or other sessions; also most often subclasses are derived from it in order to redefine callback methods for reacting to changes in the status of the initiated call or the arrival of session instant messages,
– Buddy - represents a remote "friend" or contact whose status (present/not registered) can be subscribed to by the client; out-of-session instant messages can be sent through this object.

Application design and structure

Class diagram

The program logic of the application is placed in the C++ code of the application where the code is organized into several classes. In the class diagram (Figure 2), it can be seen that the classes BjEndpoint, BjAccount and BjCall inherit from the classes Endpoint, Account and Call respectively, which are classes from the PJSUA2 library. These classes enable basic functionalities related to VoIP communication. Through them, the user registers and logs out of the SIP server, makes a call, accepts a call, rejects a call and receives a status about the reason for the end of the call. The class that represents the core of the program logic is BjSip, which inherits from the QObject class, which is the basic class from the Qt framework and whose purpose is to enable the graphical representation of an object of a given class. The BjSip class has multiple purposes, but its primary purpose is to provide a link between other C++ classes and the graphical interface, that is, QML. Qt offers a number of APIs to bridge the gap between C++ and QML, the most notable of which is the Signals and Slots API, which also underlies all other APIs (Eltengy, 2021). Signals and slots are actually ordinary functions that are related by broadcasting; calling the signal function automatically calls the slot function. In this way, the functions from QML are connected with the functions from C++, in the concrete example with the methods of the BjSip class (Ivanović, 2023).

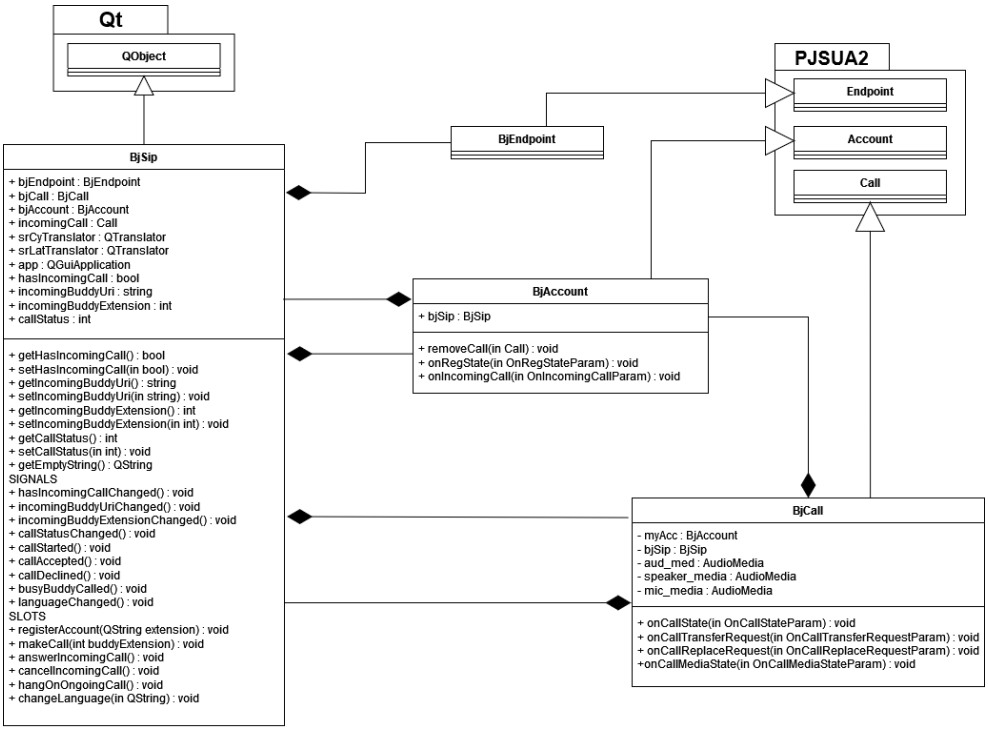

Figure 2 – Test application – Class diagram

Application activities

Registration activity

When starting the application, it is necessary for the user to log in to the predefined SIP server. To log in, it is necessary to first create a local account with a user name, password and extension (the number with which the user is identified on the SIP server), which can be done from the activity of creating a new user account.

After the account is created, the user can log in with a username and password. After entering the parameters for registration on the server, the user starts the process of registering the account on the server by pressing the "Log in" button.

Main activity

The main activity of the application is divided into two tabs: "call history" and "contacts". The "call history" tab is not implemented in this version of the application. On the "contacts" tab, there is a list of contacts created by the user, where each contact has an extension (a number on the SIP server) and a contact name. Next to each contact there are buttons for voice and video calls, although a video call is not implemented in this version of the application. There is also a button for creating a new contact on the "contacts" tab, which forwards the user to the form for entering a new user.

Figure 3 shows the main activity of the application and the "contacts" tab. The user can add new contacts by pressing the "Add new contact" button, which opens the form for adding a new contact (Figure 4).

On the form, the user should enter the extension of the new contact and the name of the contact, before pressing the "Add new contact" button, which adds the new contact to the contact list.

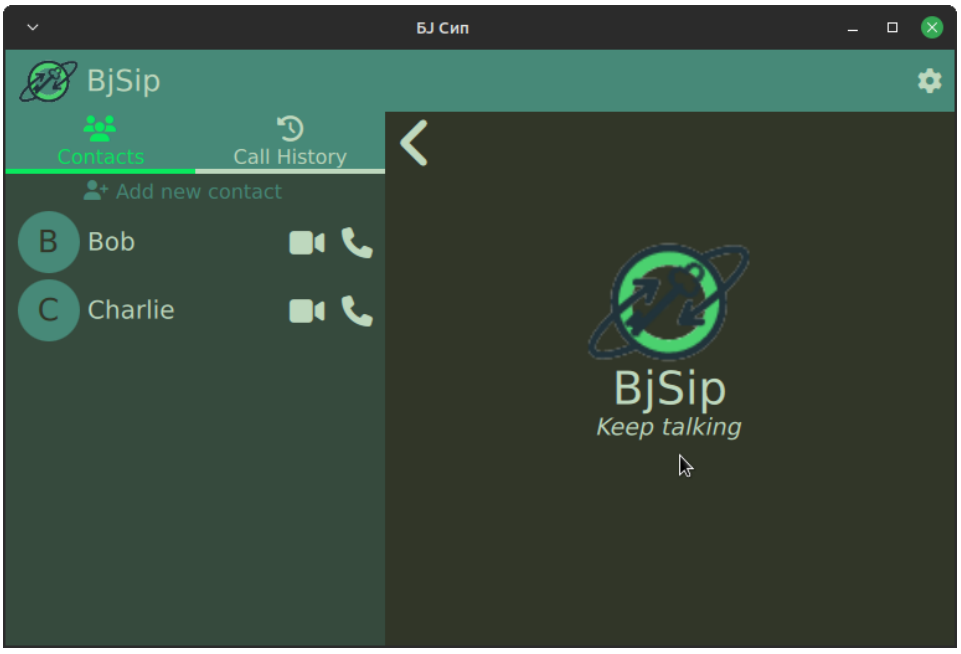

Figure 3 – Test application - Main activity in the dark mode in English

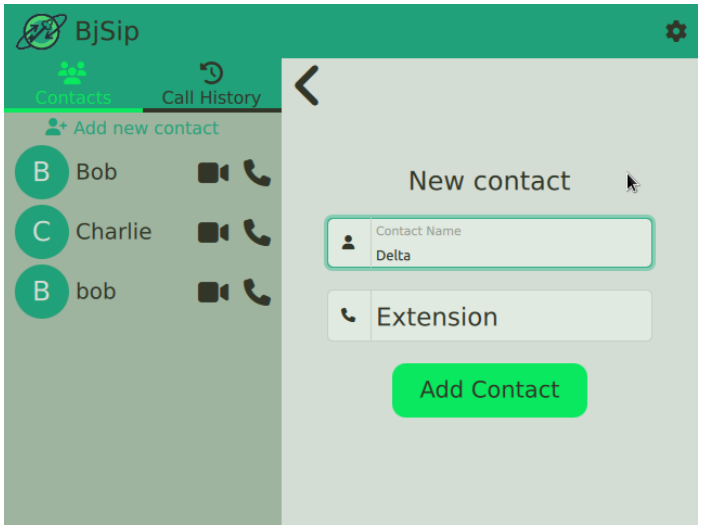

Figure 4 – Test application – Add the new contact activity in English

Call activities

In the current version of the application, only voice calls between two users are enabled. Pressing the voice call button in the contact list sends a call to the desired contact, where the user is forwarded to the call establishment activity (Figure 5). On a given activity, the user has the option to end the started call or to wait for the call to be established.

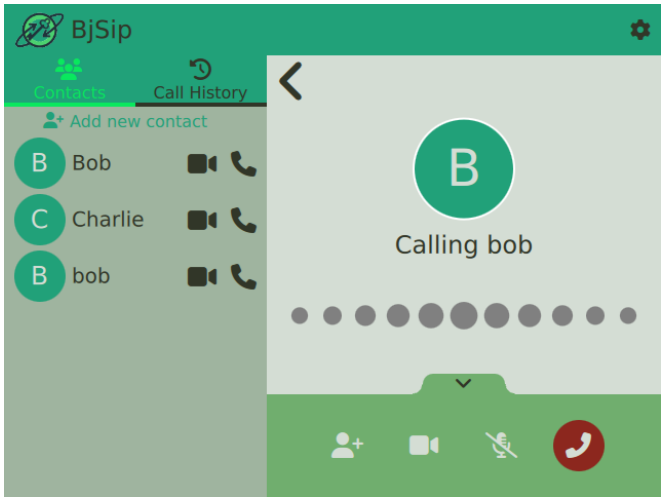

Figure 5 – Test application – Pending call activity in English

If the contact is unavailable for any reason, the user is forwarded to the end-of-call activity shown in Figure 6, where the reason for the termination of the initiated call is printed. On a given activity, the user has a button to restart the same call, a button to return to the initial activity, as well as the written name of the contact with whom he participated in the call and the reason for ending the call.

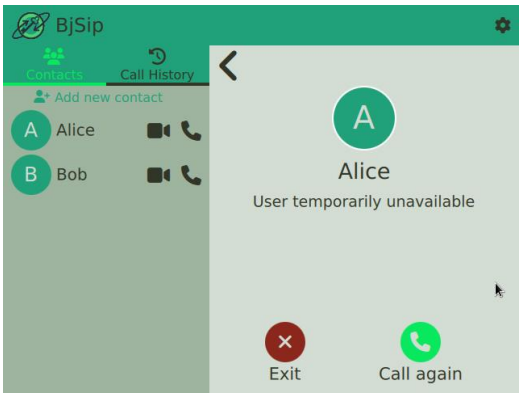

Figure 6 – Test application – Call ended activity in English

In case the called contact accepts the call, both users are forwarded to the voice call activity (Figure 7). On a given activity, users have buttons to add a new participant, switch to a video call, mute the microphone, and end the call. In the current version, only the button to end the call is implemented. An established call continues until one party ends the call by pressing the end call button, which forwards both users to the end-of-call activity (Figure 6).

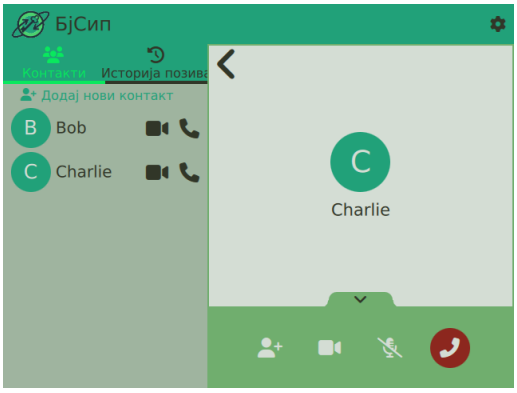

Figure 7 – Test application – Outgoing call activity in Serbian

If the server forwards an incoming call to the application, the user is shown a pop-up menu (Figure 8) in the lower right corner of the application window with the information about the user who made the call and the buttons for accepting and rejecting the call. If the application detects an incoming call while a call is in progress at that moment, it refuses to give the call by passing the status to the caller that the user is busy, which is displayed on the end-of-call activity (Figure 6).

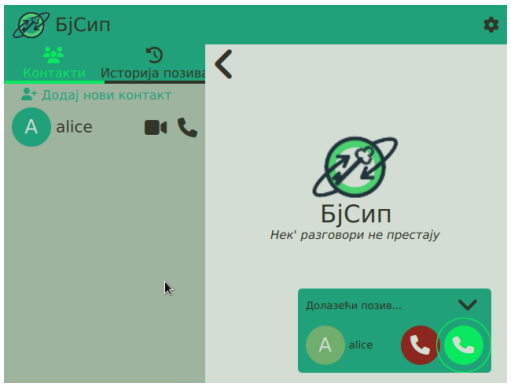

Figure 8 – Test application – Incoming call popup in Serbian

Settings activity

There is a settings activity in the application (Figure 9) that currently has two settings that are there to improve the user experience. One setting allows the selection of the color mode between light and dark mode, while the other setting allows the selection of the language. Currently, the application supports Serbian (Latin and Cyrillic) and English. Figure 9 shows the appearance of the main activity of the application in the light color mode in Serbian.

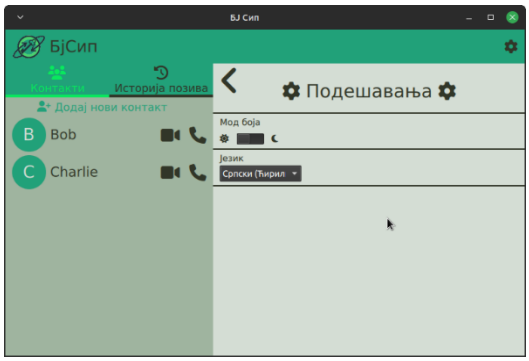

Figure 9 – Test application – Settings activity in the light mode in Serbian

Test environment

In order to test the functioning of the application, it was necessary to create a test environment in which there is a SIP server to which the test application connects. The network environment is simulated by a router with Wi-Fi access points through which a laptop device running three client processes and a virtual machine running a server are connected to a wireless LAN network. The FusionPBX SIP server is running on a Linux Debian 11 virtual machine, with its network settings set to Bridge, so that the server can be accessed from other physical machines on the network. FusionPBX can be configured via web interface (Figure 10). If the application functions as intended in this environment, it can be concluded that it will function in any network that operates according to TCP/IP network protocols (Tot et al, 2021).

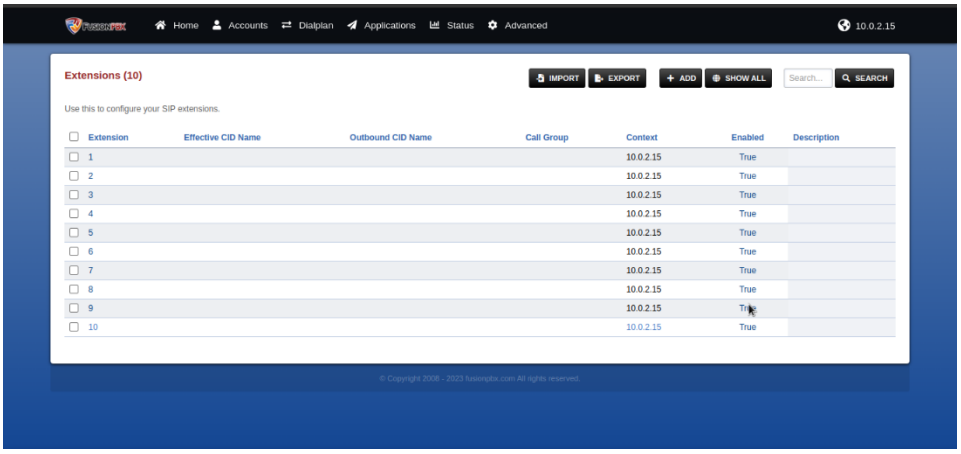

Figure 10 – Test environment – Web interface for FusionPBX

Conclusion

Exchanging any type of content over unprotected media is practically unacceptable in today's world. With the advancement of technology, the demands for faster and better communication have increased, which must also be protected due to today's security challenges. Through the integration of cryptographic protocols such as the ZRTP protocol, the application enables the creation of secure communication channels and the exchange of secret keys between the users. This provides encryption and authentication, contributing to the impenetrability of unwanted activities. Using the SIP protocol of the application level, the way of mutual

communication between users and servers is standardized. The development of an application for cryptographic protection of speech is of great importance in the context of a growing need for secure communications both in business and private spheres as well as in the military. Challenges such as compatibility with different devices and operating systems, and compliance with the existing privacy standards and regulations need to be addressed.

The level of protection as well as the range of information aspects that are protected in the proposed solution are not sufficient for applications in real systems. In order to further improve the security and protection of messages, it is necessary to explore the possibilities of using additional cryptographic mechanisms, such as digital signatures, random session keys, and digital envelopes for the implementation of additional security services. This would preserve the integrity of the data and the authenticity of the data source as well as the sender's non-repudiation, and the secrecy of the data itself would be more clearly protected.

The application test shows that the SIP protocol is a suitable and good solution for this type of application. In order for this application to be more comprehensive, it is necessary to expand it in the ways mentioned in the previous chapter and test it in a larger and more complex environment.

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Aplicación de escritorio para comunicación de voz criptoprotegida

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CAMPO: ciencias de la computación, telecomunicaciones, TI, criptografía
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: Todos los datos intercambiados a través de Internet, así como de otras redes informáticas, deben considerarse expuestos a

diversos tipos de amenazas a la seguridad. En vista de esto, la transmisión de aplicaciones de voz en off que no utilizan ningún tipo de criptoprotección permite que cualquiera pueda discernir el contenido de la comunicación. Dado que la transmisión de voz requiere el menor retraso posible, se utilizan varios protocolos para permitir la comunicación en tiempo real criptoprotegida. Este artículo presenta una solución en una variante de aplicación de escritorio.

Métodos: La esencia en los sistemas de intercambio de voz, así como en otros sistemas donde es necesaria la comunicación en tiempo real, es el establecimiento de una sesión criptoprotegida que es un canal virtual seguro para la comunicación al que sólo tienen acceso las partes que se comunican. Las sesiones de voz en la aplicación se establecen con el protocolo SIP (Session Initiation Protocol). Las sesiones están además protegidas mediante el protocolo ZRTP (Protocolo de transporte en tiempo real de Zimmerman). FusionPBX se utilizó como servidor SIP (registrador) para fines de prueba. La aplicación está desarrollada en lenguaje C++ utilizando el framework Qt.

Resultados: La versión final de la aplicación demuestra que los protocolos ZRTP y SIP son muy adecuados para establecer comunicaciones de voz criptoprotegidas con bajo retardo.

Conclusión: Esta solución proporciona funciones criptográficas para la secrecía de los datos y gestión de claves criptográficas. Mejorar la solución con firmas y certificados digitales dará como resultado funciones criptográficas adicionales: integridad de datos e identificación personal. Con esta mejora, esta solución podrá resistir las amenazas de seguridad modernas con poca demora.

Palabras claves: sesiones criptoprotegidas, comunicación en tiempo real, sesiones de voz, protocolo SIP, protocolo ZRTP, comunicaciones.

Десктопное приложение для криптозащиты голосовой связи

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РУБРИКА ГРНТИ: 20.15.05 Информационные службы, сети, системы в целом,
28.21.19 Теория кодирования,
49.33.35 Надежность сетей связи и защита информации,
81.93.29 Информационная безопасность. Защита информации
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Безопасность всех данных, которыми обмениваются через интернет, а также другие компьютерные сети подвергаются различным видам угроз. Таким образом, передача голоса через приложения, которые не используют криптозащиту, обеспечивает возможность любому желающему перехватить голосовое сообщение. Поскольку передача голоса должна осуществляться с минимальной задержкой, используются различные протоколы для обеспечения криптозащиты связи в режиме реального времени. В данной статье представлено решение в виде десктопного приложения.

Методы: Суть систем голосового обмена, а также других систем, где необходима связь в режиме реального времени, заключается в установлении криптозащищенного сеанса. Криптозащищенный сеанс представляет собой виртуальный защищенный канал связи, доступ к которому имеют только общающиеся стороны. Голосовые сеансы в приложении устанавливаются с помощью протокола SIP (Session Initiation Protocol). Сеансы дополнительно защищены с помощью протокола ZRTP (Zimmerman Real-time Transport Protocol). FusionPBX использовался в целях тестирования SIP-сервера (регистратор). Приложение разработано на языке C++ с использованием фреймворка Qt.

Результаты: Окончательная версия приложения демонстрирует, что протоколы ZRTP и SIP обеспечивают криптозащищенную голосовую связь с минимальной задержкой.

Выводы: Данное решение предоставляет криптографические функции при обеспечении конфиденциальности данных и управления криптографическими ключами. Усовершенствование решения с помощью цифровых подписей и сертификатов приведет к появлению дополнительных криптографических функций: целостности данных и идентификации личности. Благодаря такому усовершенствованию данное решение сможет противостоять современным угрозам безопасности с минимальной задержкой.

Ключевые слова: криптозащищенные сеансы, связь в реальном времени, голосовые сеансы, протокол SIP, протокол ZRTP, коммуникации.

Десктоп апликација за размену криптозаштићеног говора

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ОБЛАСТ: рачунарске науке, телекомуникације, ИТ, криптографија
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Сви подаци размењени преко интернета, као и преко других рачунарских мрежа, подложни су разним типовима безбедносних претњи. Узимајући то у обзир, пренос гласа уз коришћење апликација које не користе никакав вид криптозаштите омогућава било коме да пресретне садржај комуникације. Како пренос гласа захтева што мање кашњење, користе се разни протоколи за криптозаштиту за комуникацију у реалном времену. Овај рад представља решење у варијанти десктоп апликације.

Методе: Суштина размене гласа, као и комуникације у реалном времену, јесте у обезбеђењу криптозаштићене сесије, која представља виртуелни заштићени канал за комуникацију коме могу приступити само легални учесници. Гласовне сесије успостављене су у апликацију коришћењем SIP (Session Initiation Protocol) протокола. Сесије су заштићене коришћењем ZRTP (Zimmerman Real-time Transport Protocol) протокола. FusionPBX је коришћен као SIP сервер за тестирање. Апликација је развијена у C++ језику коришћењем Qt фрејмворка.

Резултати: Коначна верзија апликације демонстрирала је да ZRTP и SIP протоколи обезбеђују криптозаштићену гласовну комуникацију са минимумом кашњења.

Закључак: Ово решење обезбеђује криптографске функције за тајност података и размену криптографских кључева.

Унапређивање решења, коришћењем дигиталних потписа и сертификата, резултирало би додатним криптографским функцијама: интегритетом података и аутентикацијом. Овим унапређењем решење би било отпорно на модерне претње уз мало кашњење.

Кључне речи: криптозаштићене сесије, комуникација у реалном времену, гласовне сесије, SIP протокол, ZRTP протокол, комуникације.

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Implementation of two-factor user authentication in computer systems

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Abstract:

Introduction/purpose: The paper explores the implementation of two-factor authentication (2FA) in computer systems, addressing the increasing need for enhanced security. It highlights the vulnerabilities of password-based authentication and emphasizes the advantages of 2FA in mitigating digital threats. The development of the VoiceAuth application, integrating 2FA through a combination of password and voice authentication, serves as a practical illustration.

Methods: The research adopts a three-tier architecture for the VoiceAuth application, encompassing a database, server-side REST API, and client-side single-page application. Speaker verification is employed for voice authentication, analyzing elements like pitch, rhythm, and vocal tract shapes.The paper also discusses possibilities for future upgrades, suggesting enhancements such as real-time voice verification and additional 2FA methods.

Results: The application's implementation involves a detailed breakdown of the REST API architecture, Single Page Applications (SPAs), and the Speaker Verification service.

Conclusion: The research underscores the crucial role of two-factor authentication (2FA) in bolstering the security of computer systems. The VoiceAuth application serves as a practical demonstration, showcasing the successful integration of 2FA through a combination of password and voice authentication. The modular architecture of the application allows for potential upgrades.

Key words: authentication, computer systems, biometrics.

Introduction

With the development of Internet technologies and their role in our everyday lives, the need for security and data protection has become a necessity. In a time when sensitive transactions can be conducted and personal and financial information can be accessed over the Internet or other computer networks, the possibility of secure access to data becomes crucial. Authentication in computer systems represents the confirmation of a user's identity before allowing access to the system or data. This involves verifying and confirming the authenticity of associated information to prevent unauthorized access and protect sensitive data.

Classical computer systems often used password-based authentication methods, but the drawbacks of such methods are becoming more pronounced in modern systems. Passwords are vulnerable to brute-force attacks, as modern high-performance computers can quickly uncover them if they are not sufficiently complex. Users of computer systems often use the same passwords for all systems, so in the case of data leaks from one popular service, an attacker can gain access to all user accounts. For these reasons, the need for an additional layer of security during data and service access is highly emphasized today.

Two-factor authentication provides that extra layer of security by requiring an additional proof of the user's authenticity in addition to the username and password. The significance of two-factor authentication is evident in the fact that major companies like Google and Meta require their users to use two-factor authentication in the future to protect against data breaches.

The concept of authentication

Authentication represents the process of verifying and confirming the identity of a user or system in computers and information systems. This security measure is applied to ensure access only to authorized individuals and to prevent unauthorized access and misuse.

1) Authentication is the most crucial step in the process of gaining access to data, consisting of three main steps:
2) Identification: During this step, the user asserts who they are.
3) Authentication: During this step, the user provides evidence that confirms their identity.
4) Authorization: During this step, it is determined whether the user has the right to access.

In most computer systems, identification and authentication are combined into a single step, where the user sequentially enters a username for identification and a password as an authentication factor. The combination of a username and password is the most common way to prove identity, especially in web environments (Marky et al, 2022).

Vulnerabilities of password-based authentication

Despite the widespread use of passwords as an authentication method, they are by no means secure and have multiple vulnerabilities that can easily lead to identity theft if exploited (Tot et al, 2021). The vulnerabilities of passwords do not lie solely in the authentication method itself when considered in isolation. In theory, a sufficiently long password that combines letters with numbers and other characters poses a significant barrier to any brute-force attack (Bondarchuk et al, 2023).

It is clear that a sufficiently complex password serves as a significant barrier against brute-force attacks, but a small number of passwords fall into this category. The vulnerabilities of passwords lie in their widespread use as well as in users' bad habits. Some weaknesses of passwords in the context of users include:

- Users choose easily memorable passwords such as "12345678," "11111111," or "password." Attackers can guess such passwords manually, and any short passwords are quickly guessed by computers.
- Users do not want to enter passwords with each login and carelessly use the browser's save password options.
- Users use the same passwords for accounts on different services. This practice leads to identity theft, even in the case of very complex passwords. Almost all major platforms have reported data breaches in the past few years.

Recommendation: It is advised to use different passwords, especially for systems authorized to perform financial transactions.

Two-Factor Authentication as a method of protection

Two-factor authentication involves adding another layer of security during identity verification. It commonly combines a password method with another method, but any of the two methods used can be classified into one of the following three groups:

- Something the user knows: This could be a password or some form of code or response to a question.

- Something the user possesses: often a hardware device like a mobile phone or payment card.
- Something the user is: Typically, a biometric data point such as a fingerprint or eye biometrics.

By combining two factors from different groups, the likelihood of unauthorized access is significantly reduced, as the chances are lower that an attacker possesses both factors, especially if they are not in any way related to each other (Chandrakar & Om, 2015).

Common methods of two-factor authentication

Today, various types of two-factor authentication are in use, and some of the decisive factors in their prevalence are speed of use, ease of setup, and security.

1) Authentication Using SMS messages - Two-factor authentication via SMS. After receiving the username and password, the website sends the user a one-time code (OTP) via text message. The user must enter the OTP code into the application to gain access (Yuan, 2013).

2) Software Tokens - A recommended alternative to SMS codes involves using software-generated time-based one-time codes (known as TOTP). First, the user needs to download and install a free two-factor authentication app on their mobile phone or computer. They can then use the app with any website supporting this type of authentication. Software tokens eliminate the possibility of interception by hackers, addressing a concern with methods delivered via SMS (Reese et al, 2019).

3) Push Notification Method - The push notification is an authentication request sent to the mobile phone, and the user approves or rejects it with a single touch. Due to its speed of use, Push Notification is considered a two-factor authentication method that prioritizes user convenience.

4) Biometric Methods - In the past, the obstacle to biometrics was the high cost of devices capable of recognizing biometric data. Today, biometric authentication has become commonplace for most people. Most smartphones now have fingerprint or facial recognition capabilities. However, some

biometric methods have emerged but are not widely used, such as voice authentication, gait analysis, and typing habits. Biometric authentication has several drawbacks. All characteristics it relies on are permanent user traits. Another significant problem is that biometric data is extremely sensitive and allows not only user authentication but also person identification. Therefore, the collection and transmission of this data to digital services should be treated with exceptional care. Hence, biometric data is usually used for local authentication and stored and processed on the device to avoid sending it over the network (Kaur & Kumar, 2021).

Development of the VoiceAuth Application

The practical part of this work encompasses the development of a test application that applies the concepts of two-factor user authentication. An application has been created that allows users to authenticate through a combination of password and voice authentication. Since the user's voice has been chosen as the second authentication factor, the application has been named VoiceAuth. The application was developed in a three-tier architecture with a separate data store, server-side, and client-side web application. The database was created using the PostgreSQL object-relational DBMS, allowing data manipulation through enhanced SQL commands. The server-side web application was created as a REST API service and written in the TypeScript programming language, using the NestJs framework that enables the creation of modular web applications. The client-side application was built as a single-page application (SPA) in TypeScript using the Angular framework, which possesses a similar modular architecture to the NestJs framework. The client application is tailored for use on both mobile and desktop devices. For the purpose of voice verification, a service was developed in the Python programming language, communicating with the server application via the HTTP protocol (Zou et al, 2021).

REST API Architecture

The REST API (Representational State Transfer Application Programming Interface) represents a standard way of communication and data exchange between various software applications and systems over the Internet. This technology enables simple and efficient interaction between client applications and servers, providing a means for requesting,

updating, and sharing data in a manner consistent with the fundamental principles of web architecture.

In REST API architecture, resources (such as data or functionalities) are represented as URLs, and operations are performed using HTTP methods like GET (retrieve data), POST (send new data), PUT (update existing data), and DELETE (delete data). This allows programmers to easily communicate with servers and perform various actions based on their needs.

REST API architecture is widely applied in various domains, including web applications, mobile applications, and data exchange services, and it facilitates the integration of different software systems in a simple and cost-effective manner. This popular technology provides a modern approach to the development, integration, and communication between web applications.

The complete code written for the REST API of the VoiceAuth application can be found at (Tomić, 2023a).

Single Page Applications (SPAs)

A single-page application (SPA) is a type of web application that runs on a single web page without the need to redirect to new pages when communicating with the server or processing user actions. Instead, SPAs dynamically change the content and structure of the page using asynchronous communication with the server and exchanging data with the server using technologies such as AJAX (asynchronous JavaScript and XML).

In SPA applications, one page typically contains components that are dynamically loaded and displayed, achieving faster responsiveness and less server load. Users can interactively work with the application without the need to refresh the entire page.

This concept has become popular in recent years due to its user-friendliness and quick development. Well-known web frameworks and libraries such as Angular, React, and Vue.js are often used for developing SPA applications.

The complete code written for the SPA VoiceAuth application can be found at (Tomić, 2023b).

Speaker verification

Speaker verification is a biometric authentication method used to confirm the identity of a person based on their voice. This technology is

employed to determine whether a person's voice matches a previously registered voice in the system (Zhu et al, 2020).

During speaker verification, the system analyzes various aspects of the voice, such as pitch, rhythm, vocal tract shapes, and other characteristic parameters. These data are compared with a voice sample registered earlier in the system. If the system determines that the analyzed voice matches the registered sample, it is considered a successful verification, and the user is granted access.

There are several types of speaker verification, but the most common distinction is between text-dependent and text-independent methods. In text-dependent verification, the user is required to read words from the screen, and such methods often involve speech recognition in addition to the speaker verification system.

Speaker verification methods commonly utilize machine learning algorithms and neural networks.

The complete code written for the Speaker Verification service in the VoiceAuth application can be found at (Tomić, 2023c).

Authentication implementation techniques in web applications

In the previous chapters, we talked about what authentication is and which authentication methods exist, but we did not explain how authentication mechanisms are implemented in different systems. In this chapter, we will look at the most common techniques for implementing authentication in web applications.

In the previous chapters, it was mentioned that authentication is the process of verifying and confirming the identity of a user using some form of proof, often referred to as credentials. In modern systems, users do not provide their credentials for every action they perform; instead, they provide them to the system during login, and for a certain period, they are considered authorized to work with the system. During this time, the system is responsible for keeping information about the logged-in user, and this is also called maintaining a session. Due to the nature of the HTTP protocol, which does not imply session persistence, there are various techniques in web applications to achieve this, and we will now look at some of them.

Basic HTTP authentication

This is the simplest method of session persistence implementation. The client-side of the application is responsible for storing user credentials

in memory and sending them to the server during each HTTP request in the authorization header, usually encoded in Base64 format.

This session persistence method is not suitable for use because the user's credentials are sent with every request, making it susceptible to theft and identity loss.

Session cookie

An HTTP cookie is a block of data created by a web server when a user visits a website and is stored on the user's computer or other device through a web browser.

A session cookie is a cookie that lasts for the duration of a session. The session begins when the user logs in to work. Session cookies contain information stored in temporary memory or on the server's disk and are deleted after the session ends. A session cookie is tied to a specific server. This means that a session cookie cannot be read or accessed by any machine other than the one that generated it. The corresponding server is the one that stores the web application the user is visiting. The same server also creates the session ID. The session ID is a unique, randomly generated number stored in the session cookie.

A session cookie is suitable for use in applications that use the MVC architecture because most frameworks have built-in support for server sessions. Still, it is not suitable for use in implementing REST API solutions because one of the principles of the REST methodology is not to store session data on the server. This way, servers can scale horizontally, with multiple instances of web servers each able to handle any HTTP request.

JSON Web Token (JWT)

JSON Web Token (JWT) is a standard used to exchange information between two entities, usually a client and a server (Jones et al, 2015). JWTs contain JSON-format objects that carry information to be shared (). Each JWT is signed using hashing functions or asymmetric cryptography algorithms to ensure that the contents (known as JWT claims) cannot be altered by the client or a malicious party. JWT can take the form of JWS (JSON Web Signature) or JWE (JSON Web Encryption). JWS tokens contain public information that anyone can read but whose contents are verified by the server that issues them. JWE uses asymmetric cryptography algorithms to encrypt messages, allowing them to contain private information.

Commonly, JWT has three parts:

- Header, which contains information about the algorithm used for signing or encrypting and information about the token type.
- Payload, the part containing claims that are verified. It also includes the expiration period of the token.
- Signature, in the case of JWS, contains the cryptographic digest of the associated header, claims, and a secret key stored on the server.

JWT is suitable for implementation in the REST API architecture. The token is stored on the client-side of the application (whether it is a SPA, mobile, or desktop application) and is attached to each request in the authorization header. The token is then verified on the server by creating a new message digest and compared with the one in the token's signature. Only the server can issue and verify tokens.

Analysis of the proposed solution

The VoiceAuth application was developed as a test application to review data on employees' working hours and days off in the company (Tomić, 2023d). The data in the application is randomly generated, but in a real system, it would be retrieved from a third-party system, whether it is an embedded check-in system, a time-tracking application for projects like Clockify, or an accounting program. The application distinguishes two types of users: regular users and administrators, who have different rights and different login systems for work.

The best way to represent the structure of the application is by using UML diagrams. This is a way to visualize a software program through a collection of diagrams. Unified Modeling Language (UML) is a standardized modeling language that helps programmers visualize, construct, and document new software systems and drawings. UML is used to create diagrams of static structure based on various engineering practices that have proven successful in creating complex systems. There are different types of UML diagrams used for different software structures. There are 14 official types, with some additional versions that are not officially recognized but are widely used. In this work, two diagrams will be described: the Class Diagram and the Use Case Diagram.

Use Case Diagram

The Use Case Diagram is a representation of the interaction between the user and the system, illustrating the relationship between the user and different use cases in which the user is involved.

The use case diagram can identify different types of users in the system and different use cases.

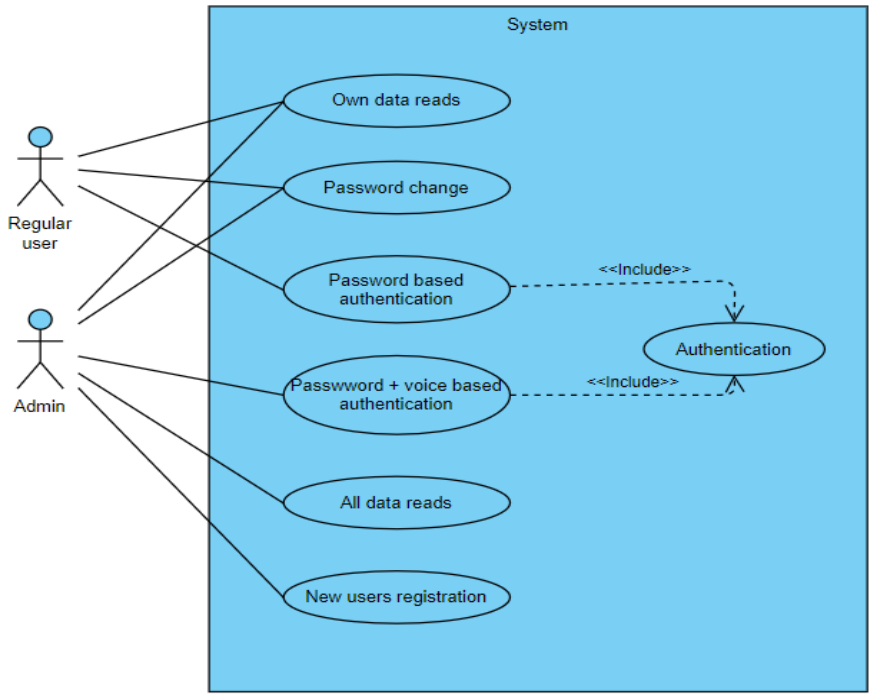

Figure 1 – Use Case Diagram

Fig. 1 shows the use case diagram for the application described in the paper.

The first step is user login. Regular users use only their username and password, while administrators, after logging in with their password, must verify their voice.

Figure 2 shows the login process for regular users. The appearance of the application on a mobile phone is also depicted.

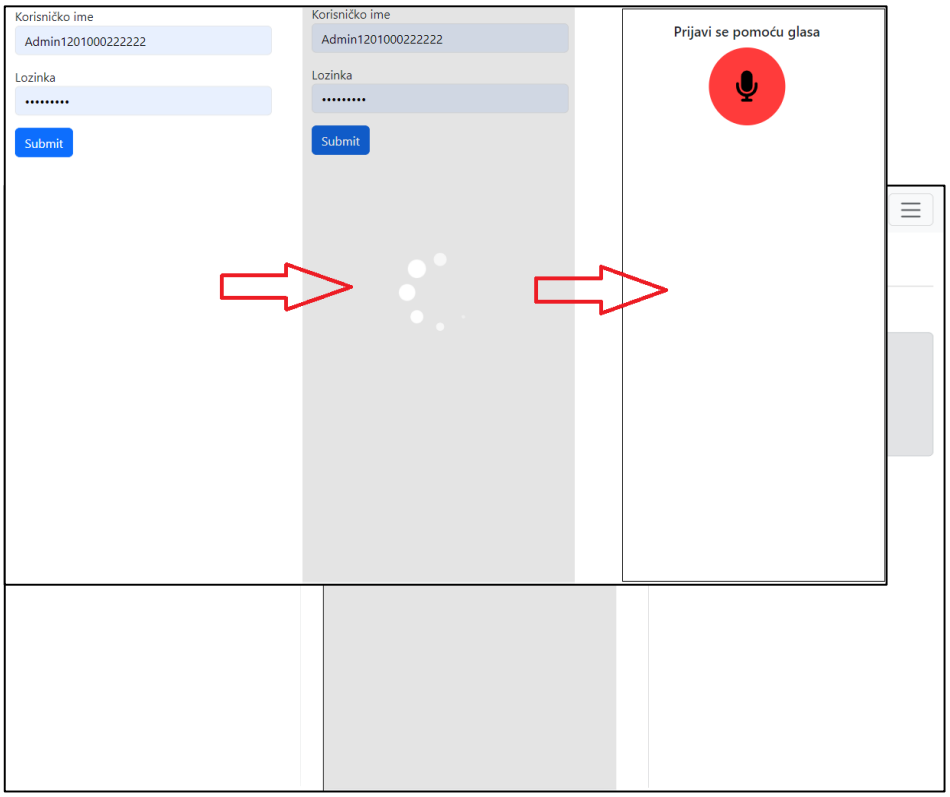

Figure 2 – Regular user login

Administrators log in to the application first with a username and password, and then they verify their voice. Voice verification is not possible if authentication has not been successful.

As mentioned earlier, voice verification is done using a service developed in the Python programming language, and the Speechbrain package is used.

The machine learning models provided by this package are suitable because voice verification only requires one recording for comparison, achieving an accuracy of over 80 percent.

The authentication flow for administrators is shown in Figures 3 and 4.

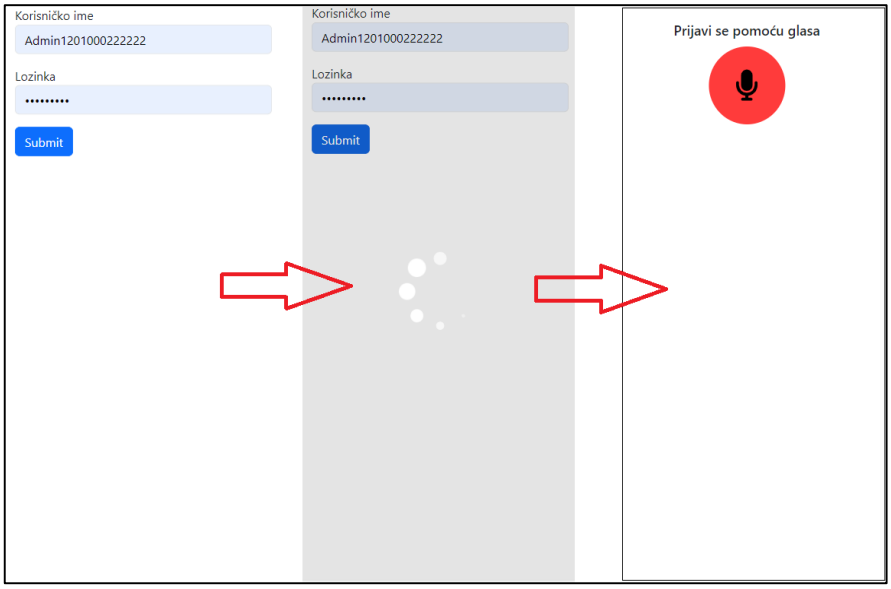

Figure 3 – Administrator login, part 1

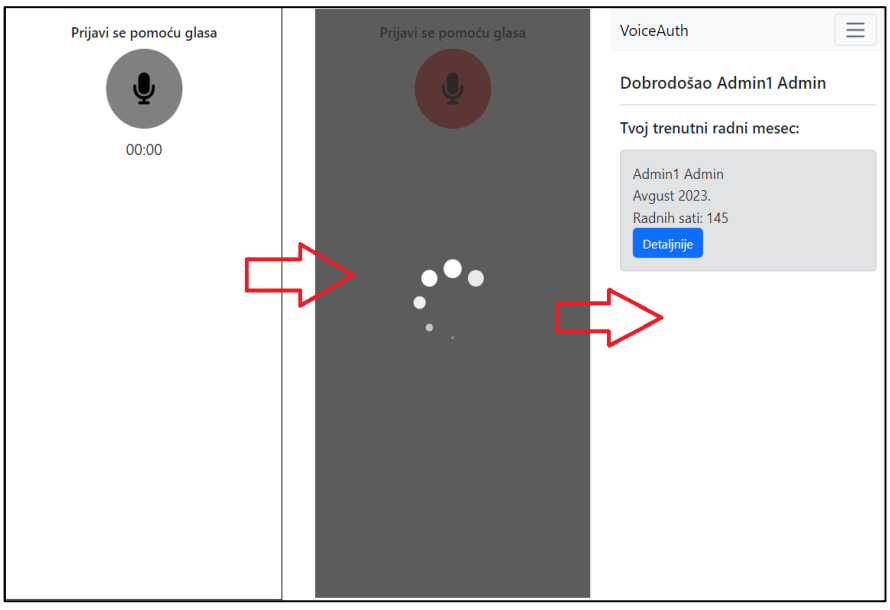

Figure 4 – Administrator login, part 2

After the administrator logs in with a username and password, they will be redirected to the voice verification page. The dependency between the two login steps is achieved by creating a temporary JSON Web Token, which serves as confirmation that the administrator has successfully completed password verification.

In the application, the registration of new users is performed by administrators, and in this way, only regular users can be registered. The registration of new users is done through an email address entered by the administrator. The administrator enters the user's information, including the first name, last name, ID number (JMBG), and the email address to which the user will receive a message for further registration, as shown in Figure 5.

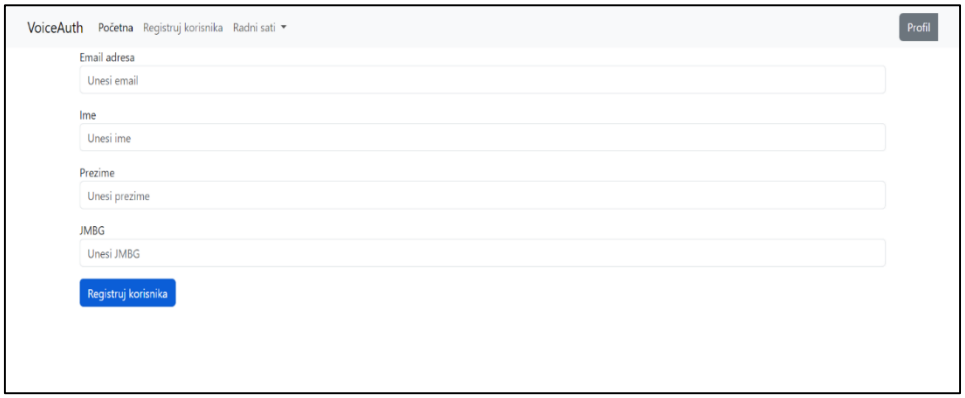

Figure 5 – New user registration

Figure 6 – Confirmation email

After this, an invitation with a link arrives at the email address, which can be used for further registration and creating a password for future logins, as shown in Figure 6.

Class diagram

In order for the above to be realized, the implementation of the application has a certain number of classes in the TypeScript programming language, which are implemented in the manner shown in the class diagram. The best way to understand and overview the entire code is by displaying class diagrams. The class diagram allows us to map the system structures by showing different classes, attributes, operations, and relationships between objects. In the diagram, a class is represented by a rectangle. Each rectangle is divided vertically into three parts. The upper part has the class name. The second and third sections provide details about the class's operations, behavior, and attributes. Figure 7 shows the class diagram for the REST API application described in this paper because it contains the majority of the business and domain logic of the system, without the presentation layer.

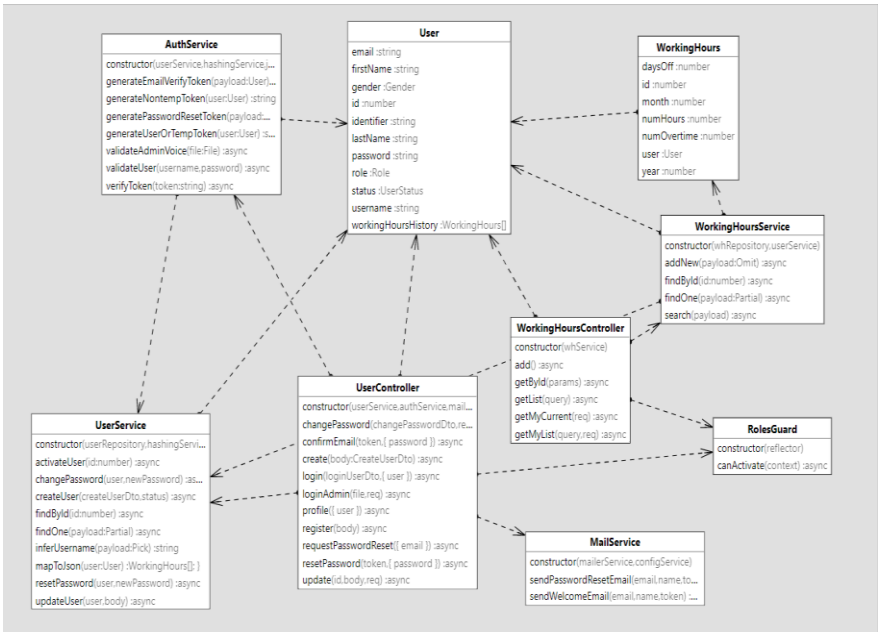

Figure 7 - Class diagram

The class diagram shown in the figure contains the most basic classes that represent the key components of the entire application, namely: UserController, WorkingHoursController, UserService, WorkingHoursService, User, WorkingHours, AuthService, MailService, and RolesGuard. The explanations of the main classes are given below:

- UserController and WorkingHoursController: These are controller classes defining the inputs to the system and operations provided by the created API. Each method in these classes corresponds to a URL resource that allows data manipulation in the system.
- UserService and WorkingHoursService: These are the core service classes containing the main business logic of the application. They define methods that, using an Object-Relational Mapper (ORM) tool, manipulate data in the database. These service classes are intended to be used by controller classes but can also be utilized in other service classes.
- AuthService: This auxiliary service class handles user authentication. Besides the basic authentication role, it also incorporates two-factor authentication and token generation.
- MailService: This auxiliary service class is responsible for sending messages via email. It utilizes the SMTP protocol to send messages to users, with messages playing a role in registering new users and changing passwords.
- User and WorkingHours: These are data model classes defined using an ORM tool. The attributes of these classes are used for generating tables and fields in the database.
- RolesGuard: This class plays a role in user authorization when accessing resources. It provides a generalized solution for authorization in the application. With the specific syntax for the programming language, it allows adding user authorization based on their role in the system (regular user or administrator) with just one line of code for each resource (represented as methods in the controller classes).

Analysis of the proposed solution

As mentioned in the previous chapters, the majority of the application is written in the TypeScript programming language, along with a voice verification service written in the Python programming language. The text below provides the basic information about the software tools and packages used in the development of the application.

NestJs

NestJS is a modern, flexible, and scalable framework for developing server-side applications in the TypeScript programming language. This framework provides a contemporary way of structuring applications using a modular concept and views the application as a set of interconnected modules.

NestJS relies on fundamental concepts from object-oriented programming as well as advanced concepts such as Inversion of Control (IoC) and Dependency Injection (DI), enabling better code organization and testing. This architecture encourages the development of applications that are easy to maintain and test.

With support for synchronous and asynchronous code, NestJS allows the development of high-performance applications. Additionally, within NestJS, there is access to a wide range of modules and packages that facilitate the implementation of various functionalities, including authentication, database management, routing, and many others.

TypeORM

TypeORM is an object-relational mapping (ORM) library for JavaScript and TypeScript programming languages. This tool allows developers to easily communicate with relational databases using objects and classes.

TypeORM provides an intuitive way to define and model databases using object-oriented programming concepts. Working with databases and tables is achieved through classes and annotations, reducing the need for SQL queries and direct table interactions.

Angular

Angular is a popular framework for developing web applications. Developed by Google, this framework enables programmers to build dynamic and interactive web applications using HTML, CSS, and the TypeScript language.

Angular uses the concept of components, where different parts of the application are developed as a set of blocks that can be reused multiple times. This approach facilitates the organization and maintenance of code, as well as the development of various functionalities. Angular supports modular code organization and the use of object-oriented programming principles in the development of the presentation layer of web applications.

Speechbrain

SpeechBrain is an open-source Python framework for speech processing that covers various aspects of speech and language analysis. This framework allows researchers and programmers to develop applications and models for speech processing, speech recognition, speech synthesis, emotional analysis, and many other applications in the field of natural language processing (NLP).

SpeechBrain provides a straightforward way to build and experiment with different models and algorithms for speech analysis. It offers a dataset, preprocessing tools, model-building modules, and the ability to test and fine-tune models.

Possibilities of upgrading the proposed solution

This test application provides only the basic scope of functionality and represents a demonstration of using modern biometric authentication techniques in the Internet and other network systems. The application itself does not provide utility value but can serve as a good foundation for building a more complex system and its use through the internet or private computer networks. The application can be upgraded as a time-tracking system by introducing integrations with external time-tracking systems, providing necessary legal and accounting information within the company. Additionally, the modular nature of the developed solution allows for efficient transformation of the application into a microservices architecture, enabling its use as a standalone service for user authentication and authorization.

Further upgrades to the application would depend on the needs of the real system and the features it would offer, but some possible functionalities that could enhance the application's significance include:

- Enabling the use of voice verification dependent on spoken words by adding speech recognition algorithms to the verification service. This would allow real-time voice verification based on the uttered words, significantly improving the system's security.

- Providing other types of two-factor authentication, contributing to user experience.
- Enabling two-factor authentication for all types of users.

From a technical perspective, the quality of the already developed solution can be enhanced by allowing access to the application in a test environment via a web server for users to test application functionalities from their computers. Simplifying the installation of the application on servers could be achieved by introducing DevOps work methodology and automating the installation process through integration with version control systems like GitHub, used during solution development, and CI/CD (Continuous Integration & Continuous Deployment/Delivery) systems such as Jenkins and GitHub Actions.

Conclusions

Modern information technologies and information systems provide us with increasing possibilities day by day, penetrating into more and more areas of our lives. Internet users are becoming owners of new accounts on various systems and services every day. With the increase in accounts and the processing power of modern computers, there is a growing occurrence of attacks and digital identity theft. Two-factor authentication is one solution to this problem, offering users a higher level of security when accessing their accounts and becoming a standard in complex services.

This paper explores the possibility of implementing two-factor authentication for users in an information system. The ultimate goal was to demonstrate that two-factor authentication is not a burden to users and can be used easily and efficiently in computer systems. Additionally, the paper aims to show that biometric methods can be successfully used as one of the factors.

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Implementación de la autenticación del usuario a través de dos factores en sistemas informáticos

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CAMPO: ciencias de computación, TI
TIPO DEL ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: El artículo explora la implementación de la autenticación de dos factores (2FA) en sistemas informáticos, abordando la creciente necesidad de una mayor seguridad. Destaca las vulnerabilidades de la autenticación basada en contraseñas y enfatiza las ventajas de 2FA para mitigar las amenazas digitales. El desarrollo de la aplicación VoiceAuth, que integra 2FA mediante una combinación de contraseña y autenticación de voz, sirve como ejemplo práctico.

Métodos: La investigación adopta una arquitectura de tres niveles para la aplicación VoiceAuth, que abarca una base de datos, una API REST del lado del servidor y una aplicación de una sola página del lado del cliente. La verificación del orador se emplea para la autenticación de voz, analizando elementos como el tono, el ritmo y las formas del tracto vocal. El documento también analiza posibilidades para futuras actualizaciones, sugiriendo mejoras como la verificación de voz en tiempo real y métodos 2FA adicionales.

Resultados: La implementación de la aplicación implica un desglose detallado de la arquitectura API REST, las aplicaciones de página única (SPA) y el servicio de verificación de oradores.

Conclusión: La investigación subraya el papel crucial de la autenticación de dos factores (2FA) para reforzar la seguridad de los sistemas informáticos. La aplicación VoiceAuth sirve como demostración práctica, mostrando la integración exitosa de 2FA a través de una combinación de contraseña y autenticación de voz. La arquitectura modular de la aplicación permite posibles actualizaciones.

Palabras claves: autenticación, sistemas informáticos, biometría.

Внедрение двухфакторной аутентификации пользователя в компьютерных системах

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РУБРИКА ГРНТИ: 28.17.33 Компьютерное моделирование реальности. Виртуальная реальность
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В данной статье исследуется внедрение двухфакторной аутентификации (2FA) в компьютерных системах, подчеркивая растущую потребность в усилении безопасности. В статье освещаются уязвимость аутентификации на основании пароля и подчеркиваются преимущества 2FA в снижении цифровых угроз. В качестве практической иллюстрации представлена разработка приложения VoiceAuth, интегрирующего 2FA с помощью комбинации пароля и голосовой аутентификации.

Методы: В данном исследовании используется трехуровневая архитектура для приложения VoiceAuth, включающая базу данных, серверный REST API и пользовательское приложение. Для голосовой аутентификации используется проверка говорящего, анализирующая такие элементы, как: высота тона, ритм, тембр и такт. В статье также обсуждаются возможности будущих обновлений, в том числе проверка голоса в режиме реального времени и дополнительные методы 2FA.

Результаты: Внедрение приложения включает в себя детальную описание архитектуры REST API, одностраничных приложений (SPA) и службы аудиопроверки.

Выводы: В исследовании подчеркивается решающая роль двухфакторной аутентификации (2FA) в повышении безопасности компьютерных систем. Приложение VoiceAuth демонстрирует на практике успешную интеграцию 2FA посредством комбинации пароля и голосовой аутентификации. Модульная архитектура приложения допускает возможность его модернизации.

Ключевые слова: аутентификация, компьютерные системы, биометрия.

Имплементација двофакторске аутентификације у рачунарским системима

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ОБЛАСТ: рачунарске науке, информационе технологије
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: У раду се истражује имплементација двофакторске аутентификације (2FA) у рачунарским системима и наглашава растућа потреба да се унапреди безбедност. Истиче се угроженост аутентификације на основу лозинке и наглашавају предности 2FA у смањивању дигиталних претњи. Развој апликације VoiceAuth, која интегрише 2FA кроз комбинацију лозинке и аутентификације гласом, служи као практичан приказ.

Методе: Истраживање користи трослојну архитектуру за развој апликације VoiceAuth, обухватајући базу података, REST API на страни сервера и клијентску апликацију. За аутентификацију гласом користи се верификација говорника, анализирајући елементе као што су тон, ритам и облици вокалног тракта. У раду се, такође, разматрају могућности за будућа унапређења; предлажу се додаци као што су верификација гласа у реалном времену и додатне методе 2FA.

Резултати: Имплементација апликације укључује детаљан опис архитектуре REST API-а, клијентске апликације и сервиса за верификацију говорника.

Закључак: Улога двофакторске аутентификације (2FA) у јачању безбедности рачунарских система је кључна. Апликација VoiceAuth служи као практична демонстрација, приказујући успешну интеграцију 2FA кроз комбинацију лозинке и аутентификације гласом. Модуларна архитектура апликације оставља простор за потенцијална унапређења.

Кључне речи: аутентификација, рачунарски системи, биометрија.

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Mathematical modeling and simulation of a half-vehicle suspension system in the roll plane

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Abstract:

Introduction/purpose: The study of vehicle suspension is a challenge for researchers in the field of vehicles regarding the impact of the suspension system on vehicle performances such as ride comfort, road holding, and working space. This paper presents the simulation of the Land Rover Defender 110 vehicle in the roll plane (half vehicle) in Simulink/MATLAB. The obtained results were compared with the results obtained in the ADAMS/CAR software package of the Land Rover Defender 110 simulation model previously experimentally validated. The Defender 110 vehicle has a dependent suspension system in both axles and a passive suspension type with four degrees of freedom (4 DOF).

Methods: The equations of the system can be solved mathematically with a scheme in Simulink/MATLAB while half-vehicle modeling has been done in ADAMS/CAR.

Results: The comparison of the vehicle characteristics obtained by the two simulation methods was done for three different scenarios, and it was noticed that there is a good correlation between them.

Conclusion: It was concluded that the Defender 110 vehicle simulation model in Simulink/MATLAB is validated. The validated model can be used to perform suspension system optimization in future work.

Key words: suspension system, Defender 110, ADAMS/CAR, Simulink/MATLAB.

Introduction

Automotive researchers pay attention to suspension because it ensures the comfort, stability and safety of passengers and keeps the wheels always in contact with the road whatever the nature of the road is.

Most of research activities during last decades have been directed to vibration control of vehicles which are influenced by the harmful effects of vibrations caused by road irregularities on driver's comfort (Mitra et al, 2013).

The primary function of the suspension is to minimize vibrations arising from irregularities in the road profile. Consequently, it is crucial to meticulously choose suspension characteristics such as spring stiffness and the damping coefficient to ensure optimal performance across diverse road profiles. When the vehicle is driven over an uneven road profile, there should not be too large-amplitude oscillations, and if they occur, they must be removed quickly (Turakhia & Modi, 2016).

One of the models used in the literature is a quarter vehicle model because of its modeling simplicity. This model can give sprung mass acceleration, road holding, and suspension working space. In (Mitra et al, 2018), an experiment was conducted on a quarter car test rig to obtain the ride comfort by varying different parameters. The same dimensions of the test rig were replicated to develop a quarter car simulation model in ADAMS/CAR.

Another model that has been carried out by researchers is a bicycle type model which is more complex than the quarter vehicle model. This model provides one more parameter than the quarter vehicle model, and that is the pitch angle. In (Žuraulis et al, 2014), there are the analyses of the impact of the road micro-profile on the duration and the type of the vehicle wheel contact with the road surface driving at different speed, and the selected vehicle bicycle model describes vertical displacements of front and rear wheels and their suspension as well as the impact of the vehicle body motion and longitudinal oscillation.

There are some other parameters which are essential in the study of vehicle suspension and among them is the roll angle. In order to be able to study this parameter, we have developed a mathematical model of the

Land Rover Defender 110 in the roll plane. The dynamic motions of the vehicle in the roll plane are generally described by a 4DOF model. The vehicle has a dependent type suspension, meaning that there is an axle which connects the left wheel to the right one and the suspensions are of a passive type.

The Land Rover Defender 110 model was made in ADAMS/CAR software and the simulation model was validated using the instrumented experimental vehicle for two scenarios, namely, the bump test and the double lane change maneuver (Khettou et al, 2016).

This article focuses on the validation of the mathematical model using Simulink/MATLAB with the ADAMS/CAR model of the vehicle in the roll plane of the Land Rover Defender 110.

In the analysis of suspension in general, there are parameters called design variables which are: stiffness and damping coefficients and the performances such as ride comfort, road holding, and suspension working space. These performances are dependent on design variables. The objective of this work is to validate and compare the mathematical model with the Adams model in order to optimize the performance characteristics of the suspension system in the future work.

Mathematical model for suspension

A Land Rover Defender 110 vehicle in the roll plane with four degrees of freedom (4 DOF) is presented in Figure 1: the vehicle body mass (sprung mass), the moment of the sprung mass relative to the vehicle x axis points forward and is parallel to the vehicle plane of symmetry, the unsprung mass and the moment of the unsprung mass relative to the vehicle x axis are identified by m_v, I_{vx}, m_a and I_{ax}, respectively.

The suspension stiffness k and the damper coefficient c are placed at a distance d from the center of gravity of the suspension system. The tire stiffness k_t and the damper coefficient of the tire c_t are placed at a distance b from the center of gravity of the suspension system.

The vertical displacement, the rolling angle of the sprung mass, the vertical displacement and the rolling angle of the unsprung mass are represented by z_v ,θ_v , $z_a$and θ_a, respectively.

The vertical excitation in the left and right wheels is represented by z_{0l} and z_{0r}, respectively, and Figure 1 shows the details of the vehicle half in the roll plane. The specifications of the suspension system are given in Table 1.

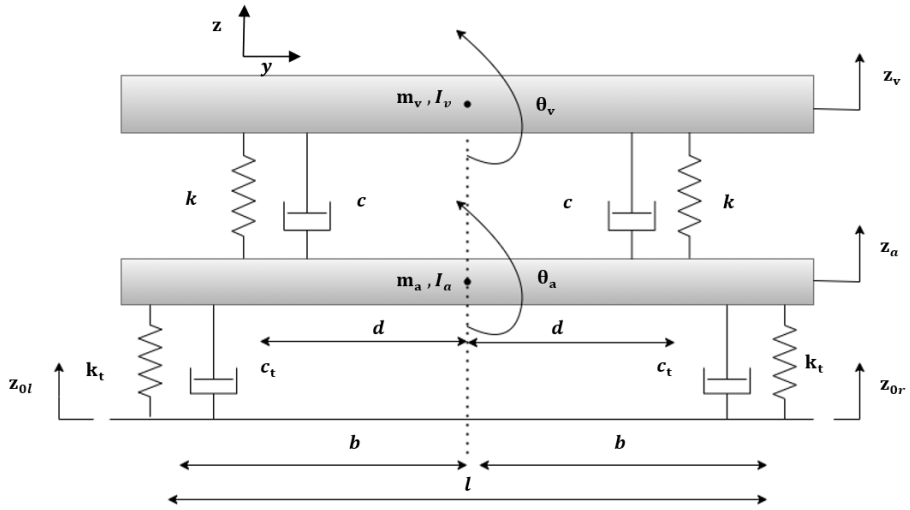

Figure 1 – Suspension system of the half vehicle in the roll plan

Table 1 – Suspension system specifications

Entity	Value	Entity	Value
m_v	$2125\ kg$	m_a	$232\ kg$
I_{vx}	$744\ kgm^2$	I_{ax}	$45.08\ kgm^2$
k	$55000\ N/m$	k_t	$200000\ N/m$
c	$5700\ Ns/m$	c_t	$0\ Ns/m$

The equations of motion of the passive model are given in Eqs. (1), (2), (3), and (4):

$$m_v \ddot{z}_v + 2c\dot{z}_v + 2kz_v - 2c\dot{z}_a - 2kz_a = 0 \quad (1)$$

$$m_a \ddot{z}_a + 2c\dot{z}_a + 2kz_a - 2c\dot{z}_v - 2kz_v + c_t(\dot{z}_{0l} + \dot{z}_{0r}) + k_t(z_{0l} + z_{0r}) = 0 \quad (2)$$

$$I_{vx}\ddot{\theta}_v + 2cd^2\dot{\theta}_v + 2kd^2\theta_v - 2kd^2\dot{\theta}_a - 2kd^2\theta_a = 0 \quad (3)$$

$$\mathrm{I_{ax}}\ddot{\theta}_\mathrm{a} + 2\mathrm{cd}^2\dot{\theta}_\mathrm{a} + 2\mathrm{kd}^2\theta_\mathrm{a} - 2\mathrm{cd}^2\dot{\theta}_\mathrm{v} - 2\mathrm{kd}^2\theta_\mathrm{v} + \mathrm{c_t b}^2(\dot{z}_{0l} - \dot{z}_{0r}) + \mathrm{k_t b}^2(z_{0l} - z_{0r}) = 0 \quad (4)$$

The performance characteristics are described as follows:

1. The vertical acceleration of the vehicle body is a measure of the comfortability of ride and is expressed in Eq.(5):

$$f_1 = |\ddot{z_v}| \tag{5}$$

2. The dynamic tire load is a measure of the road holding and is expressed in Eq.(6):

$$f_2 = |z_a - z_0| \tag{6}$$

3. The suspension working space is expressed in Eq.(7):

$$f_3 = |z_v - z_a| \tag{7}$$

4. The roll angle is expressed in Eq.(8):

$$f_4 = |\theta_v| \tag{8}$$

Development of a simulation model

Two methods are used for the simulation of the half vehicle model to make the comparison between them. The first method is to perform the simulation using Simulink/MATLAB Software and the second method is to use ADAMS/CAR Software.

Simulink model

Figure 2 shows the Simulink model which is made using Eqs. (1), (2), (3), and (4). In the solver, we chose step fix equal to 0.001, and automatic solver selection.

Following the input excitation and from the graphic representation of the model, we obtain essential information such as: displacement, velocity, acceleration along the z axis and the angular displacement, angular velocity, and angular acceleration along the x axis for the two masses (sprung and unsprung).

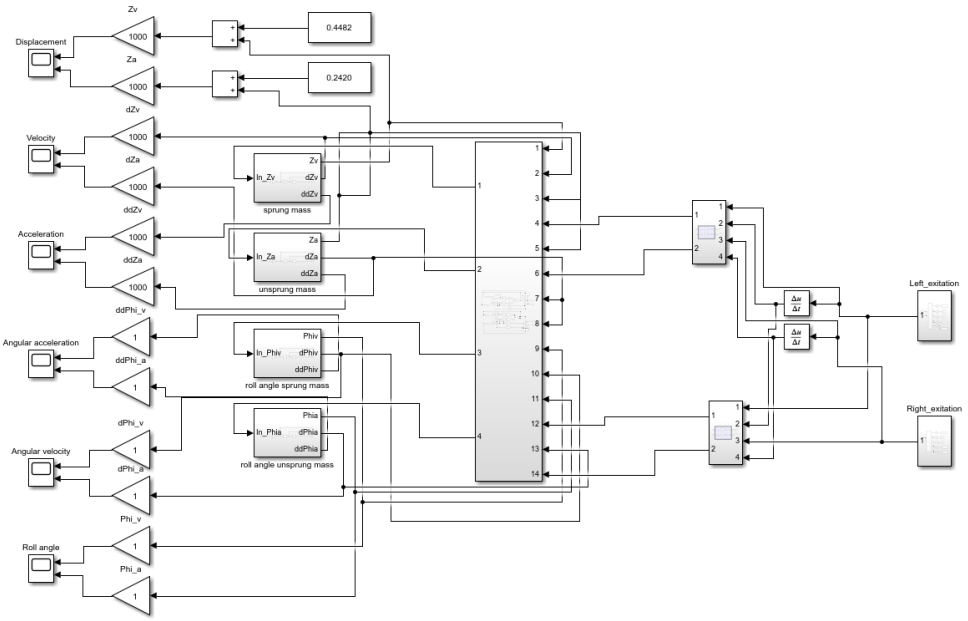

Figure 2 – Simulink model for the vehicle in the roll plan

Adams/Car model

The Land Rover Defender 110 suspension model was initially developed by (Khettou et al, 2016) and, based on it, some modifications were made, shown in Figure 3 representing the vehicle in the roll plane in ADAMS/CAR. The model is represented by two masses connected by a suspension system. One of the masses is called sprung mass and it represents the body which carries the same characteristics of the vehicle while the other is called unsprung mass and it represents the axle with two wheels which have the same characteristics as real vehicle wheels.

After preparing the model and specifying input excitations of the wheels, the simulation was performed using the same test parameters used in the original model and in Simulink model which are cited in Table 1. We chose the resolution parameters in the solver: integrator: GSTIFF, Formulation: I3, Corrector: Modified, and at the end we read the simulation results in the postprocessing windows.

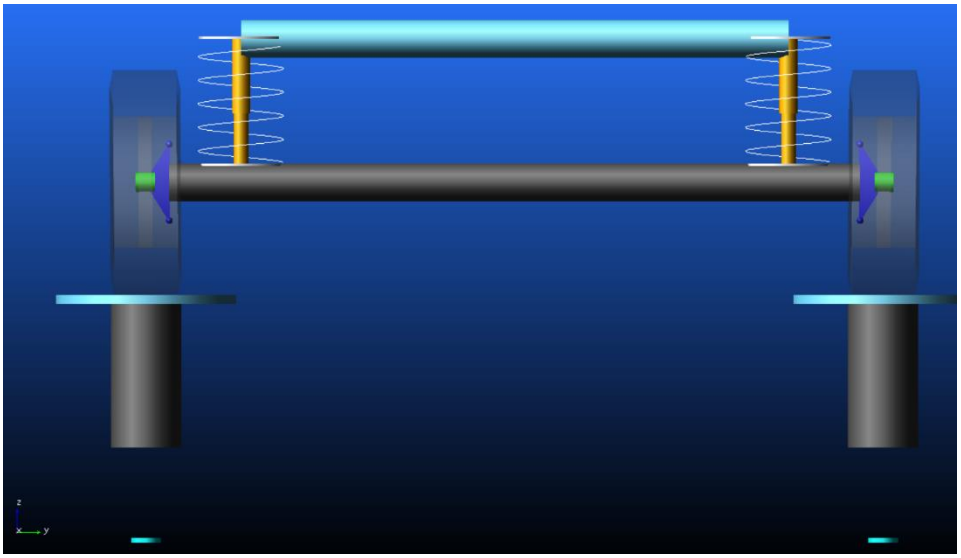

Figure 3 – Representation of the vehicle Defender 110 in the roll plan in Adams/CAR

Results and discussion

In this study, we focus much more on the performance characteristics mentioned above, in addition to vertical displacement, vertical velocity, and angular velocity of the vehicle in three scenarios:

- Sinusoidal profile;
- Obstacle test; and
- Double bump test.

Scenario 1: sinusoidal profile

The profile of (Baumal et al, 1998) is used and shown in Figure 4.

The profile of the road is of a sinusoidal shape with the amplitude $h_l = 0.102m$, $h_r = 2h_l$ and the wavelength $\lambda = 24.4\,m$.

The vehicle velocity v is assumed to be $24.4m/s$.

As a function of time, the road conditions are given by Eqs.(9) and (10):

$$z_{ol} = \frac{h}{2}(cos(\omega t) - 1) \qquad (9)$$

$$z_{or} = \boldsymbol{h}(cos(\omega t) - 1) \qquad (10)$$

where z_{0l}, z_{0r} are the road profiles in the left and right wheel, respectively, represented in Figure 4, while ω is the forcing frequency and is given by Eq.(11):

$$\omega = \frac{2\pi V}{\lambda} \tag{11}$$

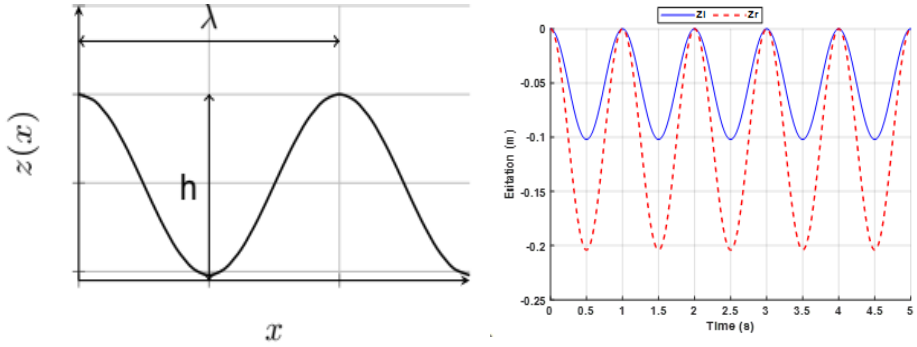

Figure 4 – Sinusoidal profile of the road (scenario1)

Figure 5 shows the comparison between the Adams and Simulink results of the sprung mass for scenario 1, while Table 2 shows the comparison of the performance characteristic values between the Adams and Simulink models for scenario 1.

Table 2 – Comparison of the performance characteristic values between Adams and Simulink for Scenario 1

Performance characteristic	$Max\lvert\ddot{z}_v\rvert$ $(^m/_{s^2})$	$\mathrm{Max}\lvert(z_a - z_{0l})\rvert$ (m)	$\mathrm{Max}\lvert(z_a - z_{0r})\rvert$ (m)	$Max\lvert z_v - z_a\rvert$ (m)	$Max\lvert\theta_v\rvert$ (rad)
Adams	6.96	0.083	0.058	0.113	0.101
Simulink	7.20	0.085	0.057	0.117	0.101
Deviation (%)	3.34	2.67	1.81	3.65	0

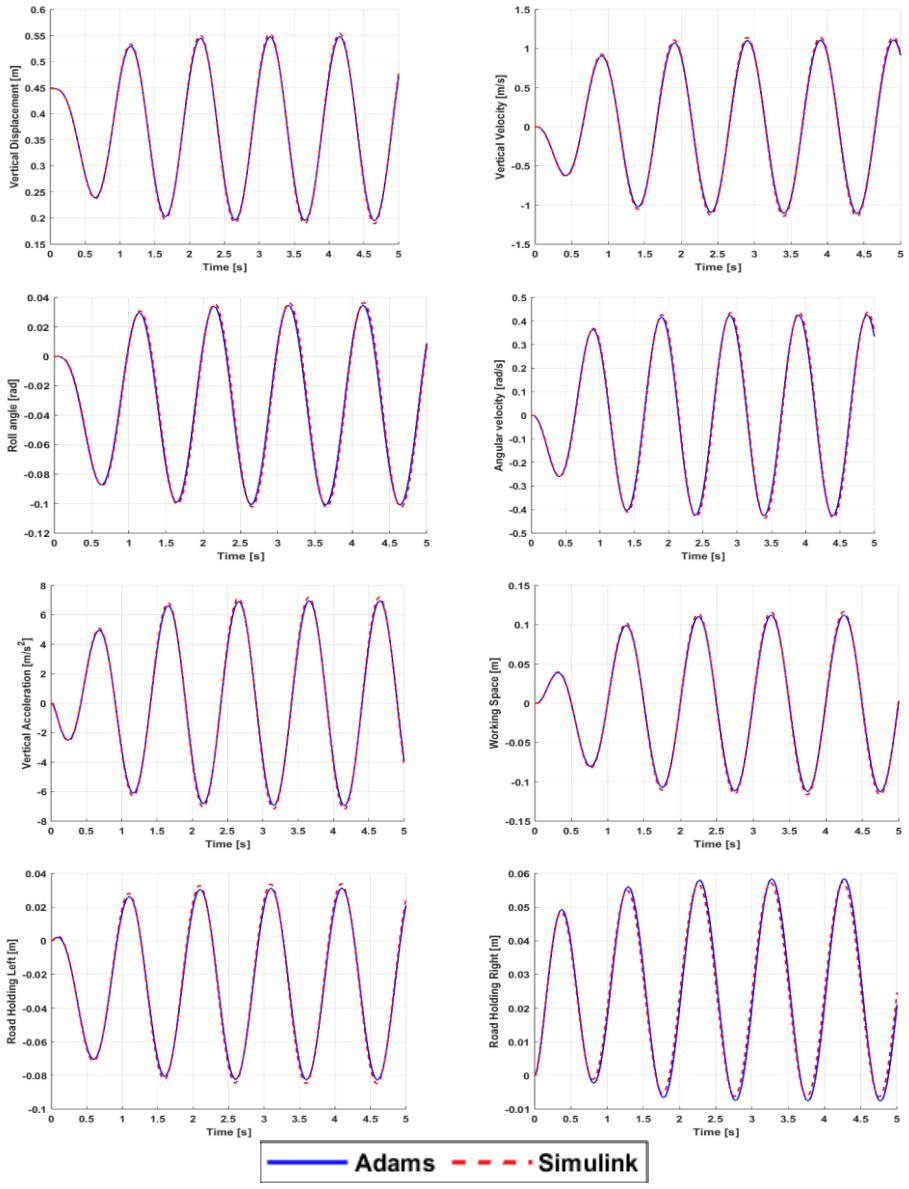

Figure 5 – Simulation results in Adams and Simulink of a sinusoidal road profile

Scenario 2: Obstacle test

In this test, the vehicle must cross a discrete obstacle with one wheel (left) and then its response is determined.

The same discrete obstacle with the same speed, $v = 8.33\ m/s$, was used as in (Khettou et al, 2016).

The characteristics of the discrete obstacle are presented in Figure 6:

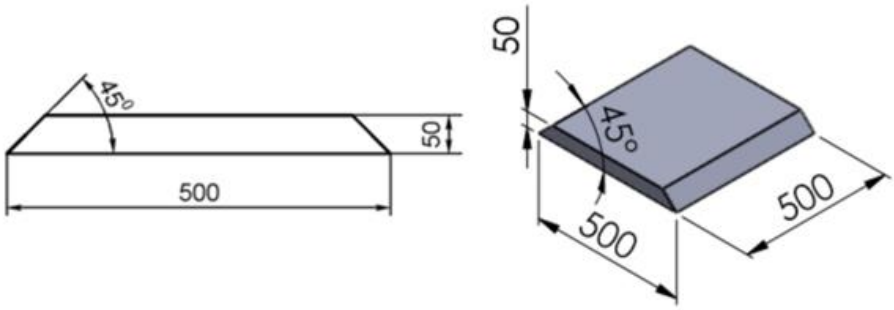

Figure 6 – Dimensions and the profile of the discrete obstacle (scenario 2)

Figure 7 shows the comparison between the Adams and Simulink results of the sprung mass for scenario 2, while Table 3 shows the comparison of the performance characteristic values between the Adams and Simulink models for scenario 2.

Table 3 – Comparison of the performance characteristic values between Adams and Simulink for Scenario 2

Performance characteristic	$Max\lvert\ddot{z}_v\rvert$ $(^m/_{s^2})$	$\mathrm{Max}\lvert(z_a - z_{0l})\rvert$ (m)	$\mathrm{Max}\lvert(z_a - z_{0r})\rvert$ (m)	$Max\lvert z_v - z_a\rvert$ (m)	$Max\lvert\theta_v\rvert$ (rad)
Adams	2.79	0.049	0.021	0.0172	0.011
Simulink	2.91	0.050	0.023	0.0191	0.0109
Deviation (%)	4.3	2.27	8.53	10.6	0.91

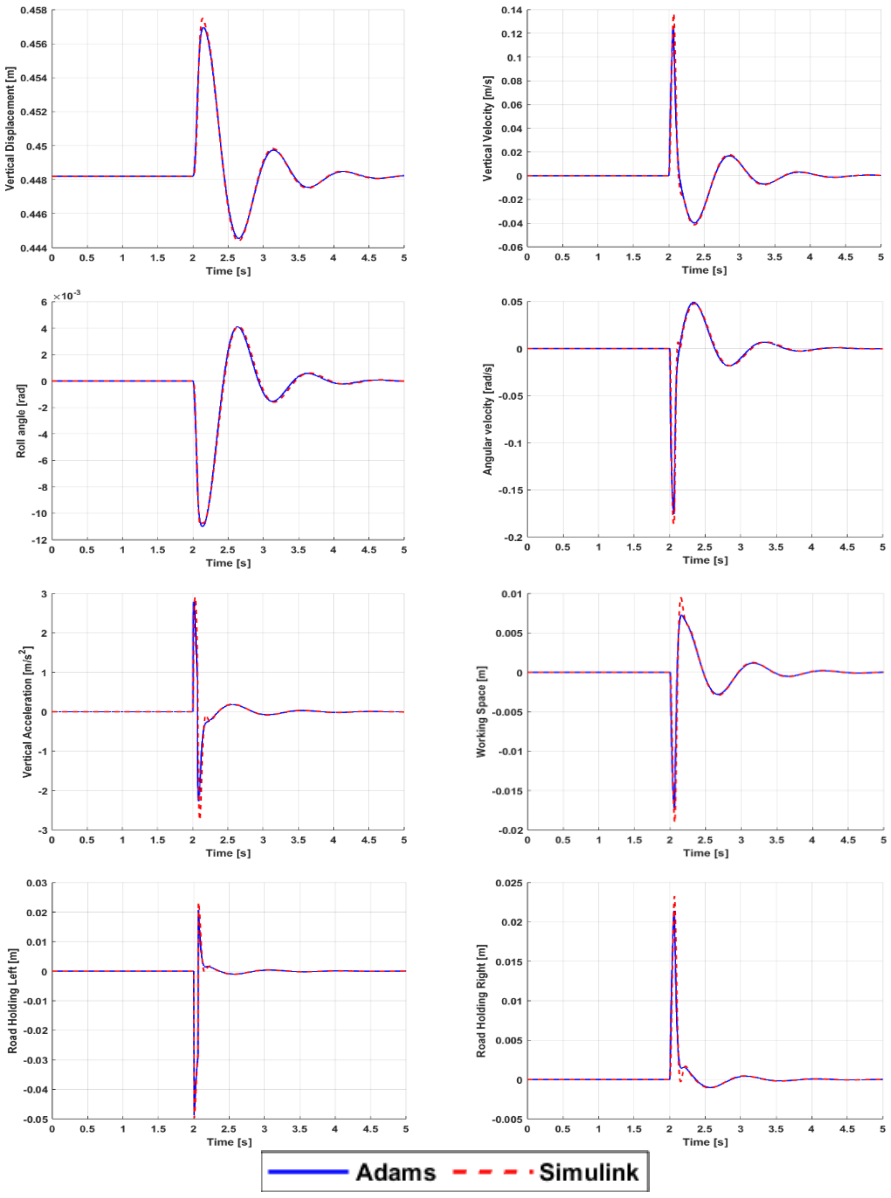

Figure 7 – Simulation results in Adams and Simulink of the discrete obstacle

Scenario 3: Double bump test

In this test, the vehicle is driven over a double bump shape shown in Figure 8. The wheel on the right-hand side is late in time t_0 in comparison

to the wheel on the left-hand side. The vehicle has a speed of $v = 8.33\ m/s$ while the bump width is $L = 0.5m$ and its amplitude is $h = 0.1m$.

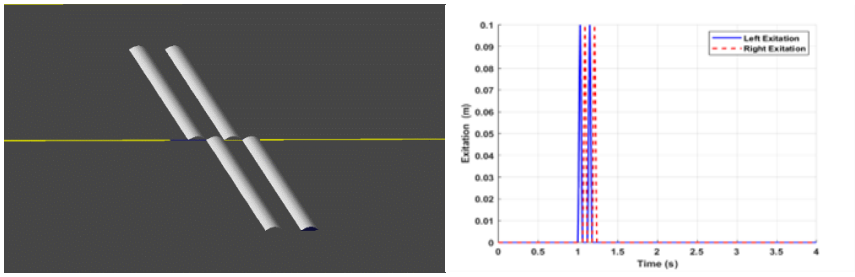

Figure 8 – The double bump profile scenario 3)

As a function of time, the road conditions are given by Eqs. (12) and (13):

$$z_{ol}(t) = \begin{cases} \frac{h}{2}\left(1 - cos\left(\omega(t - t_1)\right)\right) if\ t_1 < t < t_2 \\ \frac{h}{2}\left(1 - cos\left(\omega(t - t_3)\right)\right) if\ t_3 < t < t_4 \\ \mathbf{0} \qquad elsewhere \end{cases} \tag{12}$$

$$z_{or}(t) = \begin{cases} \frac{h}{2}\left(1 - cos\left(\omega(t - t_2)\right)\right) if\ t_2 < t < t_3 \\ \frac{h}{2}\left(1 - cos\left(\omega(t - t_4)\right)\right) if\ t_4 < t < t_5 \\ \mathbf{0} \qquad elsewhere \end{cases} \tag{13}$$

And the time steps are given in Eq.(14):

$$t_1 = 1s$$
$$T = \frac{L}{V}$$
$$t_i = t_1 + nT \quad n = 2, \dots, 5 \qquad t_0 = T \tag{14}$$

Figure 9 shows the comparison between the Adams and Simulink results of the sprung mass for scenario 3, while Table 4 shows the comparison of the performance characteristic values between the Adams and Simulink models for scenario 3.

Table 4 – Comparison of the performance characteristic values between Adams and Simulink for Scenario 3

Performance characteristic	$Max\lvert\ddot{Z}_v\rvert$ $(^m/_{s^2})$	$\mathrm{Max}\lvert(Z_a - Z_{0l})\rvert$ (m)	$\mathrm{Max}\lvert(Z_a - Z_{0r})\rvert$ (m)	$Max\lvert Z_v - Z_a\rvert$ (m)	$Max\lvert\theta_v\rvert$ (rad)
Adams	5.34	0.086	0.077	0.024	$9.62\ 10^{-3}$
Simulink	5.21	0.092	0.077	0.027	$1.05\ 10^{-2}$
Deviation (%)	2.43	7.37	0	12.5	9.14

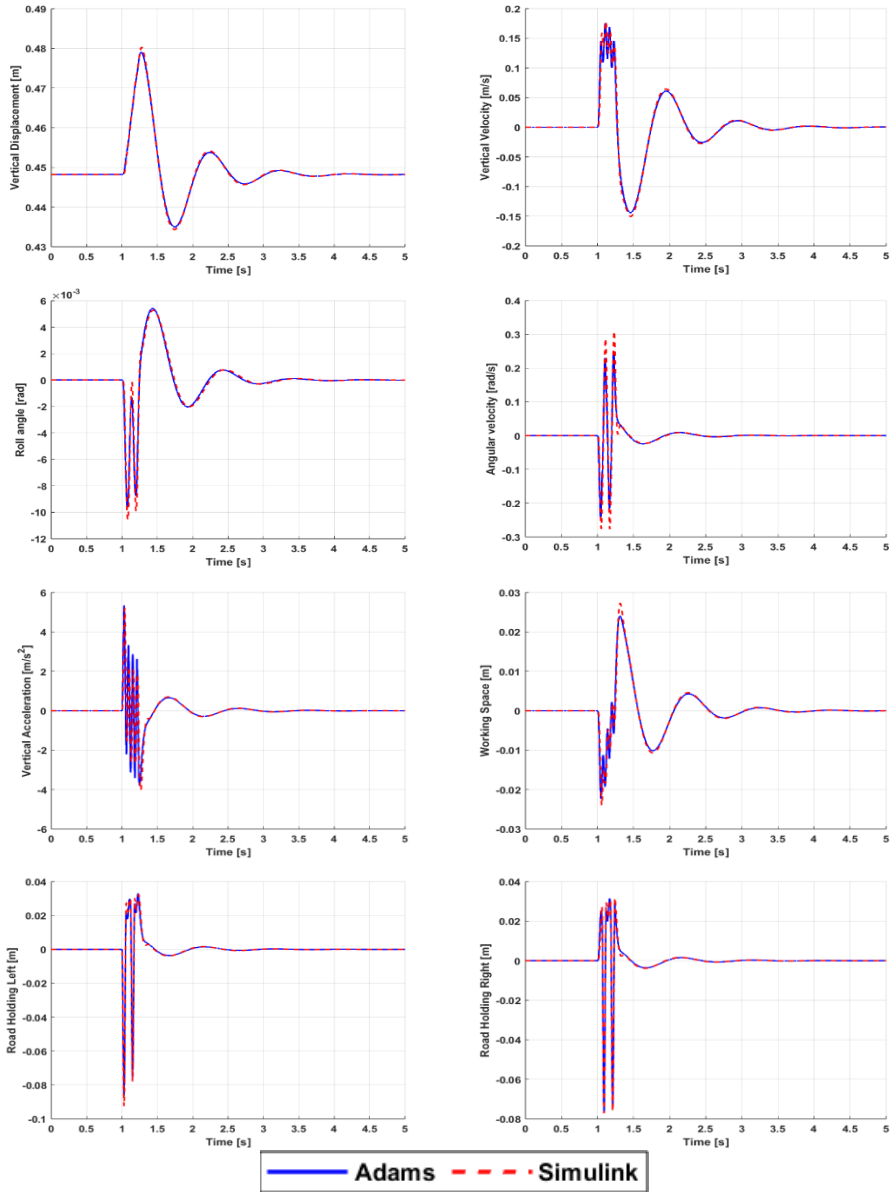

Figure 9 – Simulation results in Adams and Simulink of the double bump profile

Conclusion

In this paper, we have presented the Simulink model of the half vehicle of the Defender 110 and performed its validation with the ADAMS/CAR model for three scenarios. After the detailed analyses, we noticed that the simulation results obtained by Simulink are in good agreement with the simulation results of ADAMS. The extreme values of Simulink are greater than those of Adams which can be explained by the fact that the modeling in Adams is more detailed compared to the mathematical model. Also, another reason is that the numerical resolution method used in Adams is different from the methods used in Simulink, and the calculated percentage error between the two simulations for the three scenarios for all performance characteristics does not exceed 15%. Therefore, we can say that the model is validated. It can be, therefore, concluded that by using the validated model, the system can be further optimized to study the relationship and sensitivity of different design variables for optimal ride comfort, road holding, and suspension working space.

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Modelado matemático y simulación de un sistema de suspensión de medio vehículo en el plano de balanceo

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CAMPO: ingeniería mecánica
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: El estudio de la suspensión de vehículos es un desafío para investigadores en el campo de los vehículos sobre el impacto del sistema de suspensión en el rendimiento del vehículo, tales como la comodidad de marcha, el agarre en carretera y el funcionamiento del espacio. Este artículo presenta la simulación del vehículo Land Rover Defender 110 en el plano de balanceo (medio vehículo) en Simulink/MATLAB. Los resultados obtenidos se compararon con los resultados obtenidos en el paquete de software ADAMS/CAR del modelo de simulación Land Rover Defender 110 previamente validado experimentalmente. El vehículo Defender 110 cuenta con un sistema de suspensión dependiente en ambos ejes y un tipo de suspensión pasiva con cuatro grados de libertad (4 DOF).

Métodos: Las ecuaciones del sistema se pueden resolver matemáticamente con un esquema en Simulink/MATLAB mientras se realiza el modelado de medio vehículo en ADAMS/CAR.

Resultados: La comparación de las características del vehículo obtenidas por los dos métodos de simulación se realizó para tres escenarios diferentes, y se observó que existe una buena correlación entre ellos.

Conclusión: Se concluyó que el modelo de simulación del vehículo Defender 110 en Simulink/MATLAB está validado. El modelo validado se puede utilizar para realizar la optimización del sistema de suspensión en trabajos futuros.

Palabras claves: sistema de suspensión, Defender 110, ADAMS/CAR, Simulink/MATLAB.

Математическое моделирование системы подвески автомобиля в поперечной плоскости

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РУБРИКА ГРНТИ: 78.25.09 Военная автомобильная техника
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Изучение систем подвески транспортных средств является непростой задачей для исследователей, изучающих влияние систем подвески на характеристики автомобиля: удобство при вождении, устойчивость автомобиля, управляемость автомобиля и т. д. В данной статье представлено моделирование работы системы подвески автомобиля Land Rover Defender 110 в поперечной плоскости. Имитационная модель разработана в программном пакете Simulink/MATTLAB. Полученные результаты были сопоставлены с результатами ранее экспериментально проверенной имитационной модели Land Rover Defender 110. Автомобиль Land Rover Defender 110 имеет зависимую систему подвески на обеих осях и подвеску пассивного типа с четырьмя степенями свободы (4 DOF).

Методы: Уравнения системы могут быть решены математически по схеме в Simulink/MATLAB, а моделирование транспортных средств в поперечной плоскости выполняется в ADAMS/CAR.

Результаты: Сравнение характеристик автомобиля, полученных двумя методами моделирования, было выполнено по трем различным сценариям. Сравнительный анализ подтвердил удовлетворительное совпадение полученных результатов.

Выводы: На основании результатов исследования сделан вывод, что имитационная модель автомобиля Defender 110, разработанная в Simulink/MATLAB дает удовлетворительно точные результаты. Следовательно, можно считать, что верификация выполнена. Валидированная модель может быть использована в оптимизации системы подвески в будущей эксплуатации.

Ключевые слова: система подвески, Defender 110, ADAMS/CAR, Simulink/MATLAB.

Bemeddah, A. et al, Mathematical modeling and simulation of a half-vehicle suspension system in the roll plane, pp.192-208

Математичко моделовање и симулација система за ослањање возила у попречној равни

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ОБЛАСТ: машинство
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Проучавање система за ослањање возила представља изазов за истраживаче који сагледавају утицај система за ослањање на перформансе возила: удобност вожње, стабилност и управљивост возила, итд. У раду је представљена симулација рада система за ослањање возила у попречној равни, за возило Land Rover Defender 110, која је развијена у програмском пакету Simulink/MATLAB. Добијени резултати поређени су са резултатима добијеним у програмском пакету ADAMS/CAR за симулациони модел возила Land Rover Defender 110 који је верификован са експерименталним резулатима. Возило Land Rover Defender 110 има систем зависног ослањања на обе осовине и пасивни тип ослањања са четири степена слободе (4 DOF).

Методе: Једначине система могу се математички решити шемом у Simulink/MATLAB-у, а моделирање возила у попречној равни урађено је у пакету ADAMS/CAR.

Резултати: Поређење перформанси возила добијених помоћу две методе симулација извршено је за три различита сценарија; уочено је да постоји задовољавајуће подударање добијених резултата.

Закључак: Закључено је да симулациони модел возила Defender 110 у Simulink/MATLAB-у даје задовољавајуће тачне резултате, чиме се може сматрати да је извршена његова верификација . Верификовани симулациони модел може се користити са великом тачношћу за оптимизацију система за ослањање у будућем раду.

Кључне речи: систем за ослањање, Defender 110, ADAMS/CAR, Simulink/MATLAB.

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Numerical analysis of the penetration process of a 30mm armor-piercing fin-stabilized discarding sabot projectile

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FIELD: mechanical engineering, materials
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: In recent times, with the tendency to develop new types of armor-piercing ammunition, constant investments in the development of new types of armored obstacles is necessary. Obstacles made of high-alloy steel plates are still the best form of protection against larger caliber ammunition. There are a number of factors to consider when selecting an alloy, including the weight, dimensions, intended use, desired ballistic performance, and costs. According to that, a numerical analysis of penetration of a 30mm armor-piercing fin-stabilized discarding sabot projectile into the steel alloy Weldox 460 plates of different thicknesses at a distance of 1000m with a velocity of 1300m/s is presented in this paper.

Methods: The stresses and deformations of the penetration effect were calculated through numerical analysis and finite element modeling. To specify material characteristics, the Johnson-Cook material model and the

fracture of materials model have been utilized. In order to define models and carry out numerical calculations, the software packages FEMAP and LS Dyna have been used in this paper.

Results: For a numerical analysis of the penetration process of this projectile type against armor obstacle, four different armor plate thicknesses are calculated: 10mm, 50mm, 100mm, and 110mm. For each of them, the results are shown in a form of stress and displacement, so that the interaction phenomena between the sub-projectile and the armor plate can be described.

Conclusion: Modeling the impact on armor-piercing obstacles is extremely difficult, time-consuming, and complex, and the resulting models very successfully (or with some deviation) approximate the real problem of projectile penetration. One of the most effective methods for solving problems of this kind and others of a similar nature in recent times is the finite element method analysis. The material and the target dimensions, as well as the ballistic parameters and the material of the projectile have the biggest influence on projectile penetration. The target's resistance to penetration increases when all input parameters are maintained at the same level and its thickness is increased, and vice versa.

Keywords: armor, projectile, penetration, Weldox 460, numerical analysis.

Introduction

Armor-piercing ammunition is designed to penetrate high-strength obstacles. In modern times, in addition to improving the geometric and ballistic characteristics of the projectile body, high efforts are invested in the development of new types of ammunition and new types of materials.

The projectile shape has the biggest influence on velocity and by optimizing its geometry, it is possible to decrease aerodynamic drag and to keep a high level of projectile velocity until it reaches the target.

One of the most effective types of large-caliber armor-piercing ammunition is sub-caliber ammunition which is mostly used for tank cannons. Recently, there has been a development of this type of ammunition for medium caliber cannons, e.g., 30mm.

This type of ammunition is made of tungsten heavy metal alloy (WHA). Due to the specific characteristics of the heavy metal alloy, during the process of penetration into the armor, certain phenomena occur, not characteristic of the classic armor-piercing ammunition, which will be discussed in more detail later. The high-density tungsten alloy increases weight of sub-projectile more than 2.2 times compared to steel and this increases the total kinetic energy of the moving projectile.

The mechanical properties of tungsten heavy metal alloy are adjustable via changes to the composition, sintering cycle, or post-sintering treatment. Increased strength, with a loss of ductility, comes with post-sintering deformation and aging treatments (German, 2022).

According to all mentioned, a numerical simulation of the penetration process of a 30mm caliber armor-piercing fin-stabilized discarding sabot projectile with a heavy metal alloy core into plates of various thicknesses made of Weldox 460 alloy is performed in this paper. The sub-projectile simplified drawing used in this analysis is shown in Figure 1.

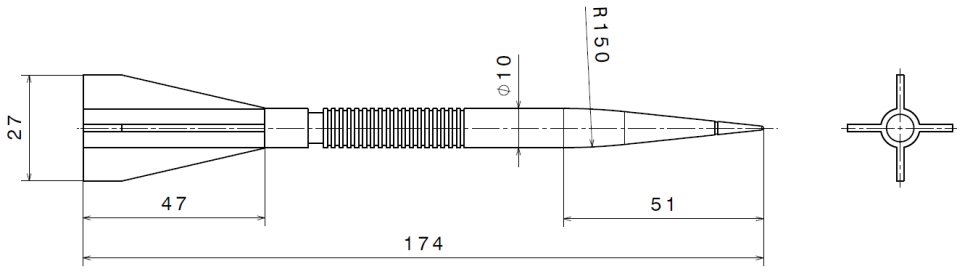

Figure 1 – 30mm sub-projectile, drawing

The armor-piercing fin-stabilized discarding sabot (APFSDS) projectile is made of several subparts: core, fins, carrier, plastic cap, and driving band. If it has a tracer implemented, it is labelled APFSDS-T.

Due to the specificity of the sub-caliber design compared to other types of projectiles, it should be emphasized that the effect on the target is achieved only by the core made of heavy metal and a negligibly small part of the fins whose role is to ensure the stability of the core on the trajectory from the muzzle to the drop point. The other parts (carrier, plastic cap and driving band) have the function of guiding the projectile in the barrel, and after that they are separated from the rest. This is ensured by the construction. In Figure 2, a projectile with a cartridge case is shown in the cross section view and it represent one design solution of this special ammunition type (Sturgeon's House, 2018).

The sub-projectile body is made of two materials:

- Heavy metal alloy Wi-Ni-Fe – core, and
- Aluminium alloy ASTM 7075-T6 – fins.

For the analysis of the penetration effect, the plate made of armor steel Weldox 460 is used. A 3D model of the sub-projectile design used in analysis is shown in Figure 3.

Figure 2 –30mm x 173 cartridge, APFSDS-T

Figure 3 – 30mm sub-projectile, APFSDS, 3D model

The projectile ballistic characteristics are presented in Table 1.

Table 1 – Ballistic characteristics of the 30mm projectile

Caliber	d x l	30 x 173	mm
Projectile weight	m	0.23	kg
Sub-projectile weight	m	0.15	kg
Sub-projectile muzzle velocity	V_0	1430	m/s
Sub-projectile velocity at a distance of 1000 m	V_{1000}	1300	m/s

Material characteristics

The penetration represents one of the typical examples of explicit nonlinear analysis, which is characterized by large deformations, deformation rates, as well as material failure.

In order to define the material properties of a high-strength steel target and a heavy metal alloy sub-projectile, it is necessary to define an appropriate material model that will describe the properties and the behavior of the material.

Pantović et al (2023) analyzed the penetration ability of a 30mm armor-piercing projectile and defined Johnson-Cook's constitutive material model (Wang & Shi, 2013; Liu et al, 2012) for metals characterized by high stresses, high strain rates and high temperatures. Each of the phenomena

(strain hardening, strain hardening rate and thermal softening) is represented by an independent factor. To determine the pressure in solids exposed to high pressure for a short period of time, the Mie-Grüneisen equation of state is defined which represents the relationship between pressure and volume of a solid at a given temperature (Heuzé, 2012; Wilkins, 1999).

Table 2 defines the Johnson-Cook parameters for various materials used in the numerical simulation of a 30mm APFSDS projectile penetration, and Table 3 provides the temperature parameters. The damage parameters for the same materials are defined in Table 4. These parameters are defining the Johnson-Cook material model used in numerical simulations (Sun et al, 2021; Flores-Johnson et al, 2014; Rezasefat et al, 2018).

Table 2 – Johnson-Cook parameters for different materials

Material	A [MPa]	B [MPa]	n	C	m
Wi-Ni-Fe alloy	1506	177	0.12	0.016	1.0
ASTM 7075-T6	520	477	0.52	0.001	1.0
Weldox 460	490	807	0.73	0.0114	0.94

Table 3 – Thermal characteristics for different materials

Material	T_{melt} [K]	c_p [J/kgK]
Wi-Ni-Fe alloy	1723	250
ASTM 7075-T6	893	910
Weldox 460	1800	452

Table 4 – Damage parameters for different materials

Material	D_1	D_2	D_3	D_4	D_5
Wi-Ni-Fe alloy	0	0.33	-1.5	0	0
ASTM 7075-T6	0.096	0.049	-3.465	0.016	1.1
Weldox 460	0.0705	1.732	-0.54	-0.015	0

Table 5 defines the parameters of the equation of state for different materials used in the numerical simulation.

Table 5 – Equation of the state parameters for different materials

Material	C_0 [mm/s]	s	Γ_0
Wi-Ni-Fe alloy	$4.029 \cdot 10^6$	1.237	1.54
ASTM 7075-T6	$5.452 \cdot 10^6$	1.259	2.14
Weldox 460	$3.574 \cdot 10^6$	1.920	1.69

Finite element modeling

For the purpose of defining the geometry of the projectile and plate, due to the existence of two symmetry planes, a quarter model is created using the finite element method. By simplifying the model, it is possible to save time and obtain calculation results many times faster. In order to obtain more accurate calculation results, the projectile and the plate model are created using a 3D element hexa.

The sub-projectile and plate models are shown in Figures 4, 5 and 6. The sub-projectile geometry is modeled using 162000 nodes and 122000 elements, while the 10mm thick plate is modeled using 108000 nodes and 96000 elements. The average size of the elements is 0.5mm.

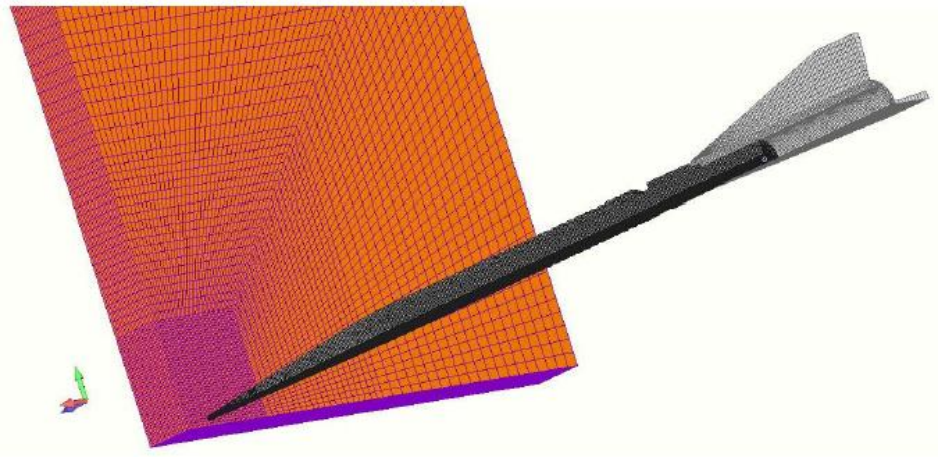

Figure 4 – FEM model of the sub-projectile and the plate, isometry

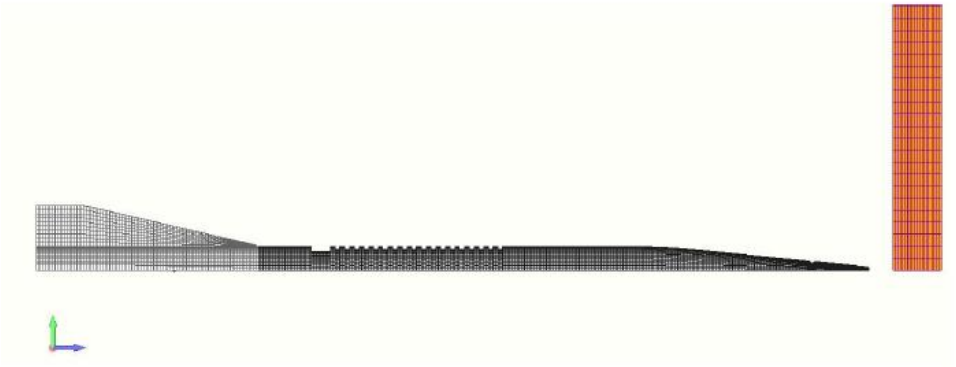

Figure 5 – FEM model of the sub-projectile and the plate, side view

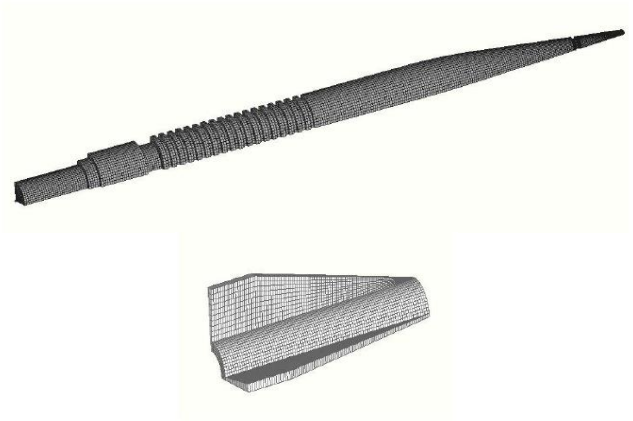

Figure 6 – FEM model of the sub-projectile elements

Results and discussion

The chapter on the results presents the numerical simulation output results for different cases. As it is mentioned, four different plate thicknesses are analysed: 10mm, 50mm, 100mm, and 110mm.

The 30mm APFSDS projectile muzzle velocity is 1430m/s, but due to the aerodynamic resistance that occurs during the projectile motion until it reaches the target, it loses some amount of its kinetic energy. At a distance of 1000m from the barrel muzzle, the sub-projectile has a velocity of 1300m/s and that is the value which is used as an impact velocity in the performed numerical simulations.

It is determined that the penetration ability of the projectile decreases with the increase of the target plate thickness, and vice versa.

Case 1 – 10mm thick plate

The Von Misses equivalent stress and penetration effect of the armor plate Weldox 460 with thickness of 10mm are shown in Figures 7-12.

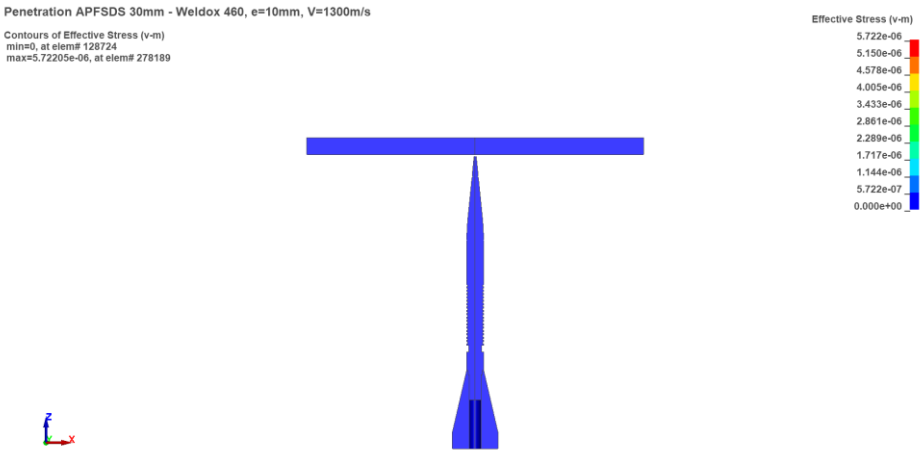

Figure 7 – Von Misses equivalent stress, step 1 – case 1

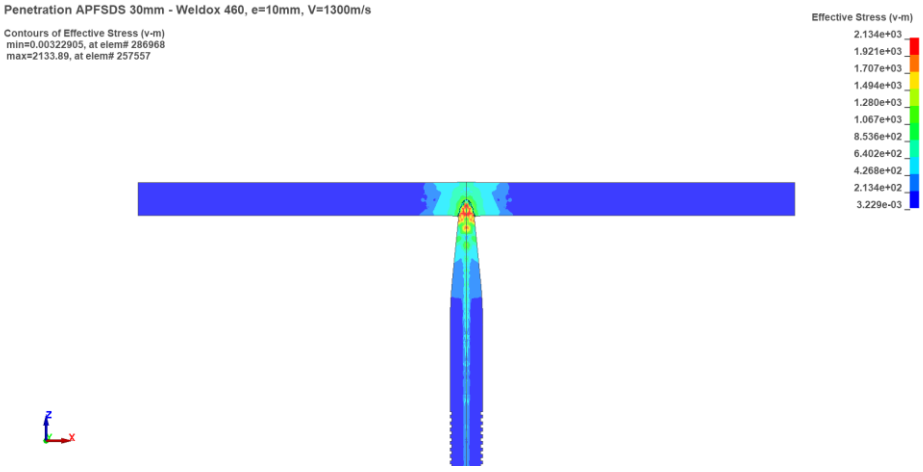

Figure 8 – Von Misses equivalent stress, step 2 – case 1

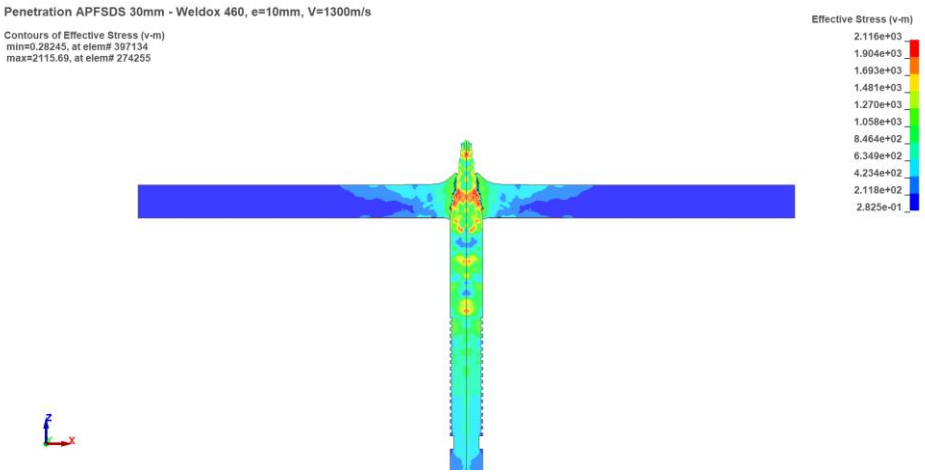

Figure 9 – Von Misses equivalent stress, step 3 – case 1

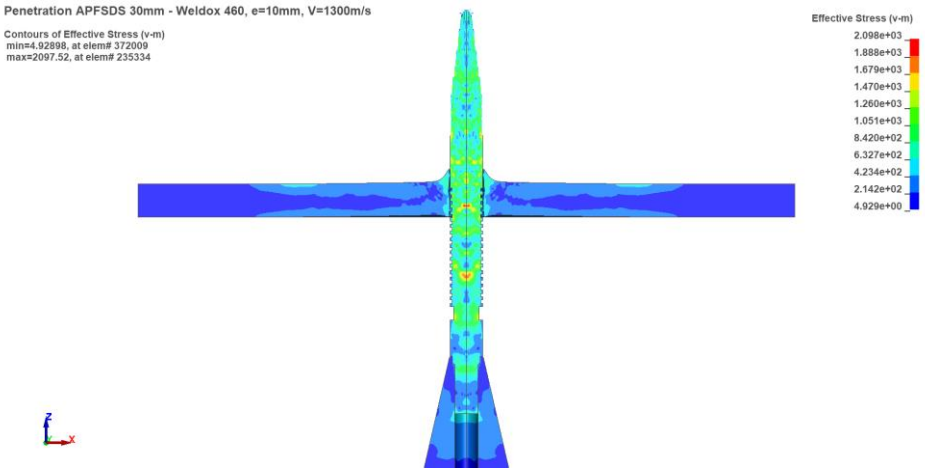

Figure 10 – Von Misses equivalent stress, step 4 – case 1

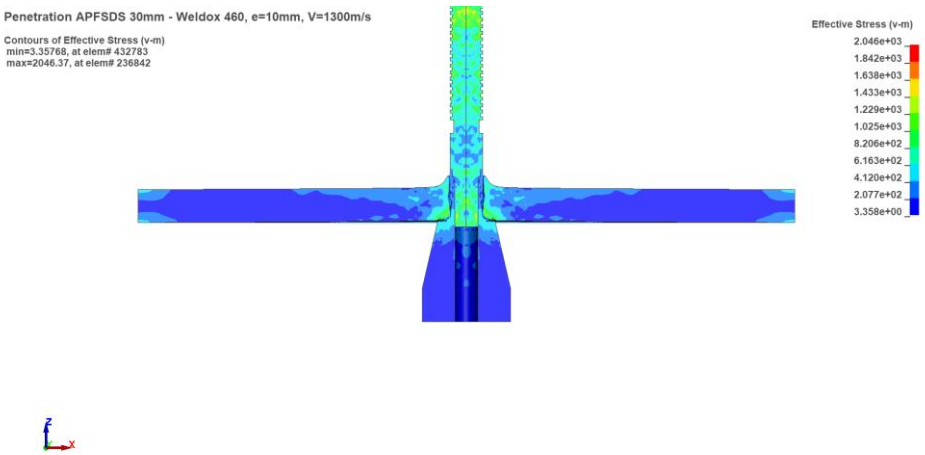

Figure 11 – Von Misses equivalent stress, step 5 – case 1

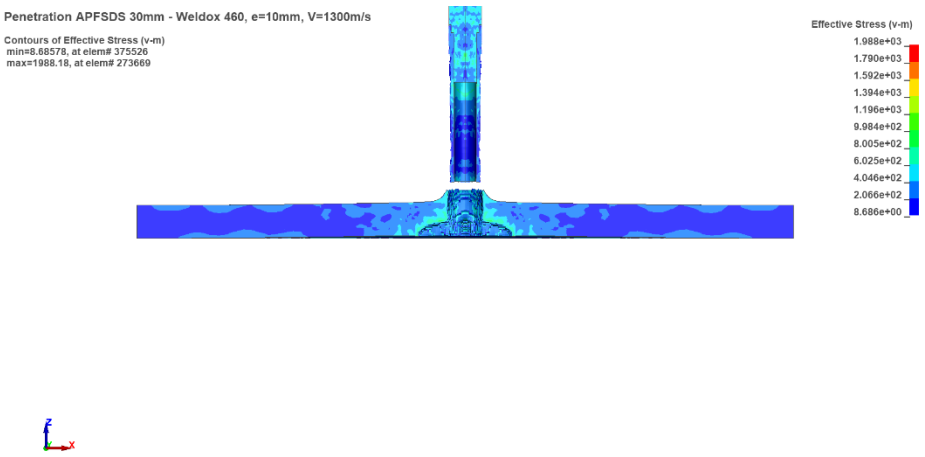

Figure 12 – Von Misses equivalent stress, step 6 – case 1

As the presented results show, the sub-projectile has enough kinetic energy to achieve the full penetration effect into the 10mm thick plate. The core of the projectile retains its structure, while the main part of the fins is welded to the structure of the plate and the cylindrical part of the fins fragments behind the plate due to stress relief.

The sub-projectile velocity is shown in Figure 13 and it represents the velocity value from the moment of leaving the barrel, until the moment it penetrates through the target plate. As it can be seen, the sub-projectile velocity after penetration is still high and has the value of 1280m/s.

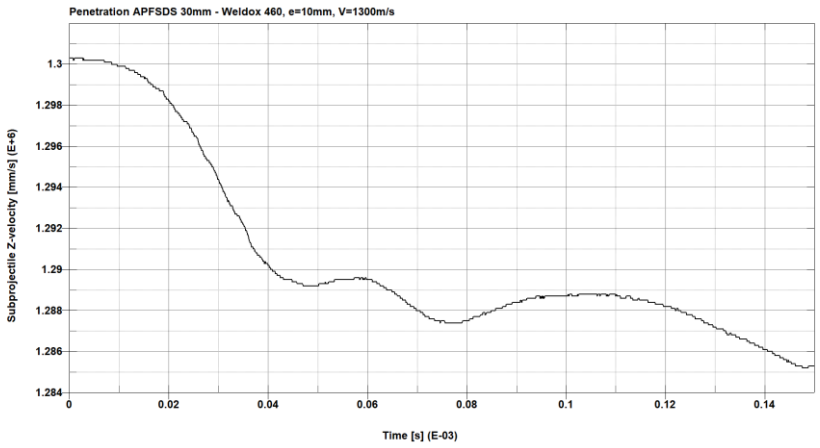

Figure 13 – Projectile velocity as a function of time – case 1

The plate displacement is shown in Figure 14. The first movement of target plate occurs after 0.1ms, and the maximum displacement is 0.3mm.

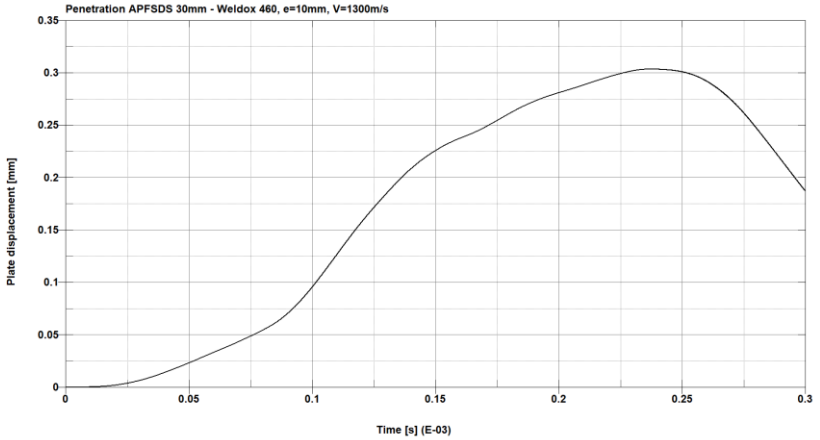

Figure 14 – Plate displacement in function of time – case 1

Case 2 – 50mm thick plate

The Von Misses equivalent stress and the penetration effect of the armor plate Weldox 460 with a thickness of 50mm are shown in Figures 15-20.

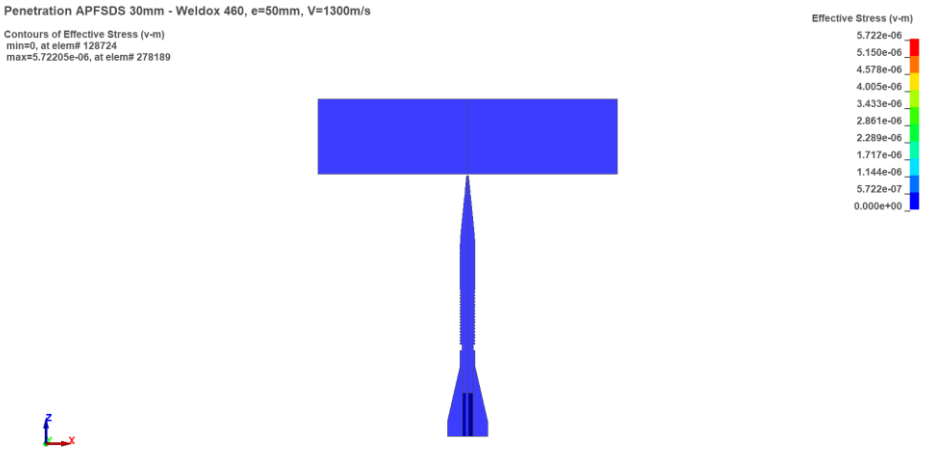

Figure 15 – Von Misses equivalent stress, step 1 – case 2

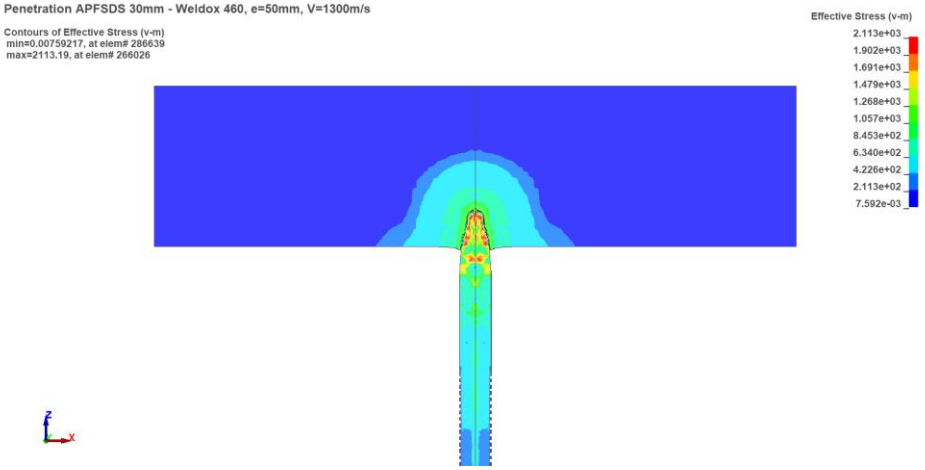

Figure 16 – Von Misses equivalent stress, step 2 – case 2

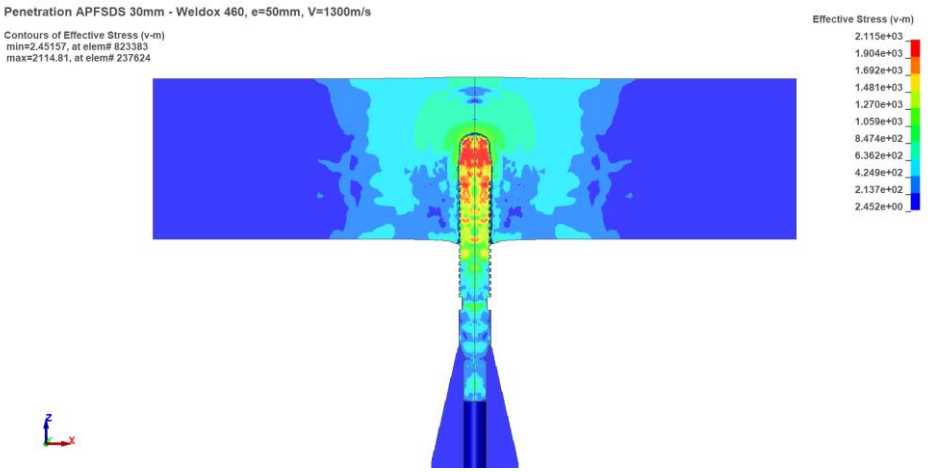

Figure 17 – Von Misses equivalent stress, step 3 – case 2

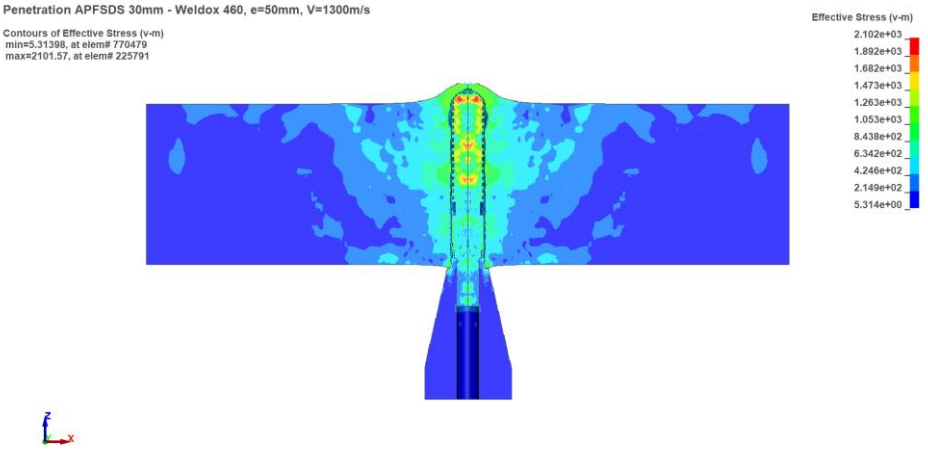

Figure 18 – Von Misses equivalent stress, step 4 – case 2

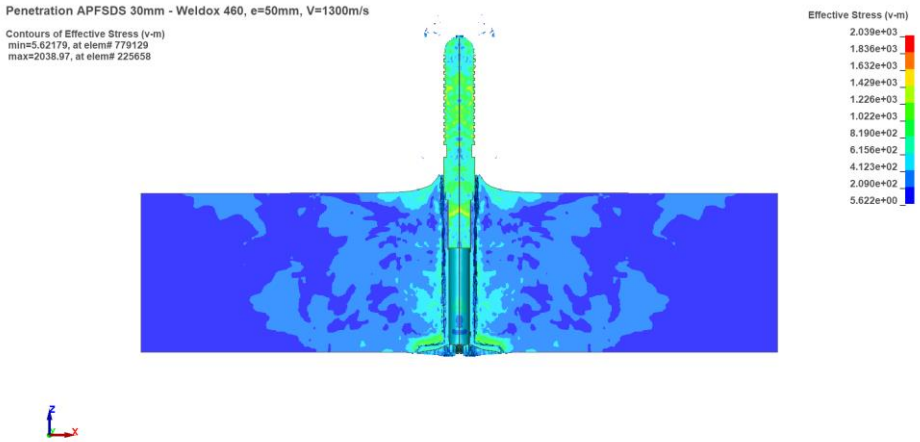

Figure 19 – Von Misses equivalent stress, step 5 – case 2

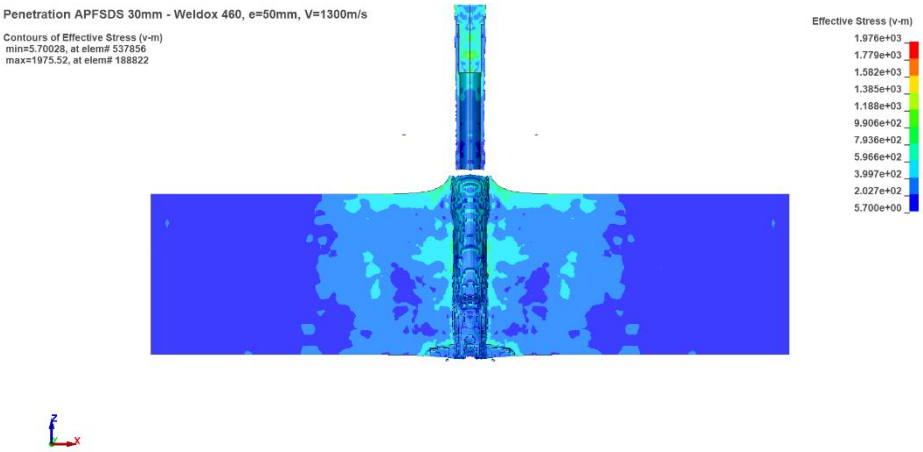

Figure 20 – Von Misses equivalent stress, step 6 – case 2

As the results show, the sub-projectile still has sufficient kinetic energy to achieve a full penetration effect in the plate of a thickness of 50mm. It is interesting to mention that compared to the standard armor-piercing (AP) ammunition type, the APFSDS projectile has a different penetration effect. This effect will be described in more detail later in the paper. Figure 21 shows the sub-projectile velocity which is still on high level after penetrating 50mm of steel and it has a value of 1210m/s.

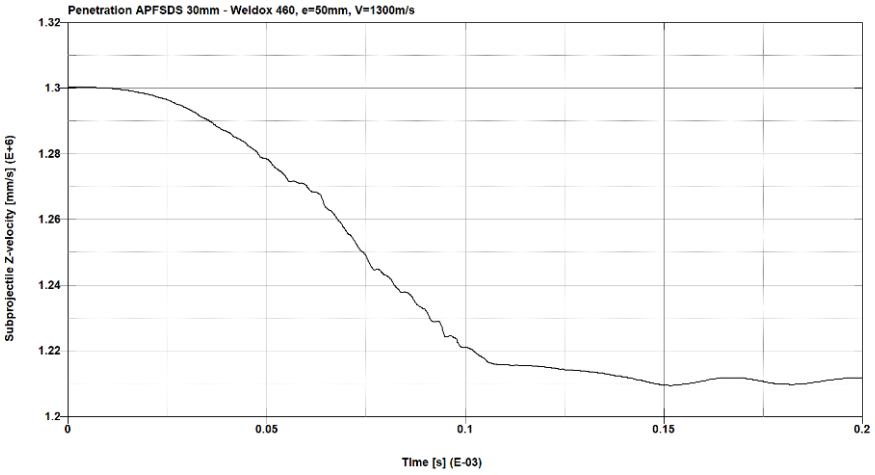

Figure 21 – Projectile velocity as a function of time – case 2

The plate displacement is shown in Figure 22. The maximum plate displacement is low, 0.06mm. It is lower than in case 1 because the plate thickness in the case 2 is much higher.

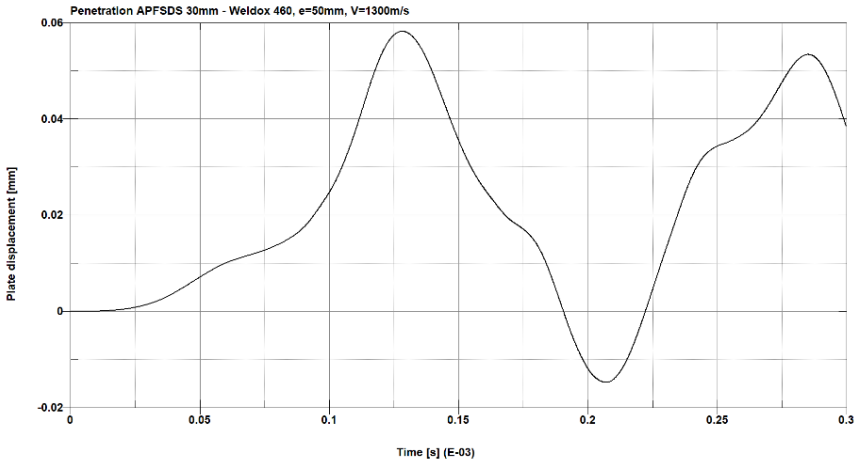

Figure 22 – Plate displacement as a function of time – case 2

Case 3 – 100mm thick plate

The Von Misses equivalent stress and the penetration effect of the armor plate Weldox 460 with a thickness of 100mm are shown in Figures 23-28.

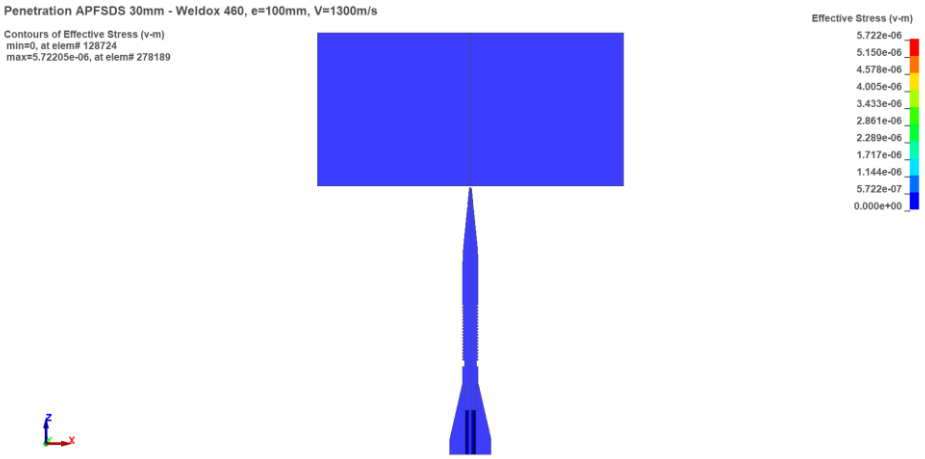

Figure 23 – Von Misses equivalent stress, step 1 – case 3

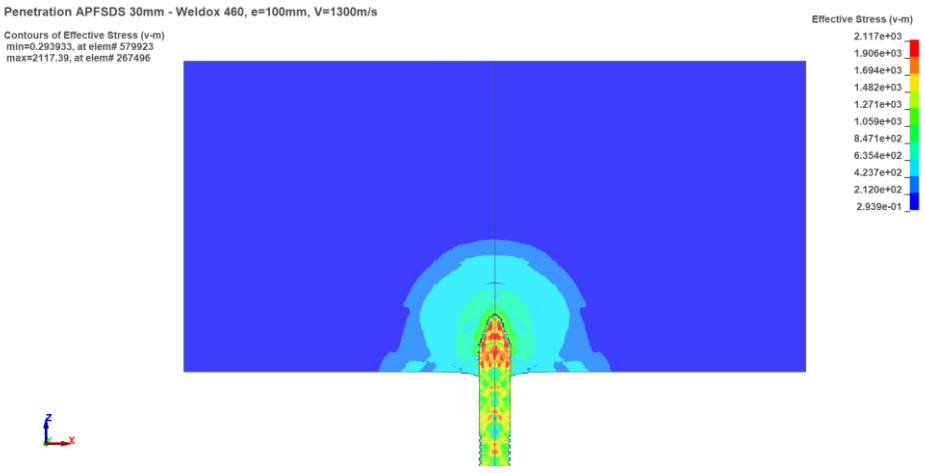

Figure 24 – Von Misses equivalent stress, step 2 – case 3

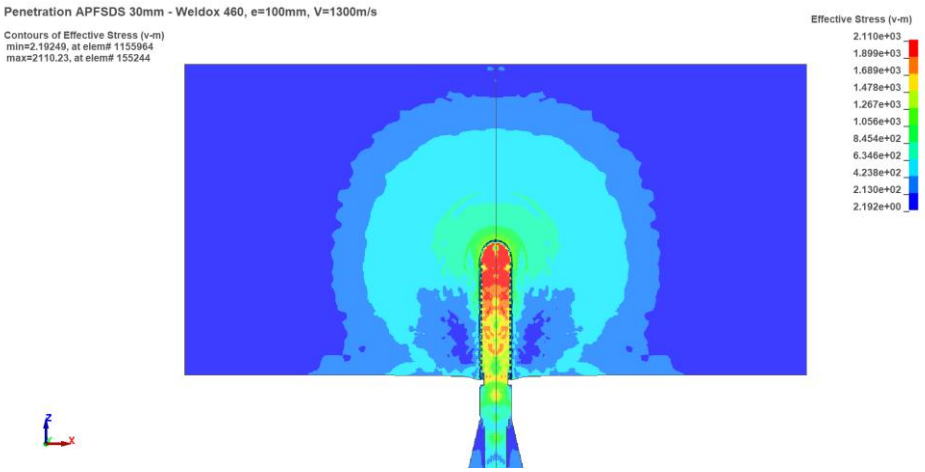

Figure 25 – Von Misses equivalent stress, step 3 – case 3

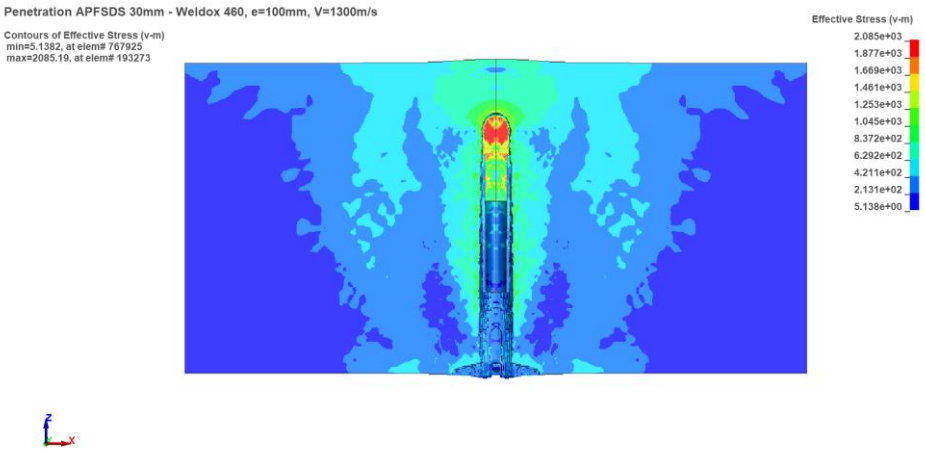

Figure 26 – Von Misses equivalent stress, step 4 – case 3

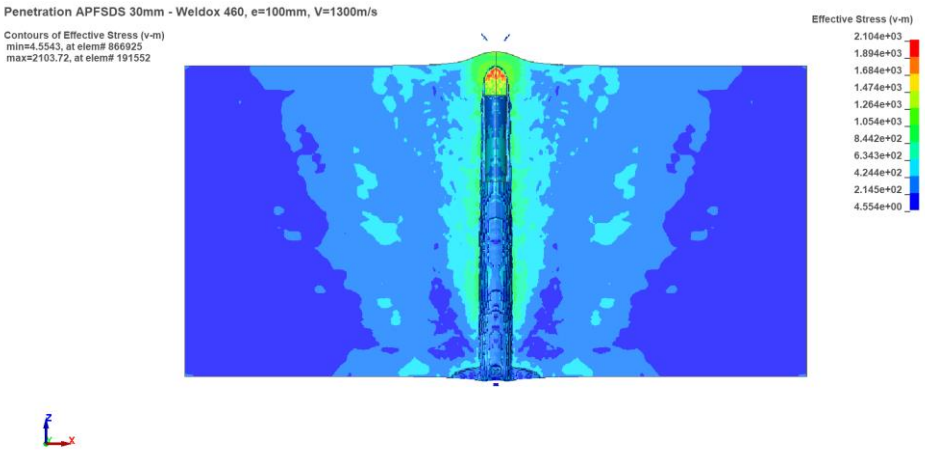

Figure 27 – Von Misses equivalent stress, step 5 – case 3

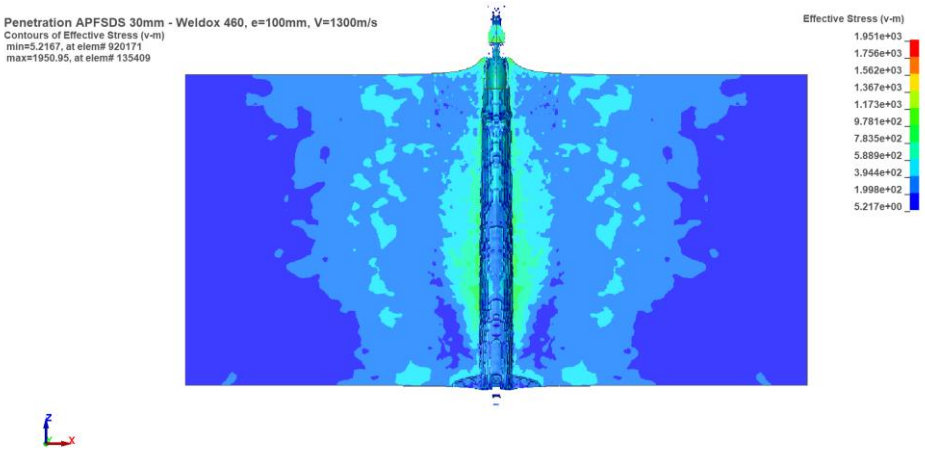

Figure 28 – Von Misses equivalent stress, step 6 – case 3

As the results show, the sub-projectile has a sufficiently high kinetic energy to achieve the full penetration effect in the 100mm thick plate. Because it loses too much of energy during penetration, its length behind the plate is short and therefore does not have a large number of fragments behind the plate (Figure 28). That reduces its effect behind the target, but in any case, it still has a high penetration ability.

The sub-projectile velocity is shown in Figure 29. The fragments velocity after penetration is around 470m/s.

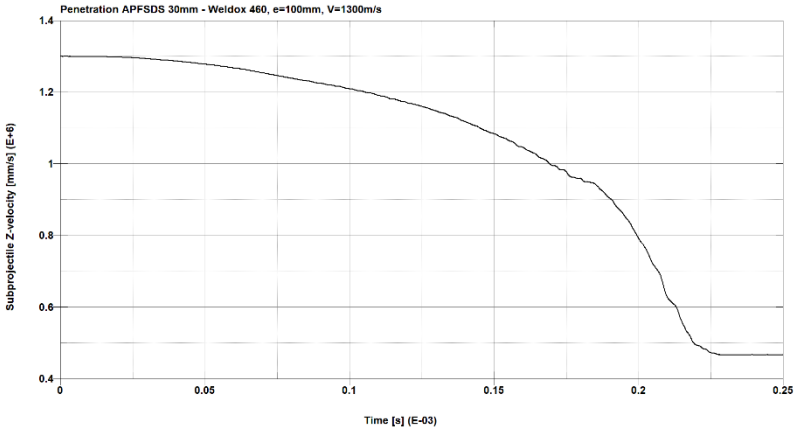

Figure 29 – Projectile velocity as a function of time – case 3

The plate displacement as a function of time is shown in Figure 30. The maximum plate displacement is 0.04mm and the first plate movement occurs after 0.05ms.

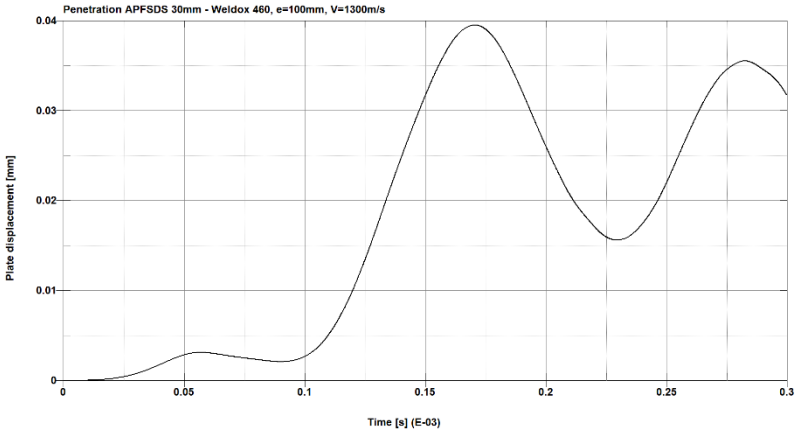

Figure 30 – Plate displacement as a function of time – case 3

Case 4 – 110mm thick plate

The Von Misses equivalent stress and the penetration effect of the armor plate Weldox 460 with a thickness of 110mm are shown in Figures 31-36.

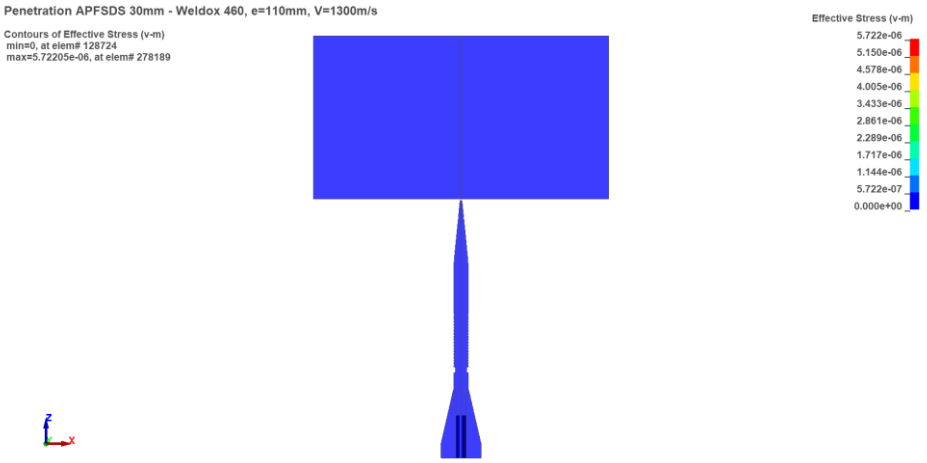

Figure 31 – Von Misses equivalent stress, step 1 – case 4

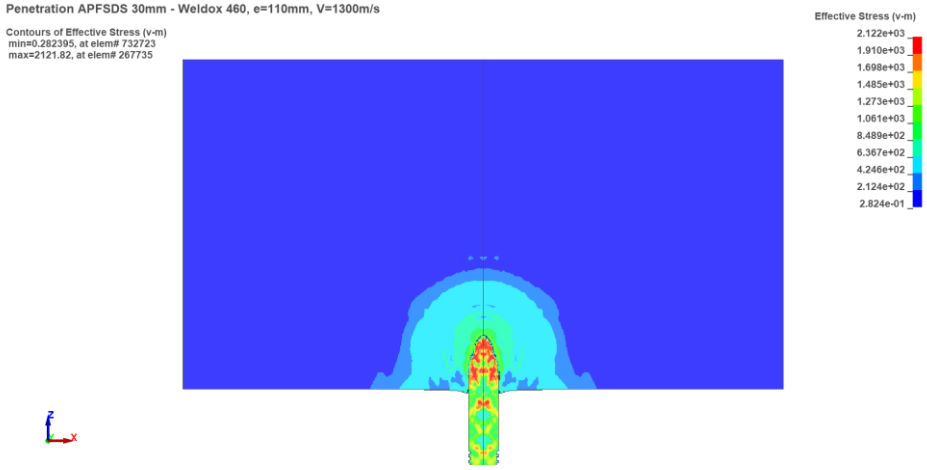

Figure 32 – Von Misses equivalent stress, step 2 – case 4

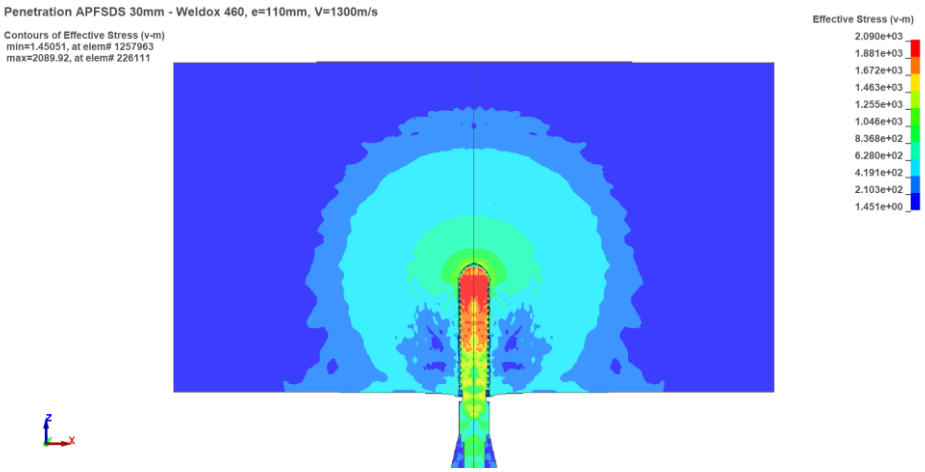

Figure 33 – Von Misses equivalent stress, step 3 – case 4

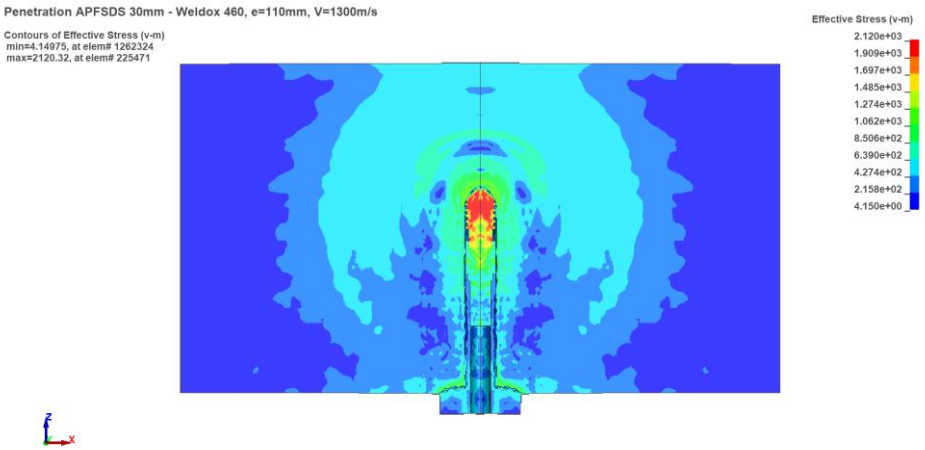

Figure 34 – Von Misses equivalent stress, step 4 – case 4

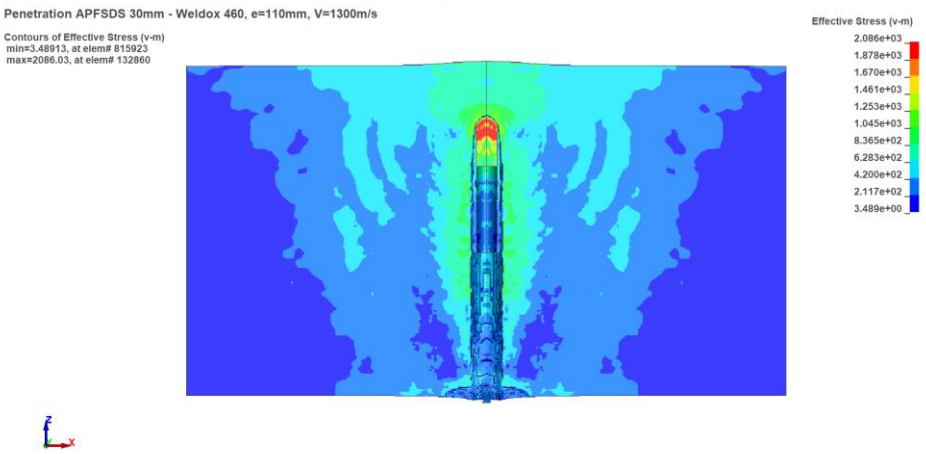

Figure 35 – Von Misses equivalent stress, step 5 – case 4

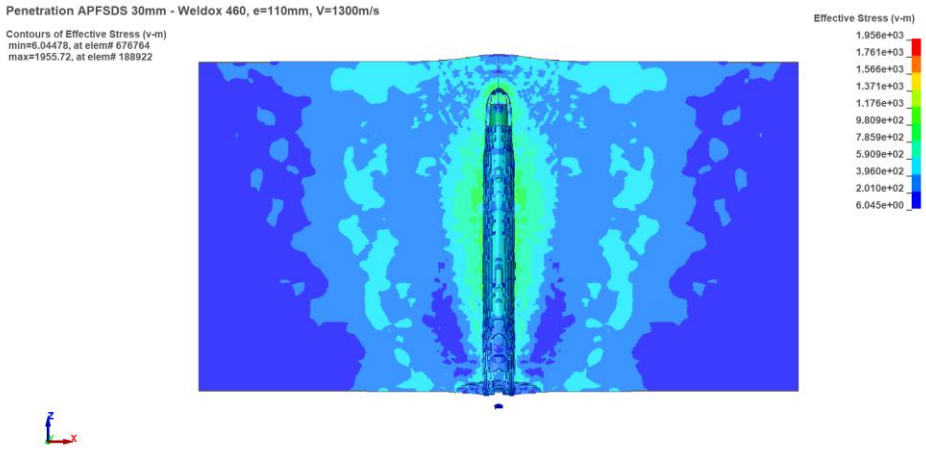

Figure 36 – Von Misses equivalent stress, step 6 – case 4

As the results show, in this case the sub-projectile does not have enough kinetic energy to achieve full penetration into the 110mm thick plate. After the impact with the plate, the sub-projectile core penetrates to the point it loses its length, weight and velocity and its kinetic energy. After that, the remained particles get jammed into the armor steel plate structure and behind the plate there are no fragments.

In Figure 37, the sub-projectile velocity is shown from the moment the projectile leaves the barrel until the moment it jams into the plate after 0.23ms.

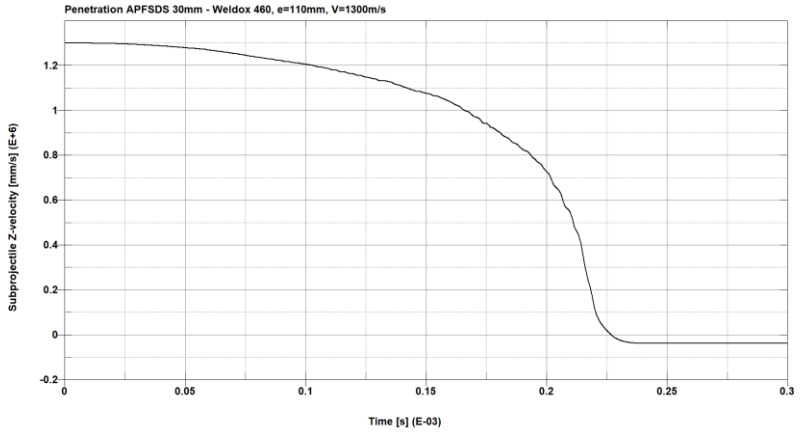

Figure 37 – Projectile velocity as a function of time – case 4

The plate displacement is shown in Figure 38. The maximum plate displacement is 0.043mm.

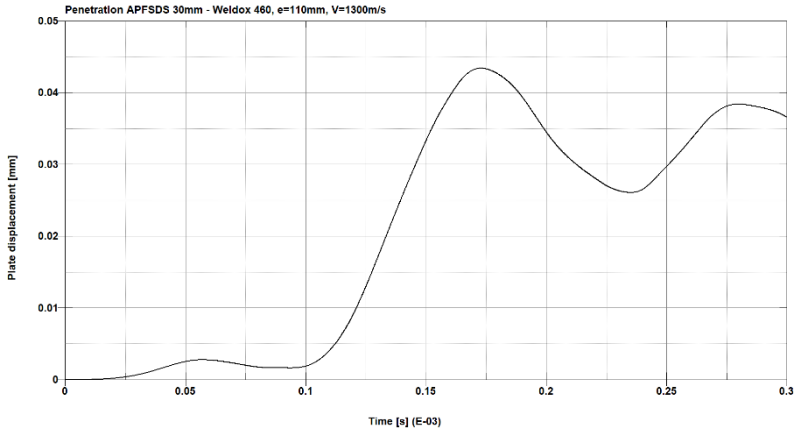

Figure 38 – Plate displacement as a function of time – case 4

The comparative overview of the analysis results is given in Table 6.

Table 6 – Comparative overview of the analysis results

Plate thickness [mm]	Penetration	Output velocity behind plate [m/s]	Plate displacement [mm]
10	yes	1280	0.3
50	yes	1210	0.06
100	yes (limited)	470	0.04
110	no	n/a	0.043

As it is already mentioned in this paper, compared to the classic armor-piercing (AP) ammunition type, the APFSDS sub-projectile has a different penetration effect. It penetrates through a steel plate without energy dissipation and “digs” the steel plate structure; while penetrating, its length becomes shorter. This effect resembles the penetration of a cumulative jet of HEAT (High-explosive anti-tank) ammunition, because of high temperatures and effect of material melting.

Magier, M. (2010) also demonstrated this specific penetration effect of APFSDS ammunition while analyzing the penetration capability of kinetic energy projectile with a tungsten alloy core for 120mm tank guns. This effect which M. Magier analyzed is shown in Figure 39.

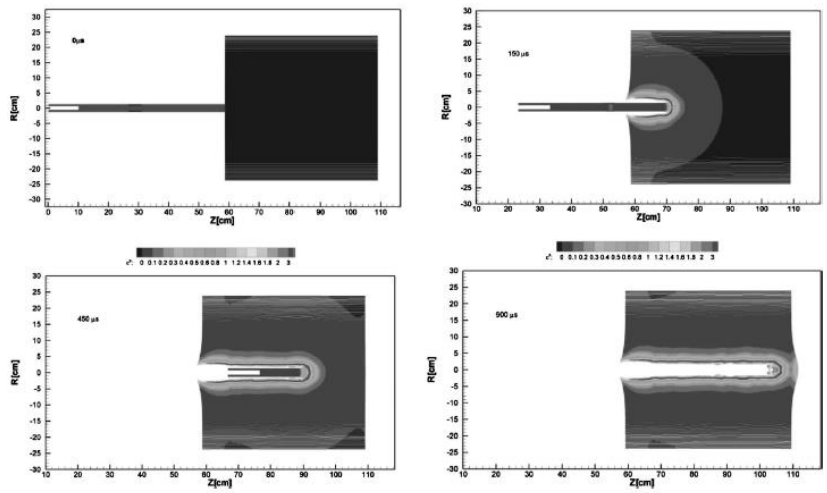

Figure 39 – The time sequence of equivalent plastic strain

The concurrence between the phenomenon shown in Figure 39 and the calculation results shown in figures in the previous part of the paper is

the confirmation of the accuracy of the claims and the applied methods and parameters used in this paper.

Table 7 shows a comparison of the penetration capabilities of 30mm APFSDS and 30mm AP projectiles (Pantović et al, 2023).

Table 7 – Comparison of the penetrating capabilities of different types of projectiles

Projectile type	Muzzle velocity [m/s]	Impact velocity at 1000m [m/s]	Penetration at 1000m [mm]
30mm APFSDS	1430	1300	100
30mm AP	970	750	33

The APFSDS sub-projectile with the defined material and ballistic characteristics has the ability to fully penetrate the Weldox 460 plate with a maximum thickness of 100mm.

Different manufacturers provide similar information on maximum penetration capability for this type of ammunition. For example, *Nammo* (Norway) in its catalogue gives a penetration value of 100mm at a distance of 1000m (Nammo, 2023).

Other manufacturers, such as *Mecar* (Belgium), give a penetration value of 50mm at 60°obliquity angle, which is similar to 100mm at 0°, due to a cosine of the angle and specific effect of penetration at a low angle of attack (Gyürösi, 2019).

Conclusion

Armor-piercing ammunition is intended to penetrate ballistic armor and different protective shields designed to protect certain defended objects. This ammunition type achieves an effect on the target thanks to its high material properties, velocity and a specially designed shape.

Representation of the effects that occur during the penetration process is extremely complex, but by using special material and geometric models it is possible to describe the real problem of armor-piercing projectile penetration. For this purpose, different calculation approaches are available in the modern times, but one of the most successful which provides the most accurate results is the finite element method.

Accordingly, a numerical analysis of the penetration of a 30mm armor-piercing fin-stabilized discarding sabot projectile into the steel alloy Weldox 460 plates of different thicknesses at a distance of 1000m with a velocity of 1300m/s is presented in this paper.

In accordance with the penetration theoretical principles, the key factors which have the greatest influence on the penetration process are deformation, strain rate, temperature, and pressure.

For the purposes of defining the phenomenon of penetration, it is necessary to define initial and boundary conditions, material characteristics, and contact conditions.

For the analysis of a 30mm armor-piercing (AP) projectile on the same type of armor steel plate, Pantović et al (2023) used the Johnson-Cook material model and the Mie-Grüneisen equation of state to describe material behavior. The maximum armor plate thickness which a 30mm armor-piercing projectile can penetrate, according to the numerical calculation result, is 33mm.

To establish the penetration ability of a 30mm APFSDS projectile, four different cases were performed in this analysis.

The 30mm APFSDS sub-projectile with defined ballistic and material characteristics had a full penetration effect into the 10mm and 50mm thick armor plates (case 1 and case 2), because its impact velocity and kinetic energy were higher than needed for the full penetration effect. The projectile velocity behind the plate, after penetration, in case 1 was 1280m/s, and in case 2, the velocity was 1210m/s.

In case 3, the sub-projectile had a limited penetration because only small particles of the core and fins went through the whole plate thickness, and the hole outer diameter was smaller than the sub-projectile core diameter. The fragments velocity behind the plate after penetration was around 470m/s.

In case 4, the sub-projectile did not have sufficient kinetic energy to achieve penetration into the 110mm thick plate. After collision with the plate, the sub-projectile core penetrates till the point it loses its kinetic energy. After that, remained particles get jammed into the steel plate structure and there were no fragments behind the plate.

By performing a penetration analysis of the sub-caliber armor-piercing ammunition with a core made of tungsten heavy metal alloy, a specific penetration effect was established and described. The appearance of such an effect is a function of a large number of different factors - the type of material, very high values of the collision speeds and the projectile and obstacles deformation speed, which together, interpenetrating, lead to a large destruction of the material structure and a high level of penetration.

The 30mm APFSDS sub-projectile with the defined material and ballistic characteristics has the ability to fully penetrate the Weldox 460 plate with a maximum thickness of 100mm.

The shown numerical results are confirmed with catalogue data given by various ammunition manufacturers, as listed in the paper.

Depending on the armor barrier design, the thickness of 100mm can be achieved in different ways – as a monoblock or as a sandwich armor with several thicker and thinner plates (e.g., 10, 20, 50mm). In the sandwich armor case, the sub-projectile penetration effect would be different because that structure would represent a sandwich barrier with different cross-sectional densities, which would give different output results.

From the aspect of ballistic protection, it is necessary to design an armored barrier in such a way that the personnel behind it is safe. For a safe protection from this projectile type, it is necessary to use armor steel with a thickness greater than the calculated one. That would neutralize the potential effect of separate fragments from the other side of the plate.

The numerical and analytical methods of calculation can provide quality results and present certain phenomena, but it is desirable to carry out experimental tests on the training ground, and at the same time numerical calculations, which would give comparable or incomparable results, which in the end would be a confirmation of the quality of the applied methods.

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Análisis numérico del proceso de penetración de un proyectil de descarte sabot perforador de blindaje de 30 mm estabilizado por aletas

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CAMPO: ingeniería mecánica, materiales
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: En los últimos tiempos, con la tendencia a desarrollar nuevos tipos de municiones perforantes, es necesaria una inversión constante en el desarrollo de nuevos tipos de obstáculos blindados. Los obstáculos fabricados con placas de acero de alta aleación siguen siendo la mejor forma de protección contra municiones de mayor calibre. Hay una serie de factores a considerar al seleccionar una aleación, incluido el peso, las dimensiones, el uso previsto, el rendimiento balístico deseado y los costos. De acuerdo con esto, en este artículo se presenta un análisis numérico de la penetración de un proyectil de descarte de sabot estabilizado con aletas perforador de armadura de 30 mm en placas de aleación de acero Weldox 460 de diferentes espesores a una distancia de 1000 m con una velocidad de 1300 m/s.

Métodos: Las tensiones y deformaciones del efecto de penetración se calcularon mediante análisis numérico y modelado de elementos finitos. Para especificar las características del material se ha utilizado el modelo de material de Johnson-Cook y el modelo de fractura de materiales. Para definir modelos y realizar cálculos numéricos se han utilizado en este trabajo los paquetes de software FEMAP y LS Dyna.

Resultados: Para un análisis numérico del proceso de penetración de este tipo de proyectil contra un obstáculo blindado, se calculan cuatro espesores diferentes de placas de blindaje: 10 mm, 50 mm, 100 mm y 110 mm. Para cada uno de ellos, los resultados se muestran en forma de tensión y desplazamiento, de modo que se puedan describir los fenómenos de interacción entre el subproyectil y la placa de blindaje.

Conclusión: Determinar el impacto sobre obstáculos perforantes es extremadamente difícil, requiere mucho tiempo y es complejo, y los modelos resultantes se aproximan con gran éxito (o con alguna desviación) al problema real de la penetración de proyectiles. Uno de los métodos más eficaces para resolver problemas de este tipo y otros de naturaleza similar en los últimos tiempos es el análisis por el método de elementos finitos. El material y las dimensiones del objetivo, así como los parámetros balísticos y el material del proyectil tienen la mayor influencia en la penetración del proyectil. La resistencia del objetivo a la penetración aumenta cuando todos los parámetros de entrada se mantienen al mismo nivel y se aumenta su espesor, y viceversa.

Palabras clave: blindaje, proyectil, penetración, Weldox 460, análisis numérico.

Численный анализ процесса проникновения 30-мм бронебойного снаряда

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РУБРИКА ГРНТИ: 78.25.00 Вооружение и военная техника
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В последнее время вследствие тенденции в проектировании новых видов бронебойных боеприпасов требуются постоянные капиталовложения в разработку новых видов бронебойных препятствий. Бронепреграды из листов высоколегированной стали по-прежнему являются лучшей защитой от боеприпасов крупного калибра. При выборе сплава следует учитывать ряд факторов, включая вес, размеры, предполагаемое использование, соответствующие баллистические характеристики и стоимость. В соответствии с вышеперечисленным в статье представлен численный анализ проникновения 30-мм бронебойно-оперенного подкалиберного снаряда в пластины стального сплава Weldox 460 различной толщины на расстоянии 1000 м со скоростью 1300 м/с.

Методы: Напряжение и деформации эффекта проникновения были рассчитаны путем численного анализа и моделирования методом конечных элементов. При определении характеристик материала использовались: модель материала Джонсона-Кука и модель разрушения материалов. Для определения моделей и проведения численных расчетов в данной статье использовались пакеты программного обеспечения FEMAP и LS Dyna.

Результаты: При численном анализе процесса проникновения такого вида снаряда в броневую преграду рассчитаны четыре различных толщины бронелистов: 10 мм, 50 мм, 100 мм и 110 мм. По каждой из них представлены результаты в виде напряжений и деформаций, а также описано взаимодействие подкалиберного снаряда с бронелистом.

Выводы: Моделирование удара на бронебойные препятствия является чрезвычайно сложным и трудоемким процессом, однако полученные модели весьма успешно (или с некоторым отклонением) аппроксимируют реальную задачу проникновения

снаряда. В последнее время анализ с использованием метода конечных элементов является одним из наиболее эффективных подходов к решению подобных задач.

Ключевые слова: броня, снаряд, проникновение, Weldox 460, численный анализ.

Нумеричка анализа процеса пенетрације панцирног поткалибарног пројектила калибра 30 mm

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ОБЛАСТ: машинско инжењерство, материјали
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: У новије време, са тенденцијом развоја нових типова оклопне муниције, неопходна су стална улагања у развој нових типова оклопних препрека. Препреке од високолегираних челичних плоча и даље су најбољи вид заштите од муниције већег калибра. Постоји низ фактора које треба узети у обзир при одабиру легуре, укључујући тежину, димензије, предвиђену употребу, жељене балистичке перформансе и цену. У складу с тим, у овом раду је приказана нумеричка анализа продора поткалибарног пројектила калибра 30 mm, брзине 1300 m/s, у челичне плоче различитих дебљина, израђене од легуре Weldox 460, на удаљености од 1000 m.

Методе: Нумеричком анализом и моделирањем коначних елемената израчунати су напони и деформације ефекта пенетрације. За дефинисање карактеристика материјала коришћени су Џонсон-Куков материјални модел и модел лома материјала, а за дефинисање модела и извођење нумеричких прорачуна – софтверски пакети FEMAP и LS Dyna.

Резултати: За потребе нумеричке анализе процеса продирања овог типа пројектила у оклопне препреке, израчунате су четири различите дебљине оклопних плоча: 10 mm, 50 mm, 100 mm и 110 mm. За сваку од њих приказани су резултати у облику напрезања и померања, а описан је и феномен интеракције између поткалибарног пројектила и оклопне плоче.

Закључак: Моделирање удара на оклопне препреке је изузетно тешко, дуготрајно и сложено, а дефинисани модели веома успешно (или уз извесно одступање) одређују прави проблем пробијања пројектила. Једна од најефикаснијих метода за решавање проблема ове врсте, и других сличних, у новије време јесте анализа методом коначних елемената. Материјал и димензије мете, као и балистички параметри и материјал пројектила највише утичу на продор пројектила. Отпор мете на пробој се повећава када се сви улазни параметри одржавају на истом нивоу, а њена дебљина се повећава, и обрнуто.

Кључне речи: оклоп, пројектил, пробој, Weldox 460, нумеричка анализа.

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Development of latent fingermarks by electrochemical deposition of nickel on brass surfaces

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FIELD: materials, chemical technology, mechanical engineering, criminalistics
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose of the research: Latent fingermarks can be found on the crime scene on various surfaces and made visible by different forensic methods. As this evidence can often be found on brass surfaces (ammunition casings, decorative items, etc.) the paper discusses the possibilities of applying electrochemical deposition of nickel on brass. The condition for the application of this technique is the existence of a conductive substrate. Fatty components of latent fingermarks have insulating properties and prevent the electrodeposition process.

Methods: Experimental thin rectangular pieces of brass foil were used as substrates for latent fingermarks. Samples were degreased in acetone and ethyl alcohol, rinsed in deionized water, and dried in a stream of compressed air before leaving the fingermarks. To enhance the presence of sweat on friction ridges, the hand was placed in the silicone glove for five minutes. A slight touch of the index finger was left on the tiles. Fingermarks were developed on brass samples by fingerprint powder and the electrochemical deposition of nickel on another brass surface simultaneously. In order to obtain the best possible evidence, the parameters affecting the deposition rate (current density, deposition time) were changed until a clear fingermark was obtained.

Results: The fingermarks were compared visually using a magnifying glass with illumination to observe the contrast between the papillary lines and the

interpapillary space and the characteristic details (minutiae). The optimal results were achieved with the current density (deposition rate) of 50mA/cm^2 for 10s.

Conclusion: Electrochemical deposition of nickel on brass is an applicable technique for developing latent fingermarks with certain limitations.

Key words: latent fingermarks, interpapillary space, brass, fingermark development, electrochemical deposition.

Introduction

Fingermarks can be used for the identification of perpetrators of crimes and have a very high evidentiary potential in criminal justice (Tutulugdžija et al, 2017; Kesić et al, 2020). The standard to be reached to decide that there is sufficient agreement between a mark and a print is still a matter of debate, but in some countries as Poland, there is a numerical standard that defines the criteria of 10 to 12 minutiae as the minimum required to identify a person (Bécue & Champod, 2023). In the Republic of Serbia, the Baltazar criterion has been used for years, according to which it is sufficient to match 12 characteristic details (minutiae) on a fingermark and a fingerprint for the identification of a person.

Fingermarks can be found on various surfaces at the crime scene. Invisible or latent fingermarks are the most problematic type of fingermarks. The most common surfaces on which latent fingermarks are searched for are glass, ceramic, porcelain, plastic, and metal (Jasuja et al, 2011).

Latent fingermarks, left by the contact of fingers, palms, or soles with the touched surface, can be developed or made visible by the application of various methods in routine forensic practice. Applying fingerprint powder, in which there is no chemical reaction between sweat and the powder for development, is the most often used one. Various chemical reagents are also used, such as silver nitrate, ninhydrin, cyanoacrylate esters, DFO, amido-black, etc. These methods include chemical reactions between the reagent and sweat. Among physical methods, it is important to mention optical methods that are often used to search for latent fingermarks. The optical methods involve the application of light of different wavelengths (Bjelovuk, 2022, p.180). It is important to emphasize that not all the methods of developing latent fingermarks are equally applicable, due to different properties of surfaces on which they can be found.

Brass is an alloy of copper and zinc, and its properties vary according to the proportions of the components in the alloy. The color of brass is

yellow-red - the higher the proportion of copper in the alloy, the closer the shade is to reddish. The most common are copper and zinc in a ratio of 2:1. It is very resistant to corrosion and friction. The melting point of brass is 900-940°C, and the density of brass is $\rho = 8.4\text{-}8.7 g/cm^3$. Brass is not a ferromagnetic material (Symetric.co.uk, 2016). As fingermarks at the scene can often be found on brass surfaces (ammunition casings, decorative items, etc.), this paper discusses a possibility of applying electrochemical deposition of metal to develop fingermarks on the surface of brass.

In the paper of Swiss scientists who analyzed a number of publications in the 2019-2022 period in which the topic is related to fingermarks, it can be found that a large number of published papers (30) dealt with fingermarks on metal surfaces and cartridge cases. In the mentioned period, the number of papers dealing with fingermark development (photography and optical - 13, chemical imaging - 26, amino-acid reagents – 19, cyanoacrylate fuming – 21, vacuum metal deposition – 8, physical developer – 4, powder dusting – 188, powder suspensions – 10, nanoparticles in solutions – 29, lipid stains – 6, other - 22) shows that the application of electrochemical deposition of metals was not singled out (Bécue & Champod, 2023). In the last decade, possibilities for a wider application of different electrochemical techniques for developing fingermarks have been explored (Qin et al, 2013; Yuan et al, 2021; Yao et al, 2023). Electrochemical deposition or in short, electrodeposition, is a well-known and conventional process of coating a layer of one metal on top of a different metal to modify its surface properties. It is a fast technique, and easy to use, but it is conditioned by the existence of a current source and a specific electrolyte. For the purpose of developing latent fingermarks, it is important to mention that the electrochemical process of metal deposition can occur only on valleys between ridges (spatially selective electrodeposition) and that by properly chosen metal to be deposited and the conditions under which the process takes place, it is possible to achieve good contrast and resolution. Electrochemical deposition of nickel is a very suitable process for many technological applications due to its low resistivity, low cost, and easy growth on different surfaces in a well-controlled manner.

Brass foil (260 1/2H, thickness 125 μm) was chosen for the substrate in the experiment in accordance with the assumption that there is a certain probability that fingermarks can be found on brass surfaces (ammunition casing, decorative objects, etc.) at the crime scene. The rectangular samples with the dimensions of 50 x 20 mm, 50 x 15 mm, and 50 x 10 mm were cut from brass foil. A brass thin plate as the cathode was first

mechanically and chemically polished, then cleaned of impurities with ethyl alcohol and deionized water and dried by a flow of compressed air. Then the chosen areas of the plate surface were covered with an insulating tape, as nickel would not be deposited on the entire surface (Figure 1). The nickel anode was prepared in such a way that it was polished with sandpaper and washed in ethyl alcohol and distilled water, after which it was dried.

Figure 1 – Nickel anode and a sample of brass foil before electrodeposition

Fingermarks of the right finger were left by the donor on the surface of the plate after the hand was in a silicone glove for 5 minutes to ensure that there would be sweat on friction ridges. After the light contact of the finger and the brass plate, a fingermark remained, which is not clearly visible (latent fingermark). The surface of the mark consists of friction ridges and interpapillary space. By immersing the electrodes in the electrolyte and connecting them to a current source in a closed electrical circuit, the process of electrodeposition begins (Figure 2). The surface of the brass electrode that is not covered by sweat corresponds to the interpapillary space. Then the resulting evidence will appear so that the friction ridges are brass-colored, and the interpapillary space is bright nickel-colored. An important fact is that a metal has been chosen to contrast with brass in color. The obtained contrast in these lines will enable the characteristics, i.e., minutiae, to be clearly visible, and the evidence is suitable for person identification.

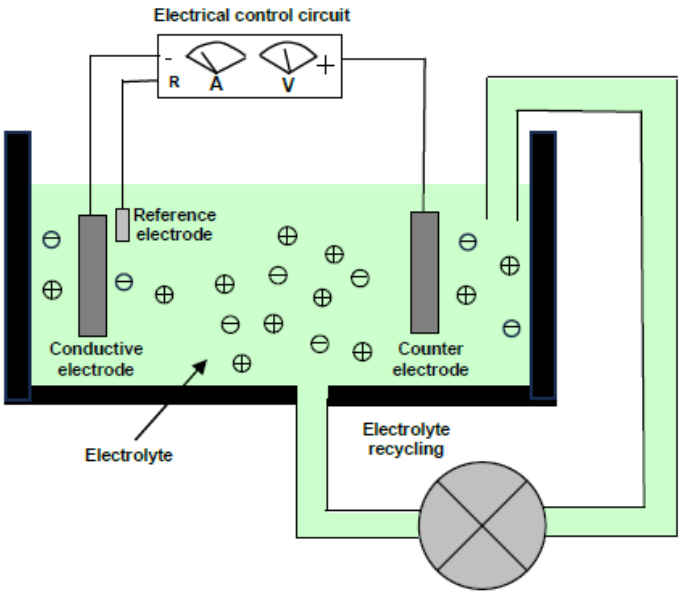

Figure 2 – Schematic representation of a set-up for electrochemical deposition

The electrodeposition of nickel was performed from a laboratory-made speed nickel electrolyte consisting of 300 g/l $Ni(NH_2SO_3)_2 \cdot 4H_2O$, 30g/l $NiCl_2 \cdot 6H_2O$, 30g/l H_3BO_3 and 1g/l saccharine. The electrolyte was constantly stirred on a magnetic stirrer. The temperature and the pH value of the electrolyte were maintained at 50 ± 2°C and 4 ± 0.05, respectively. Electrochemical deposition was carried out using the direct current (DC) galvanostatic mode. The current source could provide currents of 50, 100, 150, and 200 mA. The deposition rate was determined for each current strength. The deposition time was determined based on the deposition rate at a given current strength. After the electrodeposition, the samples were rinsed with deionized water and dried by compressed air. Before and after each deposition, the samples were weighed on an analytical balance to calculate the current efficiency of the process. The experiments were performed in controlled conditions, inside a laboratory with a temperature of 28°C, and air humidity of 46%.

The laboratory setup for the electrochemical deposition of nickel is shown in Figure 3. The experiments were carried out in the Forensic Training Center of the Ministry of Internal Affairs of the Republic of Serbia at the University of Criminal Investigation and Police Studies.

Figure 3 – The laboratory setup for the electrochemical deposition of nickel on brass

The developed fingermarks were examined by visual inspection under magnification and photographed with a camera (Samsung A50, 16 MP resolution). The assessment of the quality of the developed fingermarks by the electrochemical method was performed by comparison with the developed fingermarks using the standard method of applying ferromagnetic powder with an applicator called **"**magnetic brush" (Magnetic latent print powder, regular black No. BPM114L, Sirchie, Standard Magnetic Powder Applicator). The friction ridges were painted in black, while the interpapillary space was brass-coloured. The appearance of the fingermark visualized with magnetic fingerprint powder, photographed with a scaled photograph, is shown in Figure 4. This method is standard and has been routinely used in forensic practice for years. By applying this standard method on brass plates, the identification characteristics (minutiae), are clearly expressed.

Figure 4 – Fingermark on brass surface developed with the use of black magnetic fingerprint powder

Determination of the deposition rate and the microstructure of electrodeposited nickel films

Current density and deposition time are the parameters that determine the deposition rate and the microstructure of the deposited metal film. Increasing the current density leads to the deposition of fine-grained films.

Four samples were selected and prepared to determine the rate of nickel deposition on brass substrates. On the brass samples, a 10x10 mm surface was defined using a non-conductive tape, due to the easier determination of the current density value. The deposition time was fixed at 60 s, and by measuring the difference in the mass of the sample before and after the process, it was possible to calculate the thickness of the films and the deposition rate. The rates of the nickel electrodeposition were determined as EDNi (50 mA/cm^2) = 1.03 μm/min, EDNi (100 mA/cm^2) = 1.98 μm/min, EDNi (150 mA/cm^2) = 3.44 μm/min, and EDNi (200 mA/cm^2) = 4.04 μm/min.

It is known that electrodeposited nickel films have fine-grained columnar microstructures (Tutulugdžija, et al, 2017). The process of nickel electrodeposition is followed by the release and adsorption of hydrogen bubbles on the brass cathode, and there is a need for intensive stirring during the process. With increasing the current density (the deposition rate) from 50 mA/cm^2 to 200 mA/cm^2, the efficiency of the stirring was not good enough and the porous metal films were obtained (Figure 5). The best quality of the film microstructure was achieved with a current density of 50 mA/cm^2, and it was decided not to exceed this current density value in the experiments.

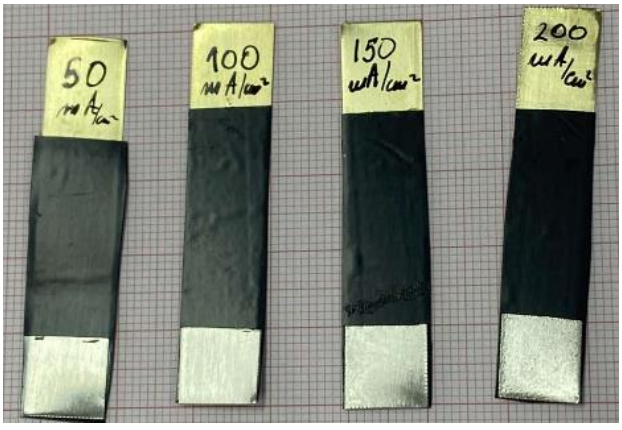

Figure 5 – Determination of the deposition rate on an area of 10x10 mm

Experimental determination of the optimal conditions for the development of latent fingermarks

Initial experiments were performed with a defined maximum current density value of 50 mA/cm^2. With the known, calculated deposition rate for different current densities, it was possible to approximately determine the thickness of the nickel deposit. The initial deposition time was decided to be 60s, with an estimated film thickness of about 1 μm. As it can be seen in Figure 6, the deposition time is too long and the nickel film has fully covered the fingermark.

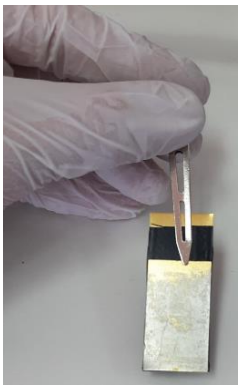

Figure 6 – Fingermark on the brass developed by the electrodeposition of nickel with the 50 mA/cm^2 current density and a deposition time of 60s

It is clear from Figure 6 that it was necessary to reduce the deposition time. The following experiments were performed with the same current density but with a deposition time of 10s, (5s + a stop for control + 5s) and 7s. The deposition duration of 5s was not enough to develop a fingermark. As shown in Figure 7, reducing the deposition time improved trace development.

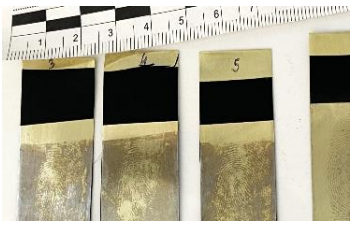

Figure 7 – Fingermark on the brass surface developed by the electrodeposition of nickel with the 50 mA/cm^2 current density and a deposition time of 10s (sample 3), 5+5s (sample 4), and 7s (sample 5). On the right is sample 6, on which the fingermark was developed using the standard powder application method

When nickel deposition is performed on specific surfaces (which is the case here, because it is about surfaces on which there are fingermarks), a high deposition rate is not an advantage because it reduces control of the thickness and the uniformity of nickel films on such surfaces.

The deposition rate decreases with the decrease in the current density. The following experiments were performed with a reduced current density of 30 mA/cm^2. Due to the decrease in the deposition rate, the deposition time was extended and the experiments were performed for 25s and 12s. The results of the development of the fingermarks under new conditions are shown in Figure 8.

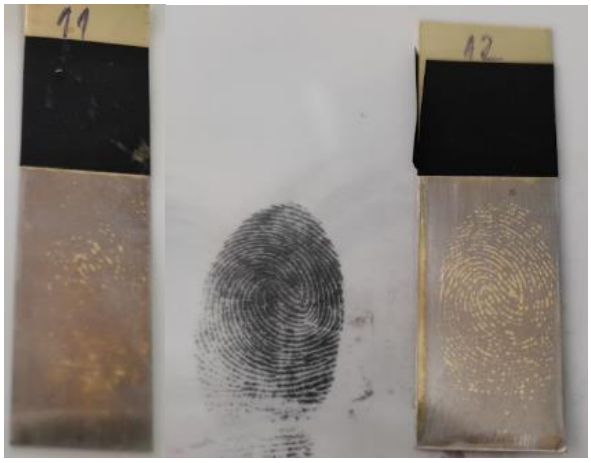

Figure 8 – Fingermark on the brass surface developed by the electrodeposition of nickel with the 30 mA/cm^2 current density and a deposition time of 25s (sample 11) and 12s (sample 12)

It can be concluded from Figure 8 that the change in the process parameters and new conditions of nickel deposition on brass substrates with fingermarks led to better quality. Lower current density and slower deposition enabled uniform coverage of the brass substrate surface. A deposition time of 25s for a current density of 30mA/cm^2 (sample 11), proved to be too long as fingermark overlap occurred. In sample 12, the characteristic details of the fingermark are clearly visible.

The following experimental research went in the direction of evaluating the quality of developing fingermarks with the further reduction of the current density. In Figure 9, four brass samples with deposited nickel films obtained with the 10mA/cm^2 current density and different deposition times are shown.

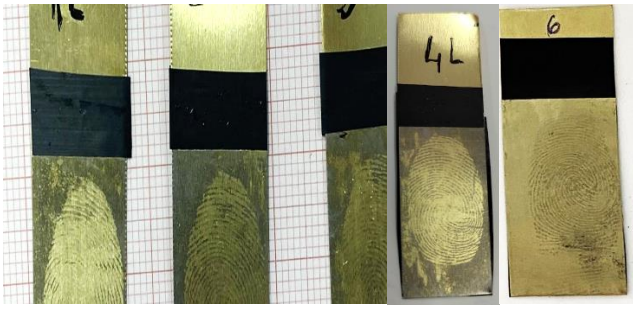

Figure 9 – Developments of fingermarks on the brass surface by the electrodeposition of nickel with the 10 mA/cm^2 current density and a deposition time of 60s (sample 1L), 30s (sample 2L), 25s (sample 3L) and 12s (sample 4L). On the right, sample 6 is shown, on which the fingermark was developed using the standard powder application method

On the basis of Figure 9, it can be concluded that good results for developing fingermarks were obtained by using a current density of 10mA/cm^2 and reducing the deposition time to 12s (sample 4L). Further reduction in deposition time led to incomplete fingermark development.

In sample 4L, some characteristic details are clearly visible, which can be important for identifying a person, and they are presented in Figure 10.

Figure 10 – Development of a fingermark on the brass surface by the electrodeposition of nickel with the 10 mA/cm^2 current density and the 12s deposition time. Some characteristic details of the fingermarks, minutiae (fingermark developed with conventional magnetic latent print powder Sirchie – left and sample L4 after photo editing - right) are shown

Discussion

During the experiment, tests were carried out with different values of current strength, time of nickel deposition, and different values of

electrolyte temperature in order to find optimal values at which the developed fingermark will be suitable for person identification. Fingermarks are suitable for the identification of a person in the Republic of Serbia. It is necessary to have twelve clearly expressed characteristics, i.e. minutiae. Smaller values of current density, shorter deposition time, and smaller values of electrolyte temperature gave a smaller thickness of the deposition layer. Then the fingermark is not clearly visible, i.e., it is of lower quality, and thus the potential of identification is small. Also, during the tests, no high-quality fingermarks were obtained when a longer time of nickel deposition was chosen. The deposition time of one minute showed that the entire surface of the brass plate will be covered with a deposited layer of nickel, i.e., the thickness of the nickel deposition layer is greater than the depth of the interpapillary space. Such a fingermark is completely covered with a layer of deposited nickel and is unsuitable for identification. The optimal current strength at which it was shown that a high-quality fingermark would be developed by electrochemical nickel deposition was I = 50 mA, while the deposition time was 60s. The electrolyte temperature was 54.2°C.

Developed fingermarks were observed under a magnifying glass in order to analyze the identification characteristics and test the usability of the fingermark for identification.

The application of fingerprint powder has been widely used for several decades in forensic practice and is suitable for developing fingermarks on various surfaces, both metal and other surfaces such as glass, plastic, porcelain, ceramic, lacquered surfaces, etc. A comparison of fingermarks developed by electrochemical nickel deposition and the method of fingerprint powder application was made.

Conventional fingerprint powders have been used for decades in forensic practice worldwide to develop fingermarks at the crime scene and such evidence is later used in fingerprint laboratories for identification. This method is very simple to apply, it does not require complex training, the equipment is not bulky and heavy (a jar with powder, a brush, and fingerprint foils for lifting the evidence), it is not expensive, and the application does not require a lot of time. It can be performed both at the scene and in the laboratory. The surface on which there is a fingermark is not damaged after the application of the powder (it is enough to pass a dry cloth over the surface on which the mark is developed and the surface returns to its original state), i.e., this method can be characterized as non-destructive. This method can be applied to both movable and immovable objects.

The application of the electrochemical deposition method in these tests proved to be equally applicable, considering that in both cases, minutiae can be found (minimum 12). However, this method is only suitable for metal surfaces, i.e., surfaces that conduct electricity. Also, this method is suitable for application on objects of small dimensions, i.e., it is necessary that the dimensions of brass objects, on which there are latent fingermarks, be smaller than the dimensions of the container with the electrolyte in order for immersion to be possible. This method is more complicated to apply at the scene, considering that it is necessary to carry the equipment (DC source, conductors, electrodes, electrolyte container, and heating element), provide the space for the equipment at the scene where it will be installed, etc. When it comes to damaged surfaces with latent fingermarks, this method can be characterized as destructive, considering that the caused trace cannot be removed so easily, but requires mechanical removal such as grinding.

Conclusion

The method of electrochemical deposition of metals is not in routine forensic application. In recent years, there have been attempts to investigate the possibility of applying this method. In this paper, experiments have shown that it is quite possible to apply this method to develop latent fingermarks on a brass surface.

The use of fingerprint powders for developing fingermarks is applicable on movable and immovable objects, at the scene and in the laboratory. It has been confirmed in forensic practice worldwide as a non-destructive method.

The limitations when performing electrochemical nickel deposition refer to the necessity of equipment at the scene, and the small dimensions of moving objects with fingermarks. Also, an object with fingermarks must be a current conductor, which brass is.

Both methods for developing fingermarks, fingerprint dusting and electrochemical deposition of nickel, are suitable for identification because the identification characteristics were clearly expressed.

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Desarrollo de huellas dactilares latentes mediante deposición electroquímica de níquel sobre superficies de latón

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CAMPO: materiales, tecnología química, ingeniería mecánica, criminalística
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: Se pueden encontrar huellas dactilares latentes en la escena del crimen en varias superficies y se pueden hacer visibles mediante diferentes métodos forenses. Como esta evidencia se puede encontrar a menudo en superficies de latón (cartuchos de munición, artículos decorativos, etc.), el artículo analiza las posibilidades de aplicar la deposición electroquímica de níquel sobre latón. La condición para la aplicación de esta técnica es la existencia de un sustrato conductor. Los componentes grasos de las huellas dactilares latentes tienen propiedades aislantes e impiden el proceso de galvanoplastia.

Métodos: Se utilizaron piezas experimentales delgadas y rectangulares de lámina de latón como sustratos para las marcas dactilares latentes. Las muestras se desengrasaron en acetona y alcohol etílico, se enjuagaron con agua desionizada y se secaron en una corriente de aire comprimido antes de dejar las marcas de los dedos. Para mejorar la presencia de sudor en las crestas de fricción, se colocó la mano en el guante de silicona durante cinco minutos. Un ligero toque del dedo índice quedó sobre los azulejos. Se desarrollaron marcas dactilares en muestras de latón mediante polvo para huellas dactilares y la deposición electroquímica de níquel sobre otra superficie de latón simultáneamente. Para obtener la mejor evidencia posible, los parámetros que afectan la velocidad de deposición (densidad de corriente, tiempo de deposición) se cambiaron hasta que se obtuvo una marca dactilar clara.

Resultados: Las marcas dactilares se compararon visualmente utilizando una lupa con iluminación para observar el contraste entre las líneas papilares y el espacio interpapilar y los detalles característicos (minucias). Los resultados óptimos se lograron con una densidad de corriente (velocidad de deposición) de 50 mA/cm2 durante 10 s.

Conclusión: La deposición electroquímica de níquel sobre latón es una técnica aplicable para desarrollar marcas dactilares latentes con ciertas limitaciones.

Palabras claves: marcas dactilares latentes, espacio Inter papilar, latón, desarrollo de marcas dactilares, deposición electroquímica.

Выявление скрытых отпечатков пальцев методом электрохимического осаждения никеля на латунных поверхностях

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РУБРИКА ГРНТИ: 55.00.00 Машиностроение,
61.00.00 Химическая технология,
10.85.31 Криминалистическая экспертиза
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Практика судебной экспертизы показала, что скрытые отпечатки пальцев можно обнаружить на различных поверхностях места происшествия, а выявить их можно различными методами. Поскольку эти следы часто встречаются на латуни (гильзы, украшения, декоративные предметы и т.д.), в данной статье обсуждаются возможности нанесения никеля на латунную поверхность методом электрохимического осаждения. Условием применения этого метода является наличие проводящей подложки, так как жировые компоненты следов папиллярных линий обладают изолирующими свойствами и препятствуют процессу электроосаждения.

Методы: В качестве подложки использовались экспериментальные тонкие прямоугольные кусочки латунной фольги, на которых остались следы папиллярных линий. Образцы были обезжирены ацетоном и этиловым спиртом, затем их промывали деионизированной водой и обдували струей сжатого воздуха до появления следов папиллярных линий пальцев. Для увеличения потовыделения на папиллярных линиях, на руку в течение 5 минут надевали силиконовую перчатку. После легкого прикосновения указательного пальца к пластине оставался след. Следы папиллярных линий на латунных образцах выявлены с помощью дактилоскопического порошка и одновременного электрохимического осаждения никеля на другую латунную пластину. В целях получения лучшего отпечатка, параметры, влияющие на скорость осаждения, менялись до тех пор, пока не был получен четкий след папиллярных линий.

Результаты: Визуальное сравнение следов производилось с помощью лупы с подсветкой, которая усиливала контраст между цветом папиллярных линий, межсосочкового пространства и характерных деталей (минуции). Оптимальные

Jevtić, T. et al, Development of latent fingermarks by electrochemical deposition of nickel on brass surfaces, pp.241-257

результаты были достигнуты при плотности тока (скорости осаждения) 50 мА/см2 в течение 10 с.

Выводы: Электрохимическое осаждение никеля на латунную поверхность является применимым методом (с некоторыми ограничениями) выявления скрытых следов папиллярных линий.

Ключевые слова: скрытые следы папиллярных линий, межсосочковое пространство, латунь, выявление скрытых следов, электрохимическое осаждение.

Изазивање латентних трагова папиларних линија методом електрохемијске депозиције никла на месингу

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ОБЛАСТ: материјали, хемијске технологије, машинство, криминалистика
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/сврха истраживања: Латентни трагови папиларних линија прста се у форензичкој пракси могу наћи на различитим површинама на месту догађаја и учинити видљивим различитим методама. Како се ови трагови често могу наћи на месингу (муницијска чаура, украсни предмети и друго), у раду су размотрене могућности примене електрохемијске депозиције никла на месингу. Услов за примену ове технике јесте постојање проводног супстрата. Масне компоненте трага папиларних линија имају својства изолатора и спречавају процес електродепозиције.

Методе: Експериментални танки правоугаони делови месингане фолије коришћени су за подлогу на коју су остављани трагови папиларних линија. Узорци су одмашћени у ацетону и етил-алкохолу, испрани у дејонизованој води и осушени струјањем компримованог ваздуха пре него што су остављени трагови папиларних линија. Ради повећања присуства зноја на папиларним линијама, рука је стављена у силиконску рукавицу на 5 минута. Лаганим додиром плочице кажипрстом остављен је траг. Трагови папиларних линија изазвани су на узорцима месинга коришћењем дактилоскопског праха и, истовремено, електрохемијским таложењем никла на другу месингану плочицу. Ради добијања што квалитетнијег трага, мењани су параметри који утичу на брзину депозиције све док није добијен јасан траг папиларних линија.

Резултати: Трагови су визуелно упоређивани помоћу лупе са осветљењем како би се уочио контраст између боје папиларних линија и међупапиларног простора и карактеристични детаљи (минуције). Оптимални резултати постигнути су струјом густине (брзином таложења) 50mA/cm^2 за 10 s.

Закључак: Електрохемијско таложење никла на месингу је применљива техника за изазивање латентних трагова папиларних линија са одређеним ограничењима.

Кључне речи: латентни трагови папиларних линија, међупапиларни простор, месинг, изазивање латентних трагова, електрохемијска депозиција.

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Probabilistic multi-objective robust design and its application in metal cutting

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DOI: https://doi.org/10.5937/vojtehg72-44518

FIELD: material processing, optimization
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: Cutting is a typical material process. However, an appropriate solution for simultaneous optimization of material machinability and tool life in material cutting processes has not been obtained yet. In this article, probabilistic multi-objective robust design (PMORD) is expounded and the robust design problem in the simultaneous optimization of material machinability and tool life is analyzed by taking the machining of ferrite-bainite dual-phase steel as an example.

Methods: According to PMORD, the arithmetic mean and its deviation of various performance and utility indexes of alternative schemes are evaluated as twin independent responses, which respectively contribute a part of the partial preferable probability to the performance indexes. In the evaluation, the arithmetic average of the utility index is taken as the representative of the utility attribute, and the evaluation is made in accordance with the function or preference of the utility index. However, the deviation term is generally used as an unbeneficial type of the index (that is, the smaller the better) to participate in the evaluation. The product of the two parts of partial preferable probability is the actual partial preferable probability of the corresponding performance index. The product of the partial preferable probability of all performance utility indexes gives the total preferable probability of the corresponding scheme, which is the only index for each scheme to participate in the competition in robust design.

Results: The optimization result of this example is that the tool life is 1297.3333 s (standard deviation is 2.0817 s) and the surface roughness is 2.22μm (standard deviation is 0.2μm), while the corresponding working

conditions are that the heat treatment temperature of the material is 790°C, the cutting speed is 150m/min, the feed speed is 0.15mm/rev, and the cutting depth is 0.2mm.

Conclusion: The example of the parameter optimization of cutting of ferrite-bainite dual-phase steel by means of PMORD indicates the rationality of the appropriate solution.

Key words: multi-objective optimization, robust design, simultaneous optimization, probability-based method, preferable probability.

Introduction

Product quality is an important issue related to the survival of enterprises. With the increasing international competition of industrial products, more and more attention has been paid to this problem by governments and industries in various countries. In Japan, many new technologies have been developed in past years, which has greatly improved the quality and productivity of industrial products. Among them, a decisive factor is the adoption of important technologies such as robust design. The application of robust design technology aims not only to improve the product quality, but also to enable enterprises to obtain considerable economic benefits. For example, after the application of robust design technology by Nippon Electric Co., Ltd., only one color TV regulated power supply can increase economic benefits by 6.7 billion yen every year due to quality improvement. In recent years, in Japan, the United States, Canada and other developed countries, there has been an upsurge in the research and application of robust design technology, which has made the technology develop continuously. Compared with developed countries in the world, the quality of many products in China is still needed to be further improved with the reduction of cost. Therefore, vigorously popularizing robust design technology is of great practical significance for improving the quality of Chinese products, including the quality and market competitiveness of petrochemical products, and accelerating modernization.

The formation of product quality has two important links: development design and manufacturing. Roughly speaking, product quality is the sum of product development and design quality and product manufacturing quality. In order to improve the quality of products, special attention could be paid to the two important links of development - design and manufacturing.

According to statistics, about 50% ~ 70% of all the quality problems of products are caused by poor product development and design, so it is

very important to improve the quality of product development and design. Robust design is an important new technology aiming to achieve high quality products at low cost. It makes full use of the nonlinear nature of the system and makes the product performance least sensitive to all kinds of interference by properly selecting the level combination of controllable factors, so as to improve the product quality and reduce the cost.

In general, the implementation steps of robust design include simplification and system analysis. First, on the basis of detailed research, the system is reasonably simplified. Then, through analysis, specific research objects, product improvement goals and quality characteristics reflecting these goals are determined, and the influencing factors and their levels are listed. The factors are divided into two categories: controllable factors and error factors. Controllable factors are factors that researchers can strictly control, while error factors are factors that researchers are difficult to control or need to spend a lot of money to control. The latter is actually interference.

The main difference between robust experimental design and traditional experimental design is that there is not only the effect of factors on the average of response but also on its deviation of response. Orthogonal design, factorial design, uniform design and comprehensive error factor method can be adopted to study the effect.

Historically, experimental design originated from the research of Prof. Fisher, a scientist who studied breeding in the 1920s. Dr. Fisher is universally recognized as the founder of this method and strategy. Early in 1925 and 1935, Ronald Aylmer Fisher published the books entitled “Statistical Methods for Research Workers” (Edinburgh: Oliver and Boyd) and “The Design of Experiments. Edinburgh” (Edinburgh: Oliver and Boyd), respectively, which laid the foundation for experimental design.

In 1950s, Genichi Taguchi realized that it was significant to improve product quality by reducing the influence of uncertain or uncontrollable factors on product performance (Mori & Tsai, 2011; Roy, 2010), and put forward the Taguchi method. Taguchi suggested that the influence of controllable and uncontrollable factors on the responses of a product can be studied and analyzed by designing experiments. Taguchi called uncontrollable factors “noises” (Mori & Tsai, 2011; Roy, 2010). The basic idea of robust design is to seek a set of controllable factors to make the product quality insensitive to noise or minimally sensitive to noise (Mori & Tsai, 2011; Roy, 2010). In addition, Taguchi adopted the term of Signal-to-Noise Ratio (SNR) to implement his robust design. It is assumed that at an optimal setting, controllable factors are selected to maximize the

signal-to-noise ratio. He further proposed three types of the signal-to-noise ratio, i.e.,

1) The expected value is optimal,

$$SNR_T = 10\log\left(\frac{\mu^2}{s^2}\right), \quad (1)$$

2) The smaller the better,

$$SNR_s = -10\log\left(\frac{1}{m}\sum_{i=1}^{m} y_i^2\right), \quad (2)$$

3) The bigger the better,

$$SNR_L = -10\log\left(\frac{1}{m}\sum_{i=1}^{m}\frac{1}{y_i^2}\right). \quad (3)$$

In Eqs. (1) to (3) above, m represents the test times of each experiment, μ represents the arithmetic average of the test results of m experiments, and s represents its standard deviation.

However, in general, the average value μ and the standard deviation s of the test results should be an independent set of responses individually (Box, 1988; Box & Meyer, 1986; Welch et al, 1990; Welch et al, 1992; Nair et al, 1992). However, in Eq. (1), it is unreasonable to attribute the two responses μ and s into a sole performance SNR_T. The optimization of the maximum SNR_T does not mean that s takes the minimum value and μ tends to its expected value at the same time! More seriously, for the cases of "the smaller the better" and "the bigger the better", Eqs. (2) and (3) above even exclude the role of the factor of the standard deviation s.

Statisticians, such as Box, Welch, Nair, et al, have clearly criticized Taguchi's Signal-to-Noise Ratio (SNR) robust design, and they suggested that two independent models should be considered to deal with the response of the mean μ and the variance s (Box, 1988; Box & Meyer, 1986; Welch et al, 1990; Welch et al, 1992; Nair et al, 1992). Therefore, the minimum value of s and the optimization of μ tending to its expected value should be treated simultaneously with separate models to ensure the rationality of robust optimization.

In fact, robust design can be considered as a problem of a bi-objective optimization with μ tending to its target and s minimization, while a mutil-objective optimization is an optimization within a system consisting of multiple objectives.

According to the system theory, the integrity, purpose, openness, stability, hierarchy, mutation, self-organization and similarity are the eight basic characteristics of a system. In accordance with the integrity principle of the system, the system is an integral body with certain new functions, composed of several elements. As a sub-unit of the system, once the elements form the whole system, they have properties and functions that individual systems do not have, thus showing that the properties and functions of the integral system are not equal to a simple sum of its elements. The reason why a system becomes a system is that it must have integrity first.

Furthermore, the optimization of a system is not the superposition of each particle's optimization, but an optimization of a system as a whole. The system has integrity, which determines that system optimization can only be its overall optimization, that is, the whole system obtains the best organizational structure and function.

For a determined goal, the relationship between the integrity and the part should be handled well under the principle of an optimal overall benefit. On the premise of overall optimization, give consideration to local interests. If the overall benefit is good, it will promote the local development and benefit local elements. For overall optimization, even if there are local defects, overall optimization can be realized through coordination.

Recently, probabilistic multi-objective optimization methodology (PMOO) was proposed to perform the overall optimization of a system and to solve the inherent problems of "addition" operation with subjective factors in traditional multi-objective optimization (Zheng et al, 2022a; Zheng et al, 2022b; Zheng et al, 2023). A new concept, preferable probability, is introduced to reflect the preference degree of performance and utility indicators of candidate schemes in the optimization process. In this new methodology, the performance and utility indexes of all schemes can be preliminarily divided into two basic types in accordance with their functions in optimization or pre-required preferences, namely, beneficial type and unbeneficial type. Each performance utility index of the alternative scheme can quantitatively contribute its partial preferable probability. In addition, according to probability theory, the total preferable probability of alternatives is equal to the product of the partial preferable probabilities of all performance and utility indexes, which is the only decisive index in the optimization process of alternatives. This treatment thus transforms a multi-objective optimization problem into a single-objective optimization problem.

The specific advantage of probabilistic multi-objective optimization is that a clear goal of multi-objective optimization is the integral optimum point of the system in the viewpoint of the system theory, which has both the viewpoint and the method, while other previous approaches have only methods but without any viewpoint on ″the intrinsic meaning and definition of multi-objective optimization″.

This paper aims to provide the detail of probabilistic multi-objective robust design for material cutting, showing the general procedures of the integral combination of probabilistic multi-objective optimization with Taguchi's for experimental design in utilization of robust design. Specifically, the cutting process of ferrite-bainite dual-phase steel is taken as a typical example to conduct the simultaneous robust design of tool life and surface roughness of the sample by means of probability-based multi-objective optimization. The input parameters to be optimized include heating temperature, cutting speed, feed speed, and cutting depth. Through this study, the general principle and procedure of robust design of industrial processing could be provided so as to improve the quality of products in industrial production.

Robust design process of probabilistic multi-objective optimization

Basis of probability-based multi-objective optimization

In probability-based multi-objective optimization methodology (Zheng et al, 2022a; Zheng et al, 2022b; Zheng et al, 2023), a brand-new concept of preferable probability is introduced to represent the preferable degree of performance utility indicators in optimization. The performance utility indicators of all alternatives can be preliminarily divided into two basic types in accordance with their roles in optimization or pre-required preferences, namely, beneficial type or nonbeneficial type. Each performance utility index of the alternative scheme quantitatively contributes to the partial preferable probability. In addition, from the viewpoint of probability theory, the total preferable probability of alternatives is equal to the product of partial preferable probabilities of all performance and utility indicators, which can reflect the essence of simultaneous optimization. The total preferable probability of the scheme is the only decisive index in the optimization process, and through it, a simultaneous optimization problem of multiple objectives is transformed into a single objective optimization problem. Figure 1 shows the operation process of the probabilistic multi-objective optimization method.

The meanings of the parameters and coefficients in Figure 1 are as follows: P_{ij} represents the partial preferable probability of the j-th performance utility index Y_{ij} of the i-th alternative; n represents the total number of alternatives; m reflects the total number of target utility; μ_j represents the arithmetic value of the *j-th* target utility index; Y_{jmax} and Y_{jmin} represent the maximum and minimum values of the *j-th* performance utility index, respectively; η_j and λ_j represent the normalization factor of the *j-th* utility index Y_{ij} of the beneficial and unbeneficial indicators, respectively; the classification of the *j-th* utility index Y_{ij} is determined in accordance with its specific role or preference in the discussed problem; and P_i represents the total preferable probability of the i-th alternative (Zheng et al, 2022a; Zheng et al, 2022b; Zheng et al, 2023).

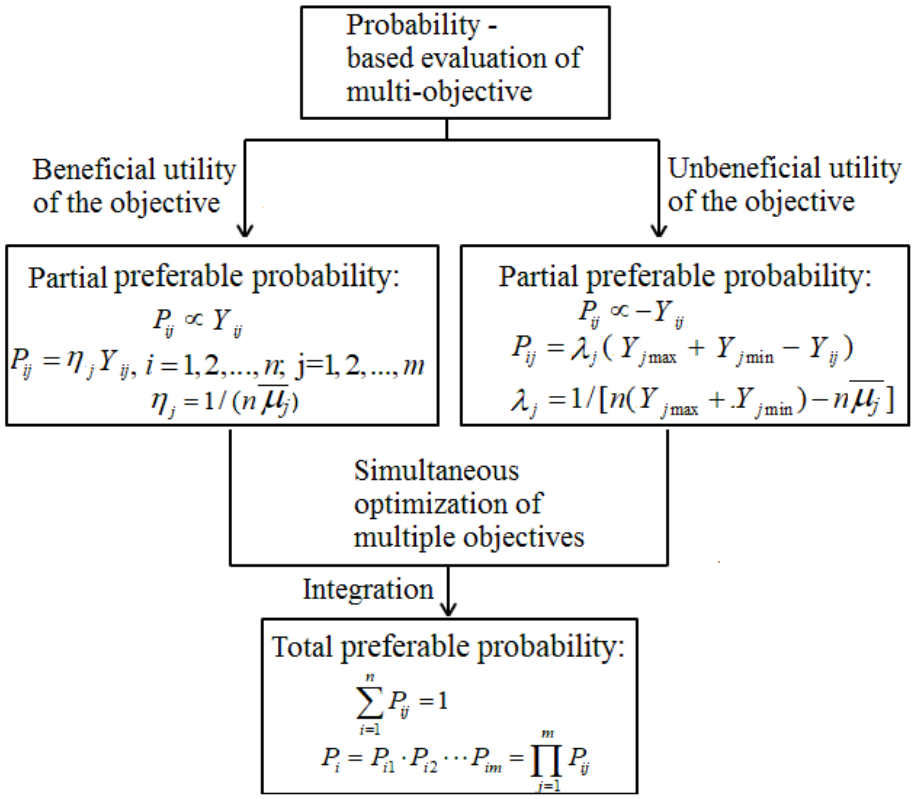

Figure 1 – Probability-based multi-objective optimization process

New robust design process based on probabilistic multi-objective optimization

According to the statisticians' suggestion and the probabilistic multi-objective optimization method, two separate models should be used to consider the response of the mean value μ and the variance s at the same time (Zheng et al, 2022a; Zheng et al, 2022b; Zheng et al, 2023). The process of robust design using probabilistic multi-objective optimization is described as follows:

A) The arithmetic average and its deviation of the performance indexes of alternatives can be used as two independent responses of alternatives for robust design. In the robust design process, each of the above two responses contributes a part of partial preferable probability to the corresponding performance index of the alternative scheme;

B) The arithmetic average of the utility index, as the representative of its effect index, is evaluated by probability of partial preferable in accordance with its function and preference, while deviation is generally evaluated as an unbeneficial index;

C) The product of the partial preferable probability of the arithmetic mean and the partial preferable probability of the deviation of the performance index constitutes the actual partial preferable probability of the performance utility index;

D) The product of the partial preferable probability of all performance utility indicators is equal to the total preferable probability of alternatives, which is the overall and unique final evaluation index of each alternative in the robust optimal scheme;

E) Take the total preferable probability of each scheme as the decisive index in robust design to perform competition.

Industrial application of probabilistic multi-objective optimization robust design

Taking the robust design of dual-phase steel cutting as an example, the specific application of this new method is explained in detail. Hegde et al. (2022) once designed the machining of ferrite-bainite dual-phase steel (AISI1040 F-B) robustly. Through experiments, the tool life and the sample surface roughness were taken as their simultaneous optimization goals, and the heating temperature, cutting speed, feed speed and cutting depth of ferrite-bainite dual-phase steel (AISI1040 F-B) were taken as the input parameters. The four control factors, heating temperature, cutting speed, feed speed and cutting depth, are marked as

the factors A, B, C and D, respectively. Each factor has three levels, and three samples were tested under each experimental condition (Hegde et al, 2022). Hegde et al. adopted Taguchi $L_9(3^4)$ for experimental design, and the arithmetic value and the standard deviation of the experimental results are listed in Table 1.

In experimental design, the tool life and the sample surface roughness are taken as the simultaneous optimization objectives. In Table 1, T_{LA} and δT_L respectively represent the arithmetic mean and the standard deviation of the tool life, while S_{RA} and δS_R reflect the arithmetic mean and the standard deviation of the sample surface roughness, and their marks are *E*, *F*, *G* and *H,* respectively.

Table 2 gives the evaluation results of the preferable probability and the ranking of this problem. In the evaluation, in accordance with the requirements of robust optimization, only quantity $T_{LA}(E)$ belongs to the beneficial type, while all other responses are attributed with the characteristics of the unbeneficial type.

Table 1 – Design and experimental results of the cutting parameters of dual-phase steel with $L_9(3^4)$

Exp. No.	Input parameter				Optimization goals			
					Mean value of life	Deviation of life	Mean value of roughness	Deviation of roughness
No.	A (°C)	B (m/min)	C (mm/rev)	D (mm)	T_{LA}, E (s)	δT_L, F (s)	S_{RA}, G (μm)	δS_R, H (μm)
1	750	80	0.13	0.2	2646	29.4618	4.2633	0.0416
2	750	115	0.15	0.4	1907	1.7321	4.0833	0.1589
3	750	150	0.18	0.6	994	3.6056	2.6233	0.0551
4	770	80	0.15	0.6	1464	6.9282	4.07	0.0458
5	770	115	0.18	0.2	2168.333	16.0728	3.11	0.0854
6	770	150	0.13	0.4	1172	19	2.5567	0.0551
7	790	80	0.18	0.4	1528.333	2.0817	3.1067	0.0902
8	790	115	0.13	0.6	700	4.3589	2.42	0.0889
9	790	150	0.15	0.2	1297.333	2.0817	2.22	0.02

Table 2 – Evaluation results of the preferable probability and the ranking of the dual-phase steel cutting experiments

Exp. No.	Partial preferable probability				Total preferable probability	
No.	P_E	P_F	P_G	P_H	$P_i \times 10^4$	Ranking
1	0.1907	0.0089	0.0743	0.1417	0.1778	9
2	0.1374	0.1508	0.0803	0.0206	0.3432	8
3	0.0716	0.1412	0.1291	0.1277	1.6679	3
4	0.1055	0.1242	0.0807	0.1373	1.4523	4
5	0.1563	0.0774	0.1128	0.0965	1.3162	5
6	0.0845	0.0624	0.1313	0.1277	0.8842	6
7	0.1101	0.1490	0.1129	0.0915	1.6961	2
8	0.0504	0.1373	0.1359	0.0929	0.8743	7
9	0.0935	0.1490	0.1426	0.1640	3.2564	1

The evaluation results in Table 2 show that experimental scheme No 9 has the highest total preferable probability value of P_i. Therefore, the configuration of robust design is near the parameters of experimental scheme No 9.

In addition, Table 3 shows the results of the range analysis of the total preferable probability of each group of the schemes shown in Table 2.

Table 3 shows that the order of the impact intensity of the input variables is $A > B > C > D$, which reveals that the optimal configuration is $A_3B_3C_2D_1$, which is experimental scheme No 9 exactly. Hegde and others used ANOVA technology to statistically analyze the relative contributions of various factors to T_L and S_R, and their optimization results were close to experimental scheme No 2 (Hegde et al, 2022).

Obviously, from the point of view of probability theory, the result of experimental scheme No 2 is worse than that of experimental scheme No 9.

Table 3 – Analysis results of the total preferable probability range for the two-phase steel cutting experiments

	Factors			
Level	A	B	C	D
1	0.7296	1.1087	0.6454	1.5835
2	1.2176	0.8446	1.6840	0.9745
3	1.9423	1.9362	1.5600	1.3315
Range	1.2126	1.0916	1.0386	0.6090
Impact order	1	2	3	4
Optimal configuration	A_3	B_3	C_2	D_1

Conclusion

The above discussion shows that the robust design of probabilistic multi-objective optimization is a reasonable design method. The arithmetic mean and its deviation of the performance index of the scheme are regarded as two independent responses of the scheme in processing, and each contributes a part of partial preferable probability to the scheme. As the representative of the utility index, the arithmetic average of the utility index is evaluated in accordance with its function and preference, and the deviation is that the utility index is the unbeneficial type of the index. The total preferable probability of each scheme is the only final index parameter in robust optimization design.

The algorithm of the present probabilistic multi-objective objective robust design accepts the idea that the arithmetic mean and its deviation of the performance index of the scheme can be regarded as two independent responses of the scheme; the agorithm is rational, adequately overcoming the puzzling problem of previous robust design approaches. The application of the model to more diverse real-life problems needs to be conducted in future.

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Diseño robusto probabilístico multiobjetivo y su aplicación en el corte de metales

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CAMPO: procesamiento de materiales, optimización
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: El corte es un proceso material típico. Sin embargo, aún no se ha obtenido una solución adecuada para la optimización simultánea de la maquinabilidad del material y la vida útil de la herramienta en los procesos de corte de materiales. En este artículo, se expone el diseño robusto probabilístico multiobjetivo (PMORD) y se analiza el problema del diseño robusto en la optimización simultánea de la maquinabilidad del material y la vida útil de la herramienta tomando como ejemplo el mecanizado de acero de doble fase ferrita-bainita.

Métodos: Según PMORD, la media aritmética y su desviación de varios índices de desempeño y utilidad de esquemas alternativos se evalúan como respuestas gemelas independientes, que contribuyen respectivamente con una parte de la probabilidad parcial preferible a los índices de desempeño. En la evaluación se toma como representante del atributo de utilidad la media aritmética del índice de utilidad, y la evaluación se realiza de acuerdo con la función o preferencia del índice de utilidad. Sin embargo, el término de desviación se utiliza generalmente como un tipo de índice no beneficioso (es decir, cuanto más pequeño, mejor) para participar en la evaluación. El producto de las dos partes de la probabilidad parcial preferible es la probabilidad parcial preferible real del índice de desempeño correspondiente. El producto de la probabilidad preferible parcial de todos los índices de utilidad de desempeño da la probabilidad preferible total del esquema correspondiente, que es el único índice para que cada esquema participe en la competencia en diseño robusto.

Resultados: El resultado de la optimización de este ejemplo es que la vida útil de la herramienta es 1297,3333 s (la desviación estándar es 2,0817 s) y la rugosidad de la superficie es 2,22 μm (la desviación estándar es 0,2 μm), mientras que las condiciones de trabajo correspondientes son que la temperatura de tratamiento térmico del material es 790°C, la velocidad de corte es 150 m/min, la velocidad de avance es 0,15 mm/rev y la profundidad de corte es 0,2 mm.

Conclusión: El ejemplo de optimización de parámetros de corte de acero bifásico ferrita-bainita mediante PMORD indica la racionalidad de la solución adecuada.

Palabras claves: optimización multiobjetivo, diseño robusto, optimización simultánea, método basado en probabilidad, probabilidad preferible.

Вероятностное многокритериальное проектирование и его применение при резке металла

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РУБРИКА ГРНТИ: 81.09.00 Материаловедение
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Резка является типичным процессом обработки материалов. Однако подходящего решения для одновременной оптимизации обрабатываемости материала и срока службы инструмента в процессах резки материалов пока не найдено. В данной статье представлено вероятностное многоцелевое робастное проектирование (PMORD) и проанализирован вопрос робастного проектирования при одновременной оптимизации обрабатываемости материала и стойкости инструмента на примере механической обработки ферритно-бейнитной двухфазной стали.

Методы: Согласно ВМРП среднее арифметическое и его отклонение различных показателей эффективности и полезности альтернативных схем оцениваются как два независимых отклика, которые своими показателями эффективности частично способствуют частичной предпочтительной вероятности. При оценке среднее арифметическое индекса полезности берется как признак полезности атрибута, а оценка производится в соответствии с функцией или предпочтением индекса полезности. Однако термин «отклонение» обычно используется как бесполезный тип индекса (иными словами, по принципу: «чем меньше, тем лучше») при оценке. Произведение двух частей вероятности частичного предпочтения представляет собой фактическую вероятность частичного предпочтения соответствующего индекса производительности. Произведение вероятностей частичного предпочтения всех индексов эффективности полезности дает общую предпочтительную вероятность соответствующей схемы, которая является единственным индексом каждой схемы, участвующей в состязании робастных проектов.

Результаты: Результаты оптимизации в этом примере следующие: срок службы инструмента составляет 1297,3333 с (стандартное отклонение - 2,0817 с), а шероховатость

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поверхности - 2,22 μm (стандартное отклонение - 0,2 μm), при соответствующих условиях эксплуатации: температура термообработки материала составляет 790°C, скорость резки составляет 150 м/с./мин, скорость подачи − 0,15 мм/об, а глубина резки − 0,2 мм.

Выводы: Пример оптимизации параметров резки ферритно-бейнитной двухфазной стали с помощью ВМРП свидетельствует о рациональности соответствующего решения.
Ключевые слова: многоцелевая оптимизация, робастное проектирование, одновременная оптимизация, вероятностный метод, предпочтительная вероятность.

Пробабилистички вишекритеријумски робустни дизајн и његова примена у сечењу метала

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ОБЛАСТ: обрада материјала, оптимизација
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Резање је типични процес обраде материјала. До сада још није пронађено одговарајуће решење за истовремену оптимизацију обрадивости материјала и животног века алата приликом обраде материјала резањем. У чланку је представљен пробабилистички вишекритеријумски робустни дизајн (ПМОРД – PMORD). Анализиран је проблем робустног дизајна у истовременој оптимизацији обрадивости материјала и животног века алата на примеру машинске обраде феритно-баинитног двофазног челика.

Методе: Према ПМОРД, средња аритметичка вредност и њено одступање различитих индекса перформанси и корисности шема алтернатива процењују се као два независна одговора који доприносе, једним делом парцијалне пожељне вероватноће, индексима перформанси. При процени, средња аритметичка вредност индекса корисности узима се као представник атрибута корисности, а процена се врши у складу са функцијом или преференцијом индекса корисности. Међутим, термин одступања се генерално користи као некорисни тип индекса (по принципу мање је боље) при процени. Производ два дела парцијалне пожељне вероватноће је стварна парцијална пожељна вероватноћа

одговарајућег индекса перформанси. Производ парцијалних пожељних вероватноћа свих индекса перформанси корисности даје укупну пожељну вероватноћу одговарајуће шеме, што представља једини индекс сваке шеме који учествује у такмичењу у робустном дизајну.

Резултати: Резултат оптимизације у овом примеру је следећи: животни век алата је 1297,3333 с (стандардна девијација је 2,0817 с), храпавост површине је 2,22 μm (стандардна девијација је 0,2 μm), а одговарајући радни услови су: температура термичке обраде материјала је 790°C, брзина резања 150 м/мин, посмична брзина 0,.15 мм/об и дубина резања 0,2 мм.

Закључак: Пример оптимизације параметара резања феритно-баинитног двофазног челика помоћу ПМОРД указује на рационалност одговарајућег решења.

Кључне речи: вишекритеријумска оптимизација, робустни дизајн, истовремена оптимизација, метод заснован на вероватноћи, пожељна вероватноћа.

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NATO attack on FR Yugoslavia in 1999 was used to test the effectiveness of new weapons

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Abstract:

Introduction/purpose: During the 1999 NATO attack on Yugoslavia, three new weapons were used and tested for the first time. The first is the strategically invisible B-2 bomber, the second is the new JDAM (Joint Direct Attack Ammunition) and the third is the "soft bomb", or the blackout bomb, made of thin electrically conductive fibers. The aim of the paper is to present the new combat devices used during the aggression on the FRY and to quantitatively detect the elements of electrically conductive fibers. The paper also presents the lawsuit of the Federative Republic of Yugoslavia (FRY) to the International Criminal Tribunal for the former Yugoslavia (ICTY) in The Hague. The lawsuit was rejected.

Methods: Physical and chemical analyzes of the fibers were performed. An electron microscope, SEM JSM Jeol 6610LV, was used to analyze the physicochemical characteristics of electrically conductive fibers. It provides the information on the morphology of the sample surface, resulting in a high-resolution image.The microscope is equipped with an X-ray detector (Oxford Instrumets X-Max 20 mm2) for EDS analysis (Energy Dispersive Spectroscopy). It enables the determination of the chemical composition of the material in the analyzed sample volume, based on the interaction between the directed electron beam and the sample atom.

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Results: The characteristics of the B-2 stealth aircraft used to bomb the FRY are shown. The JDAM bomb is an improved ordinary MK bomb with electronic devices added to guide the bomb via satellites. A semi-quantitative analysis of the fibers was performed on the SEM, confirming that the metal layer of the fiber predominantly consists of aluminum, and the non-metallic layer has the highest proportion of silicon dioxide. The fiber is carcinogenic.

Conclusion: In 1999, the territory of Yugoslavia was a testing ground for new combat weapons of NATO aviation - B-2 and JDAM guided bombs. Blackout bombs were dropped on the electrical power systems of Yugoslavia leaving the whole Serbia without electricity for hours. Not only was the bombing-caused environmental pollution radiological and chemical but it was also caused by glass-aluminum electrically conductive fibers as pollutants.

Key words: lawsuit, B-2 stealth aircraft, JDAM penetrating bombs, blackout bombs, electrically conductive fibers, environmental pollution.

Introduction

The North Atlantic Treaty Organization (NATO) bombed the Federal Republic of Yugoslavia (FRY) from 24 March, 1999 to 9 June, 1999. The NATO aggression began at 7:41 p.m. on 24 March, and, by 4:00 a.m. on 25 March, 1999, the entire territory of the FRY was under attack with the focus on the Yugoslav Air Force and Air Defense forces and facilities (Gaćinović & Tomić, 2019). The coded name of the bombing campaign was Operation Alied Force or (in the USA) Operation Noble Anvil, known in Serbia as the "Angel of Mercy". This was the final phase in the land grabbing of Kosovo and Metohija, soverign territory of Serbia.

While the aggression was going on, the Yugoslav government filed a lawsuit with the International War Crimes Tribunal in The Hague for the crimes committed by the NATO alliance in Yugoslavia, primarily Serbia, during the bombing.

On 14 May, 1999, the then-prosecutor established a commission to assess the allegations and the supporting documents with the lawsuit, and appointed a prosecutor and deputy prosecutor to consider whether there was a basis for the lawsuit to continue investigating some or all allegations or other incidents tied to the NATO bombing. (International Criminal Tribunal for the former Yugoslavia, 2022)

The lawsuit of FR Yugoslavia stated the attacks on cities, factories, civilians, columns of refugees, as well as the use of prohibited ordnance, cluster munitions and depleted uranium ammunition.

A particular emphasis was placed on crimes in the attacks on civilians:

1. Attack on a passenger train in the Grdelica Gorge on 12 April, 1999,
2. Attack on a Gjakova convoy on 14 April, 1999,
3. Attack on the RTS in Belgrade on 23 April, 1999,
4. Attack on the Chinese Embassy on 7 May, 1999, and
5. Attack on the village of Koriša on 13 May 1999.

FR Yugoslavia submitted evidence of the use of depleted uranium (DU) missiles during the bombing. The court's response was that there is no specific ban on the use of depleted uranium missiles and that there is no consensus in international legal circles that the use of such missiles violates the general principles of humanitarian law applicable to the use of weapons in armed conflict, even in the case of nuclear warheads and other weapons of mass destruction - those recognized as having the most harmful effects on the environment - it is difficult to argue that banning their use in all cases is absolute. (International Court of Justice, 1996)

Based on the information reviewed, the commission considered that neither the in-depth investigation into the bombing campaign as a whole nor the investigation into specific incidents was justified. "In all cases, either the law is not clear enough or investigations are unlikely to lead to sufficient evidence to substantiate charges against high-ranking indictees or lower-ranking indictees for particularly heinous crimes."

And as a conclusion, "based on the available information, the committee recommends that the Prosecution not initiate an investigation into the NATO bombing campaign or incidents that occurred during the campaign." This is the official position and justification of the court for the crimes of the aggression of the NATO alliance and its military members, mostly pilots, in the war against FR Yugoslavia and its people.

The number of killed Serbian citizens, soldiers and police officers is shown in the book "Merciful Angel or Book of the Dead", published in 2008 by Branimir B. Stanojević, writer (Stanojević, 2008). The book lists all civilians, military personnel and police officers killed during 1998 and 1999 by name and surname, in most cases by date of birth. The Albanian victims in refugee columns were also counted. According to the book, 3,799 people were killed during the war in the FRY, including 1,040 soldiers and police officers and 2,560 civilians, including 78 children, 117 Albanian refugees killed in two refugee columns and 82 killed in Gjakova. Unfortunately, the author was not able to find out their names. The list used the data from the Government of Serbia, the Ministry of Defence, the Association of Families Kidnapped and Killed in Kosovo and Metohija, the daily press, official websites of individual municipalities, and many books and publications published in different cities. (Stanojević, 2008)

The aggression against Serbia continues today, but in a different way. "Bombed today, die later," is one of the headlines (Graham, 2004, pp.34-36). Today, 23 years after the bombing, more and more people and children are suffering from various types of diseases, children with malformations are being born, there are more and more cases of sterility, and the nature remains polluted in the places that have been intensively bombed.

In the territory of FR Yugoslavia in 1999, an experimental war was waged, initiated to allegedly protect Albanian civilians from the so-called Serbian agression, and the goal was to break up Serbia and separate Kosovo and Metohija from its homeland.

During the aggression, the territory of FR Yugoslavia, especially Serbia, served the Western Military Alliance (NATO) as a testing ground for new weapons and for testing the efficiency of American invisible (stealth) aircraft. Three types of combat means were tested: the B-2 strategic bomber, whose deadly debut was on the Yugoslav territory; demolition precision-guided JDAM bombs carried by the B-2 bomber; and blackout bombs (electrically conductive fibers).

The environmental pollution since the 1999 bombing can be divided into three major groups:

- Radiological pollution,
- Chemical pollution, and
- Pollution due to glass-aluminum electrically conductive fibers, which can also be classified as chemical pollution.

The paper will present all aspects of the pollution, with a special emphasis on electrically conductive fiber pollution, which was not given enough attention - it was considered harmless because it is not radioactive and consists of aluminum and glass. However, there is information that the people who worked on cleaning the transmission lines and substations from that "cobweb" became seriously ill and almost all died very soon after the war (Anđelković-Lukić, 2015, p.25).

Radiological effects of pollution

Using depleted uranium (DU) missiles (anti-tank ammunition and ammunition of large caliber of great destructive power to destroy concrete fortifications and bunkers), NATO waged a specific radiological war against the FRY, with long-term pollution of ecosystems and attempts to destroy life in this area, which will have unforeseeable consequences for

the whole living world, not only in the region, but also in Europe (Fortuna & Dimitrijević, 2000).

Based on the examination of the remains of the projectiles performed by the FRY army and on the basis of the performed spectrometric measurements and identification of the present radionuclides, it can be reliably claimed that NATO forces deployed DU-core ammunition from A-10 aircraft. It is estimated that the United States alone has at least 700,000 tons of depleted uranium, or radioactive waste. Storage of such material is expensive, and a useful way has been found to reduce its amount by using it for 30 mm sub-caliber ammunition, as well as for larger calibers. Due to its large atomic mass, it is used for the core of anti-tank rounds. The US Army developed DU ammunition for 25 mm gun (85 g uranium), 30 mm air gun (278 g uranium) and 105 and 120 mm tank guns (2.2 to 4.9 kg uranium) [23].

On 21 June, 2009, Belgium became the first country in the world to ban submunitions and armors containing depleted uranium or any other industrially produced uranium.

This ammunition was banned even earlier by the Resolution of the Subcommittee on Prevention, Discrimination and Protection of Minorities of the UN Commission on Human Rights from 1996 and 1997.

During the aggression on the FRY, the Yugoslav army conducted radiological and chemical reconnaissance of the areas where A-10 were deployed. It was found out that there are four areas in Serbia outside Kosovo and Metohija where radiological contamination was recorded: (Fortuna& Dimitrijević, 2000)

"Borovac" - two locations about 6 km south-east of Bujanovac
time of impact 26.05.1999
contamination (KonZ) area 9,100 m2
DU activity (Bq / kg) in the soil samples 250-17,490

"Bratoselci" - about 10 km south-east of Presevo
time of impact 27.05.1999
KonZ area 5,400 m2
DU activity (Bq / kg) in the soil samples 1,800-23,400

"Reljan" - two locations, east of Presevo for about 10 km
time of impact 28.05.1999
KonZ area 8,700 m2
DU activity (Bq / kg) in the soil samples 70-200

"Pljačkovica" - north of Vranje for about 4 km
time of impact 29.05.1999
KonZ area 2,400 m2
DU activity (Bq / kg) in the soil samples 5,580-235,000
* KonZ- contaminated area

Pljačkovica, the hill above Vranje where a repeater is located, was hit by a large number of DU rounds. The solid, rocky base of the hill enabled firing of rounds and dispersion of radioactive aerosols over long distances. The hill dominates the city, so that a large amount of radioactive particles reached the inhabitants of Vranje, and spread farther.

The main danger to humans is the inhalation of aerosols in the immediate vicinity of the affected object. Internal radiation is much harder to avoid. The largest amount of DU is inhaled by persons who are in the immediate vicinity of the affected area at the time and immediately after the impact. It is not excluded that one hundred milligrams of DU is inhaled in such cases. Inhaled aerosols have both soluble and insoluble components. Acute consequences caused by uranium chemotoxicity are not excluded from the soluble component. Total equivalent doses can be as much as a tenth of a millisievert. (Đurović et al, 2011)

In the later phases after the impact, especially when mitigating the consequences, additional inhalation of aerosols in the vicinity of the impact site is not excluded. The reason is the resuspension of the aerosol in air caused by wind or movement of vehicles and people. Equivalent doses in these cases are significantly lower and can hardly exceed tens of millisieverts. (Đurović et al, 2011)

If the target is missed, a small percentage of DU goes into the phase of insoluble aerosols because the round penetrates the soft soil. In contact with water or moisture, uranium metal corrodes quickly. Under the influence of air and water, a very clearly visible yellow oxide layer is formed. Over time, the oxide layer becomes radioactive contamination that can be easily transferred to the wider environment. In addition to the dominant presence of uranium, the X-ray fluorescence spectrometry of the projectile core identified the presence of iron, titanium, nickel, zinc, copper, and zirconium in small concentrations.

The addition of titanium reduces the corrosion rate of the projectile (Đurović, et al, 2011). The data for central Serbia without Kosovo and Metohija and AP Vojvodina are presented.

Depending on the geological situation, pollution of even groundwater is not excluded. From 1999 to 2019, in central Serbia, there is a constant increase in mortality from various polluting agents thrown during the 1999

aggression, as shown in Figure 1. In terms of the number of cancer deaths, Serbia ranks first in Europe.

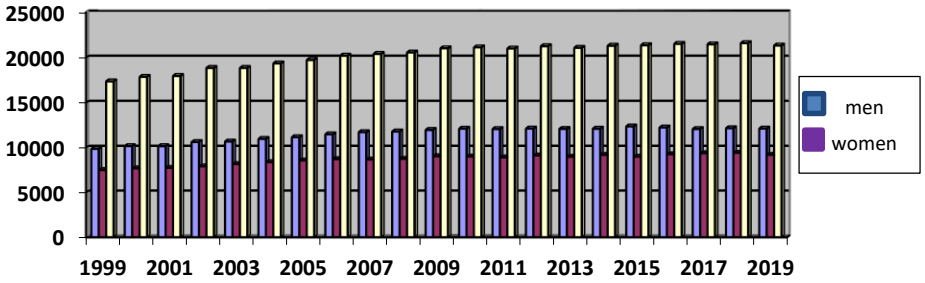

Figure 1 – Mortality in central Serbia according to the "Cancer Registry in the Republic of Serbia, 2021" (data for central Serbia, excluding Kosovo and Metohija and AP Vojvodina) (Institute of Public Health of Serbia "Dr Milan Jovanović Batut", 2021)

Projectiles dropped on the FRY territory during the 1999 aggression

Depending on their destructiveness and purpose, all projectiles dropped on the FRY during the bombing can be classified into the following groups:

- guided and unguided high-explosive projectiles of various calibers (missiles, bombs and cluster bombs),
- anti-armor and anti-concrete projectiles, filled with DU,
- new types of so-called "soft" bombs, which do not have an effect of destruction, but inflict substantial damage, and
- new piercing bombs, large in mass, used for the first time and tested on the Yugoslav battlefield, dropped on the territory of the FRY from the B-2 strategic bomber which also had its combat debut in the military operation over Yugoslavia.

During the NATO aggression on the FRY, 26,095 air raids were registered, out of which 18,168 were conducted by combat aviation. About 37,000 missiles, bombs and other projectiles were launched, out of which 1,400 were cruise missiles with about 40,000 tons of high-explosive ordnance.

At the beginning of the aggression, NATO deployed 371 aircraft a day, and at the end of the aggression, that number was increased to 1,200 aircraft a day (Anđelković-Lukić, 2015).

The NATO alliance did not directly use chemicals in the attack on FR Yugoslavia (poison gases, for example); however, by precisely targeting metal-industrial plants and warehouses of chemical raw materials, oil tanks and oil plants, as well as substations normally containing large quantities of pyralene, they produced effects which were very close to the effects of chemical warfare, that is, as if they used poison gases. (Anđelković-Lukić, 2021, pp.147-168)

The combustion products from composite gunpowder-powered missiles were dispersed in the air, heavily polluting it. The huge amount of kerosene burned in the aircraft that flew at high altitudes also contributed to chemical pollution.

Each detonation of high-explosive ordnance releases a large amount of poisonous and suffocating gases from the explosion process itself, the product of detonation in the places affected. For example, only one penetrating missile, AGM 130, loaded with the most commonly used explosive tritonal (370kg, TNT 80 / Al 20,) releases 5173 m3 of a mixture of toxic gases and 146 kg of carbon during detonation, all in the form of the most dangerous nanoparticles. (Anđelković-Lukić, 2021, p.153)

JDAM penetrating bombs first combat deployed on the territory of FR Yugoslavia

In 1999, in addition to classic unguided MK bombs for carpet bombing, FR Yugoslavia was targeted with new penetrating, laser-guided missiles powered by large masses of explosives. It is highly likely that projectiles had depleted uranium charges because they were used to penetrate fortified underground tanks, underground aircraft hangars and underground ammunition depots (Di Pietro & Accame, 2006). These are JDAM bombs (Figure 2) and AGM cruise missiles, with the GBU 31 warhead, the characteristics of which are shown in Table 1. These bombs were active in Serbia in 1999.

The Ponikve military air base, located 12 kilometers northwest of Užice, was hit by more than 700 missiles and cruise missiles in 37 attacks during the NATO bombing, out of which about 40 remained unexploded in the ground. One of the unexploded projectiles unearthed by a demining team in 2012 was the GBU31, JDAM with the MK warhead (Table 2), which proved that they had used new, modified penetration bombs experimentally. The most frequent targets of the NATO bombing were the military airports Ponikve near Užice and Dubinje near Sjenica (bombed almost 30 times with over 300 projectiles). (Tošić, 2021)

During the aggression in 1999, the Command Center on the Straževica hill near Rakovica was bombed daily, but due to its natural protection (the center was buried in the hill) it could not be destroyed.

Table 1 shows some of the characteristics of large penetrating bombs dropped by stealth aircraft on FR Yugoslavia in 1999.

Table 1 – Characteristics of laser-guided penetrating bombs which were tested in real conditions on the territory of the FRY in 1999

The name of the bomb	Winged bomb **AGM*-130, BLU**-109**	**GBU***-27 system **JDAM**** **BLU-109**	**GBU-31 system JDAM BLU-109**
Total weight (kg)	1323	1065	2130
Type of explosive	Tritonal (TNT 80/Al 20)	Tritonal (TNT 80/Al 20)	Tritonal (TNT 80/Al 20)
Explosive mass (kg)	430	240	306
Length (m)	3.9	4.24	5.27
Range (km)	48	20	10
Aircraft carriers	B1-B,B-2, B-52	F117-A	B1-B,B-2

*__AGM__ Air-launched, surface-attack, guided missile,
**__BLU__ Bomb Live Unit
***__GBU__ Guided Bomb Units
****__JDAM__Joint Direct Attack Munition

Military fortifications are made of reinforced concrete with strong metal reinforcement, rebar, and therefore it is necessary that the warhead, in addition to high explosive, have a penetrator, which upon impact releases high temperature necessary for the penetration of metal reinforcement.

One of the aerial lethal weapons used for the first time during the NATO aggression on the FRY were satellite-guided general-purpose air bombs of the JDAM system.

One of the systems of guided air bombs is shown in Figure 2.

a)

b)

Figure 2 – JDAM guided air bomb (Valka, 2022)

The JDAM bomb is a modernized variant of the unguided MK general purpose bomb, improved by adding GPS guidance, and from these cheap unguided bombs a successful variant of the JDAM guided bomb was obtained. They are applied during air strikes on well-defended objects from medium and higher heights. The carrier aircraft ejects JDAM in all meteorological conditions on the principle of "launch and forget" from a great distance and altitude and out of the reach of the Yugoslav air defense. According to the Pentagon report, the bombs carried by the B-2 stealth aircraft were marked GBU-31, with a BLU-109 warhead, powered by tritonal explosives, as shown in Table 1. (Navedtra 14014A, nd)

At the Dubai International Fair in 1999, immediately after the war in Kosovo and Metohija, an arms dealer presented the BLU-109 warhead and described its capabilities in penetrating super-armored underground targets, explaining that this model had been tested in the recent war in Kosovo (Parsons, 2002). During the aggression, more than 500 JDAM bombs were dropped on the FRY from the B-2 strategic bomber alone, which carries 16 pieces each. After the bombing of the FRY, sales of this guided bomb increased, so it ended up in the armament of many NATO members and some Arab countries.

B-2 strategic aviation aircraft carrying JDAM penetrating bombs

B-2 stealth bombers were used against the integrated air defense system of Serbia, command and control points, runways and airports, communication facilities, factories, bridges and other elements of infrastructure. The first American aircraft used in the allied forces were B-2s which took off from the Whitman Continental Base in Missouri. One such plane bombed the Chinese embassy in New Belgrade in 1999, on 5 June. Six B-2 aircraft constantly took part in the bombing of FR Yugoslavia. The report of the 509th Air Brigade states that all B-2 planes proved to be extremely efficient. Only one plane "had mechanical problems in flight" and had to stop the mission (until the breakdown was repaired). (Tirpak, 1999)

The B-2 aircraft operated exclusively at night, sometimes on a mission with two more planes, but mostly alone. They did not fly in a group with other NATO aircraft because they had a large radius of movement. They took off from the Whitman Continental Base in Missouri and returned without landing. The flight lasted for 30 hours. They were supplied with kerosene in the air. When approaching a specific target area, the B-2 had a radar image almost photographically accurate in detail and quality. This was checked on the basis of intelligence photographs, and the target was identified. At the appropriate moment, the door of the bomb bay opens, JDAM is dropped from the plane, and directed towards the target.

Table 2 – Physical characteristics of conventional explosives

Explosive	Point of melting (°C)	Heat of explosion Qe (kJ/kg)	Explosion temperature Te(°C)	Detonation velocity D (m/s)
TNT trinitrotoluen $C_7H_5N_3O_6$	181-182	4561	3169	6900 (for density 1.60 g/cm^3)
RDX Ciklo-trimetilen trinitramin $C_3H_6N_6O_6$	205	6322	4249	8750 (for density 1.76 g/cm^3)
HMX Ciklo-tetrametilen tetranitramin $C_4H_8N_8O_8$	275	6192	4249	9100 (for density 1,90 g/cm^3)

Table 2 shows that the heat of explosion Qe and the explosion temperature Te of the explosives used are very high (Hristovski, 1994), so that the detonation products are in a gaseous state with very fine combustion particles, of the order of nanometers. These particles are easily inhaled and remain in the lungs for a long time. The high temperature of the explosion enables the formation of nanoparticles in the products of detonation. The size of particles depends on the temperature - the higher the temperature, the smaller the dimensions of formed particles (Gatti& Montanari, 2004). In combination with various additives to explosives due to increased energy performance, and in synergy with released radicals (chlorine or fluorine) or oxides (mainly metals, aluminum, magnesium) in detonation products, these particles become very toxic. (Agency for Toxic Substances and Disease Registry, 2004, 2014)

Toxic gaseous products of detonation and combustion of gunpowder in high concentrations are found in craters immediately after the explosion. Later, they are dissolved in the air and dispersed in the immediate vicinity of the bombed site. They have an extended duration of action on human health.

Various heterogeneous gunpowders are used as a combustion charge in long-range projectiles, mainly missiles. These are homogeneous, physical mixtures of oxygen-rich compounds (mostly inorganic crystalline salts) and fuels (usually of organic origin) which under certain conditions in the combustion process (oxidoreduction) react with each other, producing heat and high pressure gases. Of such gunpowders, the most famous are composite rocket gunpowders, i.e., propellants.

Composite rocket propellants (Orbović, 2020, p.329) consist of oxidants, mainly ammonium perchlorate 60 - 80%, binders which ensure the cohesion and homogeneity of oxidants, and fuels, and are formed from prepolymers such as polybutadiene, curing agents (toluene diisocyanates), adhesives (triethanolamine), plasticizers (diisocotyl sebacate), cure catalysts (ferriacetone acetonate, lead chromate), aluminum, about 25% of combustion accelerators, antioxidants based on phenol and amine) and combustion stabilizers (acetylene carbon black and aluminum powder). These are mostly general components of composite rocket propellants, but they can also be enriched by very fine-grained explosives and energy fluorine compounds, such as formals, also explosives, fluoronitroformals, in order to increase energy characteristics. Combustion products contain metal oxides (aluminum, iron, lead, and chromium).

During combustion of different types of gunpowders (rocket propellants), among combustion products there are carbon monoxide,

carbon dioxide, nitrogen oxides, hydrogen cyanide, soot, etc. Metal oxides of lead, copper, magnesium, aluminum, but also some aggressive radicals caused by incomplete combustion are also found in combustion products. Some of composite gunpowders also contain transformer oil, chlorinated biphenyls, which when burned release a whole range of toxic genotoxins, polychlorinated dibenzofurans, chlorinated benzoparadioxins, chlorinated phenols, hydrogen chloride, and soot. Solid combustion products are distributed in the gaseous phase in the form of fine particles, measuring about 5 micrometers and less, forming aerosols of smoke. Salts of heavy metals present in these combustion products, especially lead, are toxic. These products can cause skin reactions. All these combustion products are toxic and carcinogenic, they fell to the ground polluting the environment and have a delayed effect on the health of the population.

There are no lethal devices such as bombs, mines or projectiles that do not contain a pyrotechnic element. A complete system of rockets, from the smallest to the largest, contains pyrotechnic parts. Pyrotechnics have enough energy in a small volume to achieve desired effects. The only external energy required for proper functioning is the initial pulse, usually electrical, which can be controlled with great precision to avoid unwanted initiation and to deliver just as much energy to the system as needed to properly and reliably start a reaction (detonation). Pyrotechnic mixtures contain oxidants, fuels (inorganic and organic) and additives. Inorganic salts of sodium, potassium, barium, lithium, strontium, lead and iron are used as oxidants. Inorganic fuels are mainly calcium, beryllium, boron, lithium, silicon, aluminum, magnesium, and of organic fuels, the most commonly used are polyethylene, polyester, asphalt, naphthalene, carbon, polyesters, polyamides, and nitrocellulose (Orbović, 2020, p.329). Pyrotechnic mixtures are very important in the initial chain - they are in fuses and if there is a break in the chain, there is no activation of ordnance. Due to that mistake, inactivated bombs fell on the territory of Serbia, representing a great danger to deminers during UXO removal and destruction.

Blackout bombs

The third weapon used for the first time during the bombing of FR Yugoslavia were blackout bombs, as the Pentagon called them. It was an extremely guarded military secret of the Pentagon, revealed on the battlefield of FR Yugoslavia. There were great expectations of this bomb which was supposed to cut off electricity in Serbia for a long time and thus

disable the functioning of the bloodstream of civilian life, the civilian infrastructure.

Electricity supply is a very important factor for the functioning of all activities in one society. Therefore, it is considered that the attack on the power grids, nuclear power plants and computer systems of one country is a terrorist act and that all security measures must be taken to prevent that from happening. Given that the power grid of FR Yugoslavia in 1999 was attacked by blackout bombs, and the whole electrical power system of Serbia was brought to a standstill for 70 hours in one period, according to the definition of American terrorism experts, it was one of the terrorist actions of the NATO alliance. In addition to being aggressors, NATO acted as a terrorist in the Republic of Serbia. (Nye, 2019)

The CBU-102 (B) 2 / B "soft bomb", a cluster bomb, was used to attack the Serbian electricity grid, with BLU-114 / B cassettes filled with small coils of electrically conductive fibers that scatter into a cloud of micron-thin threads and cause short circuits on the power grid. Similar weapons were successfully used in the Operation Desert Storm against Iraq in 1991, but these bombs contained graphite fibers.

The new CBU-102 (B) 2 / B bomb, with satellite guidance to the selected target, was carried by a B-2 stealth bomber. The bomb tracks signals from global positioning satellites to reach its target - a substation or a transmission line. Its cost is unknown, but some analysts estimate it is probably below $ 100,000. Figure 3 shows the appearance of a cassette containing fiber coils.

Figure 3 – Appearance of the cassette with threaded conductors

In each BLU-114 / B cassette there are a total of 147 coils with electrically conductive fibers. The thickness of individual threads is 6 to 7 μm. There are about 30 fibers twisted in one thread. When falling on high-voltage lines of power systems, the coils fall out of the cassettes, unwind and form giant, superconducting "cobwebs" which cover power lines and cause short circuits with huge, lightning-like electric discharges. Unwound threads have a length of about 150 m, and when falling, the basic thread is unwound into a larger number of thinner ones, creating a net that covers large areas and has a greater strength than individual threads (Dnuo Zhend Technology New material, 2022). The network of conductive fibers is dispersed on the elements of a plant or on the transmission line and brings them into a state of permanently short-circuited elements, so that they are disabled until all conductive fibers are removed, even the smallest elementary threads. It turns out that the technical problem is solved by removing the fibers to the level of elementary threads with procedures that do not require much time, and guarantee the safety of the engaged workforce. The most efficient ways to remove fibers are mechanical, with the use of convenient tools and vacuum cleaners. All conductive material has been carefully collected and disposed of so that it cannot come into contact with electrical lines again. Residues of conductive material that could not be collected from the ground were chemically treated with 5% sodium hydroxide solution so that the aluminum lost its conductivity. The most effective way of sticking the fibers to the soil was by sprinkling water glass or dilluted starch. (Filipović, 1999)

The "soft bomb" for blackout was produced in 1994, and was included in the weapons of the United States in the late 1990s as a closely guarded secret.

It was tested for the first time in real conditions on the territory of Yugoslavia on May 2, 1999 (Anđelković-Lukić & Stojanović, 2020). When it falls from the plane, the bomb rotates vertically, and then discards the outer shell and begins to rotate. When it rotates, it releases two hundred submunitions (cassettes) the size of a beer can, each of which contains thousands of thin fibers. A small explosive charge inside each box detonates, scattering fibers like electrically conductive cobwebs and forming a "net" that slowly descends. (Ricks, 2002)

The appearance of unwound electrically conductive fibers under an optical microscope is shown in Figure 4. When this conductive network falls on a target — an electric transformer, a transmission line, or a substation — it causes thousands of explosive short circuits, i.e., fires, thus disabling the target.

For a long time, no attention was paid to the information that the workers who were removing the conductive "cobweb" from the electrical grid elements (transmission lines and substations) died of leukemia very soon after (a year or a year and a half). The information about the death of these workers after cleaning the power lines from the "cobweb" was obtained from the employees of Elektrodistribucija in 1999 who were union presidents and leaders of relevant sectors. (Anđelković-Lukić , 2015, p.25). This knowledge, which has been downplayed for a long time, shows that the bombing of the FRY in 1999 had three important aspects that affected human health: radiological, chemical and conductive fibers. On the basis of both this information and the same information obtained from the ED Nis, we started detailed research on the physico-chemical characteristics of these electrically conductive fibers.

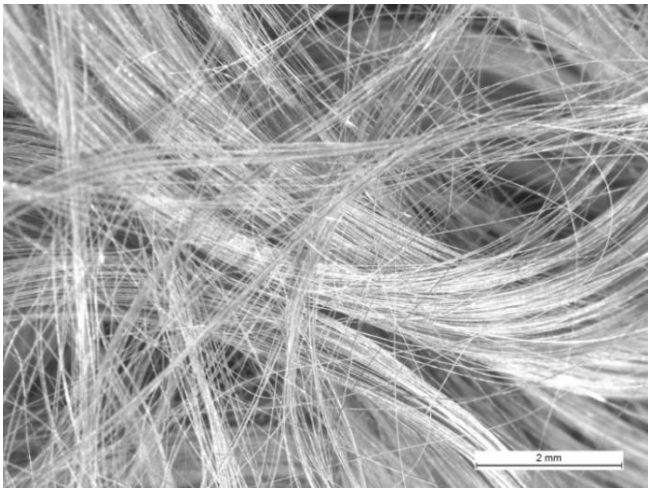

Figure 4 – Appearance of fibers under a stereo-optical microscope

The images from the electron microscope showed that the fiber consists of two bonded layers: glass (SiO_2) and metal (aluminum), as seen in Figure 5 (EDS analysis is given later in the text).

Glass fibers are a new inorganic non-metallic material. They are made from natural minerals such as kaolin, pyrophyllite, quartz sand, limestone, etc., in accordance with a certain formula, by high-temperature melting, extraction, winding and other processes. The diameter of a monofilament is between a few micrometers and more than 20 micrometers, which is equivalent to 1 / 20-1 / 5 hairs. (Dnuo Zhend Technology New material, 2022)

Synthetic glass fibers are inorganic fibrous materials, produced mainly from glass or stone. Commercially important synthetic glass fibers are primarily based on silicon dioxide, but contain various contents of other oxides (e.g. aluminum, boron, calcium, or iron oxide). Synthetic glass fibers have amorphous molecular structures, while natural mineral fibers, such as asbestos, have crystalline structures. Continuous glass filaments refer to glass fibers produced by extrusion. More than 98% of the continuous glass produced are E filaments for electrical applications. E glass fibers, which are mostly used in electronics and electrical engineering, with an adhered layer of aluminum, were used in blackout bombs. (Filipović, 1999)

Figure 5 shows a photomicrograph of a fiber, where the darker part is a layer of aluminum (Al) and the lighter part is glass (SiO_2). Microphotographs obtained from a scanning electron microscope (SEM), (Reimer, 1998), have shown that this is a modern technology, by which two very thin components of these fibers are adhered.

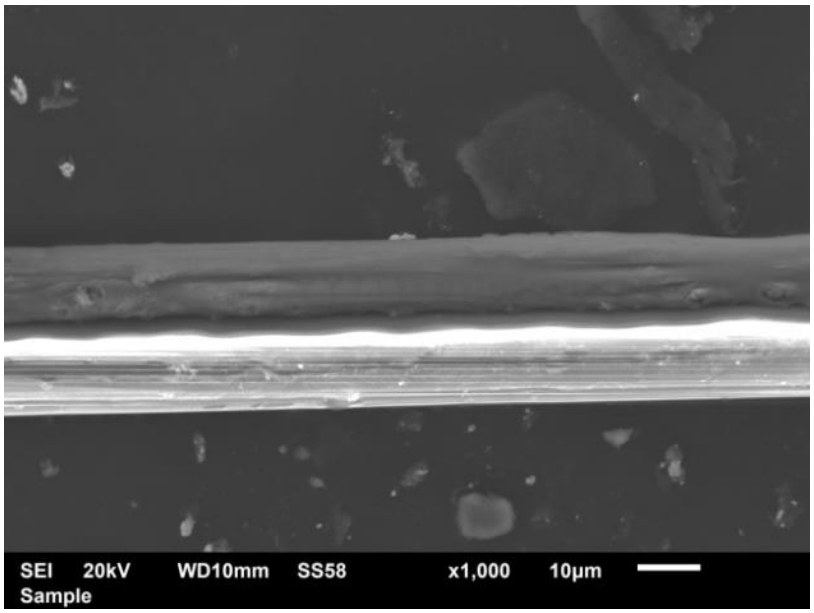

Figure 5 – Microphotograph of a SiO2 / Al composite fiber (SEM)

The thickness of the layers varies along the sample, without interrupting the continuity of the layers, and at the interface it is visible that adhesive bonding is uneven, with penetrations into one or the other

component. Figure 6 shows a segment of a composite fiber at 2,000x magnification.

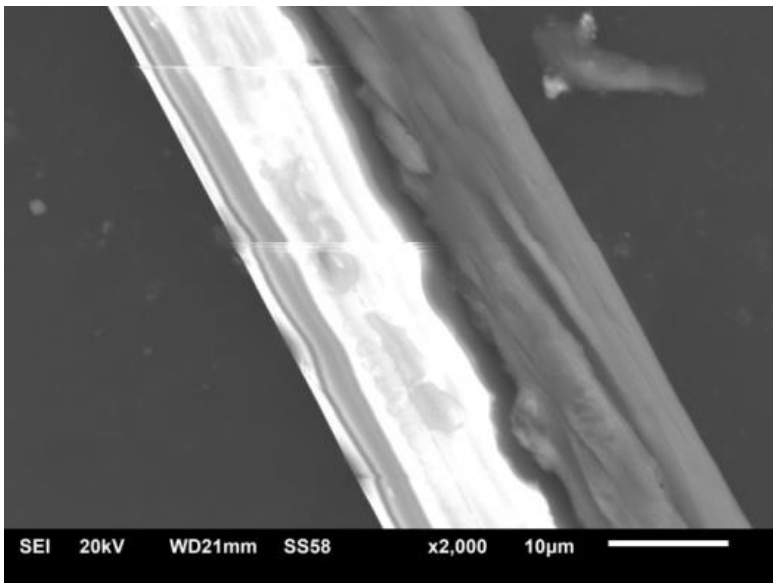

Figure 6 – Uneven adhesive bonding of fiber components (SEM)

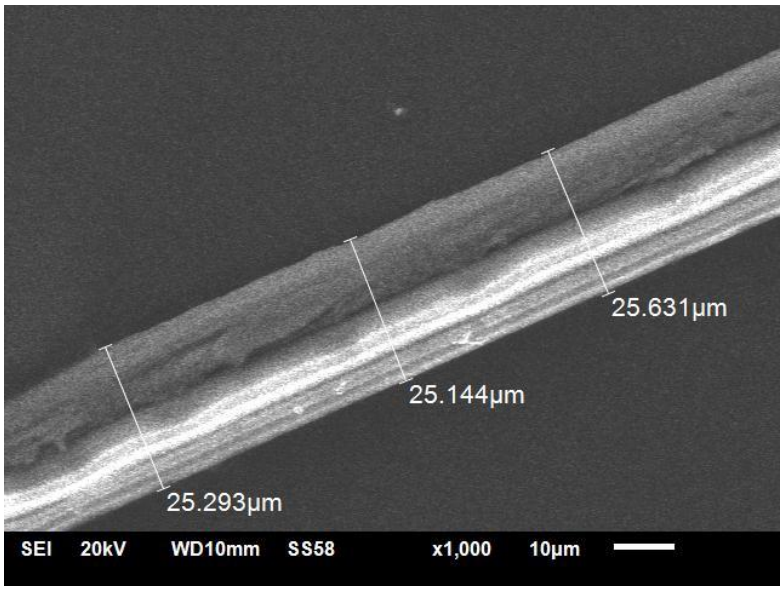

Figure 7 – Diameter of a fiber composed of two components: glass (darker) and aluminum (lighter) (SEM)

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Figure 8, which was taken at a magnification of 1000x, shows the dimensions of the individual layers of glass (SiO_2) and aluminum (Al). The thicknesses of the individual glass and aluminum composites are not the same in all sections.

However, this in no way interferes with their function, the conductivity of electric current, because the layers are continuous, without interruption.

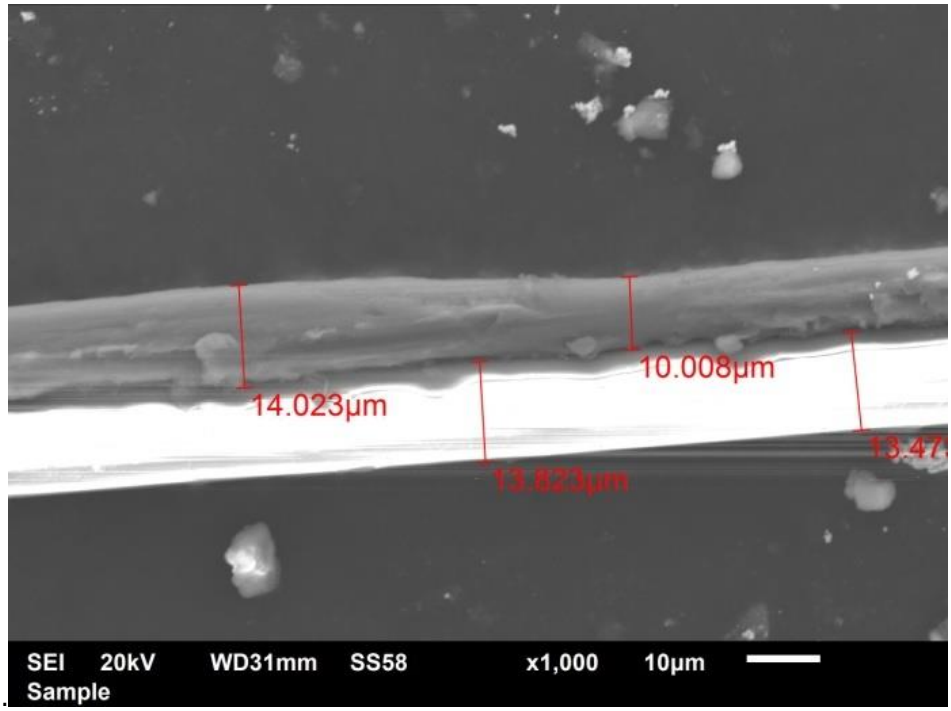

Figure 8 – Dimensions of individual components SiO2 and Al (SEM)

A semiquantitative analysis on fiber segments was performed by the EDS method (Energy Dispersive x-ray Spectroscopy - EDS) on a scanning electron microscope.

With this method, the composition of the material was obtained by analyzing the obtained spectra.

Since the analysis includes a small volume of material, the EDS method is qualitative, but semi-quantitative. (Reimer, 1998)

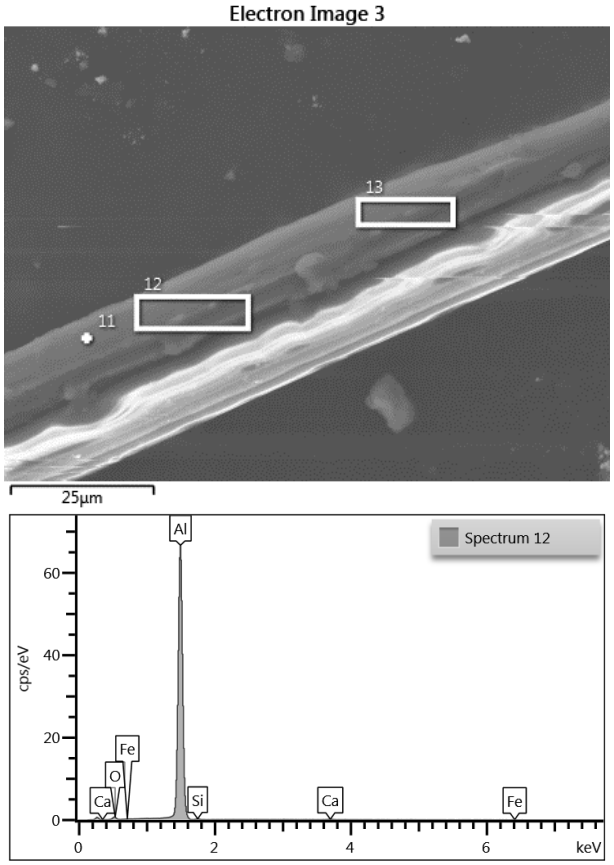

Figure 9 – Semiquantitative analysis of the composition of the aluminum part of the fiber and the typical spectrum (SEM/EDS - Scanning electron microscope/Energy dispersive x-ray spectroscopy)

Table 3 – Semiquantitative analysis of the composition of the aluminum part of the fiber from Figure 9

Element	mas.%			mas.%
	Spectrum11	Spectrum12	Spectrum13	Middle value
O	8.29	4.26	3.90	5.48
Mg	0.08	-	-	
Al	**91.43**	**94.64**	**95.76**	**93.94**
Si	0.09	0.69	0.16	0.31
Ca	0.04	0.25	-	
Fe	0.09	0.17	0.18	
total	100	100	100.00	100

The results indicate the predominant presence of aluminum and a small proportion of oxygen, while other elements are found in negligible amounts.

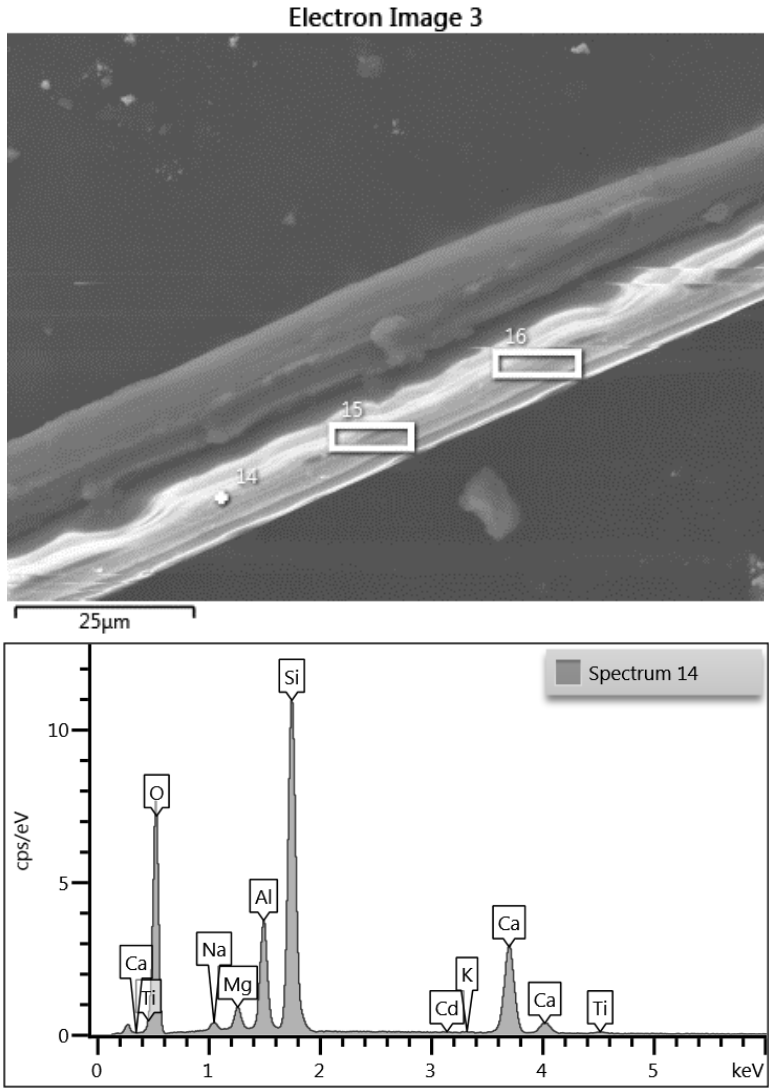

Figure 10 – Semiquantitative analysis of the glass fiber composition and a typical spectrum (SEM/EDS)

Table 4 shows the results of the EDS analysis of the glass part of the fiber from Figure 10.

Table 4 – Semiquantitative analysis of the composition of the glass part of the fiber from Figure 10

Element	mas.%			mas.%
	Spectrum14	Spectrum15	Spectrum16	Middle value
O	**52.01**	**51.25**	**51.32**	**51.53**
Na	0.83	0.88	0.85	0.85
Mg	1.76	1.83	1.78	1.79
Al	**7.80**	**8.08**	**8.17**	**8.02**
Si	**24.98**	**25.40**	**25.13**	**25.17**
K	0.11	12.30	0.11	4.17
Ca	**12.08**	**0.27**	**12.19**	**8.18**
Ti	0.30	51.25	0.28	17.28
Fe	-	-	0.17	
Cd	0.13	-	-	
total	100	100	100.00	100.00

In the glass part of the fiber, there is a large mass content of oxygen, silicon and calcium, which are the components coming from raw materials in glass processing. The oxygen content indicates the presence of oxides. The aluminum in the analysis originates most likely from the fiber glass part in the bond. In addition to aluminum, silicon and calcium, a smaller amount of sodium, magnesium and potassium was detected, as well as traces of iron and cadmium.

The health of the people who cleaned these fibers was endangered due to the inhalation of small parts of this conductive composite. This is where the causes of illness and death of people who cleaned the electro-conductive cobweb should be looked for. Doctors should examine the ffects of these fibers on health.

Types of processed glass include glass fibers and glass wool. Recently, the World Health Organization (WHO) and the IARC classified synthetic glass fibers into two categories: filaments (fibers) and wool. Direct exposure to these types of glass causes irritation of the skin, eyes and upper respiratory tract, which poses a health hazard. Glass fibers used for blackout bombs belong to the category of E fibers.

Inhalation of synthetic glass fibers suspended in the air as well as other particles causes their deposition in the lungs. Concentrations of

synthetic glass fibers in air samples are usually represented as the number of fibers per cubic centimeter of the air (number of fibers / cm3 of the air). Inhalable fiber is usually defined as a fiber <3 μm in diameter. In general, small diameter fibers are easier to suspend and remain suspended in the air for longer than larger diameter fibers.

The results of animal studies indicate that inhalation of any synthetic glass fiber can cause pneumonia. Synthetic glass fibers have been shown to cause pulmonary fibrosis, lung cancer, or mesothelioma (Agency for Toxic Substances and Disease Registry, 2004, 2014).

In the "List of Candidate Substances of Concern", out of 211 substances that are carcinogenic and toxic, silicon and aluminum fibers are listed as carcinogens at position 28. (Službeni glasnik RS, 58/2016)

Conclusion

During the 78 days of bombing of FR Yugoslavia, the NATO alliance used the opportunity to test new combat and lethal weapons developed in the late 1990s.

For the first time over the FRY, new, so-called invisible "stealth" B-2 aircraft flew in bombing operations from the Whitman land base in Missouri to bomb the Chinese embassy in Belgrade in one of their deadly flights. They carried JDAM penetrating bombs. The flight of these aircraft from the base to a certain location in the FRY and back lasted 30 hours without interruption. Their designers were very satisfied with their "successful" bombing actions destroying the infrastructure of one country and killing its population. Six B-2 aircraft took part in the aggression against the FRY.

The territory of the FRY was also used to test the effects of new bombs in urban areas, weighing from 1,100 to 2,500 kg. These were adapted JDAM penetrating bombs, produced to destroy underground warehouses, bunkers and underground air bases.

The third weapon, which was kept as a top military secret, were blackout bombs. These so-called "soft bombs" (because they do not have immediate lethal effects) also appeared on the FRY battlefield for the first time in 1999. It was a high-tech product, composed of cassettes containing coils of electrically conductive fibers formed by adhesing layers of aluminum and glass into one thin thread. These fibers were thrown from US made container bombs and when they fell, they unwound and formed huge electrical cobwebs. These cobwebs fell on Serbian electrical systems and caused power outages in a large part of Serbia due to short circuits. As a result of their actions, Serbia was without electric power for 70 hours in one period. However, Serbian engineers and electrical experts solved

the cobweb problem very quickly, so that it was no longer a threat to Serbia's energy system.

From the presented work, it can be concluded that the NATO deployed an illegal act of agression by bombing a sovereign country making its population suffer due to, among other things, depleted uranium bombs, fires set to chemical plants and oil tanks, polluted air and soil with chemical agents, etc. Thus, the health of a large number of inhabitants, children included, was and has been endangered in FR Yugoslavia. From year to year, mortality from various types of cancers is increasing. In terms of cancer mortality, Serbia ranks first in Europe.

In addition to these two health aspects, radiological and chemical, there is the third one, caused by the effects of glass-aluminum fibers during their removal. Micro pieces of fibers, smaller than 1μm in size, could be inhaled thus harming the health of people who were removing cobwebs and restoring the power grid. A large number of young people who used hand tools, brooms and various sticks to clean transmission lines and substations from conductive cobwebs died of leukemia very soon after the aggression stopped.

The consequences of that act of agression without international legal approval are still being felt today - many people have suffered from various diseases related to the bombing, and the number of cancers and sterile marriages has increased, as well as the cases of sterility in men and children born with anomalies.

Despite the fact that it was formally established in 2018, a Serbian commission with the task to examine the impact of pollution on the health of the population has not come to life until today. There is no official list of cancer-diagnosed individuals who were engaged in Kosovo and Metohija in 1999. The number of people killed and wounded during the bombing was not listed at the state level. This was done by personal effort of writer Branimir Stanojević, who listed the names of all the victims killed by NATO in FR Yugoslavia.

This 1999 savage bombing of FR Yugoslavia by NATO and its members and associated countries must never be forgotten not only because of heavy human sacrifices and destruction suffered by the Serbian people but also because of future lives to be lost due to the consequences of radiation and chemical pollution.

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El ataque de la OTAN a la República Federativa de Yugoslavia en 1999 fue usado para probar la efectividad de nuevas

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CAMPO: tecnología química
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: Durante el ataque de la OTAN a Yugoslavia en 1999, se utilizaron y probaron por primera vez tres nuevas armas. La primera es el estratégicamente invisible bombardero B-2, la segunda son las nuevas Municiones de Ataque Directo Conjunto-JDAM (Joint Direct Attack Ammunition)- y la tercera es la "bomba blanda", o bomba opaca, hecha de finas fibras conductoras de electricidad. El objetivo del artículo es presentar los nuevos dispositivos de combate utilizados durante la agresión a la República Federativa de Yugoslavia y detectar cuantitativamente los elementos de las fibras conductoras de electricidad. El artículo también

presenta la demanda de la República Federativa de Yugoslavia (RFY) ante el Tribunal Penal Internacional para la ex Yugoslavia (TPIY) en la Haya. La demanda fue rechazada.

Métodos: Se realizaron análisis físicos y químicos de las fibras. Se utilizó un microscopio electrónico, SEM JSM Jeol 6610LV, para analizar las características fisicoquímicas de fibras eléctricamente conductoras. Proporciona información sobre la morfología de la superficie de la muestra, lo que da como resultado una imagen de alta resolución. El microscopio está equipado con un detector de rayos X (Oxford Instruments X-Max 20 mm2) para análisis EDS (Espectroscopia de Dispersión de Energía). Permite determinar la composición química del material en el volumen de muestra analizado, basándose en la interacción entre el haz de electrones dirigido y el átomo de la muestra.

Resultados: Se muestran las características del avión furtivo B-2 utilizado para bombardear la República Federativa de Yugoslavia. La bomba JDAM es una bomba MK ordinaria mejorada con dispositivos electrónicos agregados para guiar la bomba a través de satélites. Se realizó un análisis semicuantitativo de las fibras en el SEM, confirmando que la capa metálica de la fibra se compone predominantemente de aluminio, y la capa no metálica tiene la mayor proporción de dióxido de silicio. La fibra es cancerígena.

Conclusión: En 1999, el territorio de Yugoslavia era un campo de pruebas para nuevas armas de combate de la aviación de la OTAN: bombas guiadas B-2 y JDAM. Se lanzaron bombas para apagones sobre los sistemas eléctricos de Yugoslavia, dejando a toda Serbia sin electricidad durante horas. La contaminación ambiental causada por los bombardeos no sólo fue radiológica y química, sino que también fue causada por fibras conductoras de electricidad de vidrio y aluminio como contaminantes.

Palabras claves: *demanda judicial, aviones furtivos B-2, bombas penetrantes JDAM, bombas para apagones, fibras eléctricamente conductoras, contaminación ambiental.*

Агрессия НАТО в 1999 году против Югославии была использована для проверки эффективности новой боевой техники

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ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Во время бомбардировок были использованы три новых боевых средств, которые были впервые испытаны в 1999 году. Во-первых, стратегический бомбардировщик-невидимка B-2, во-вторых, новые разрушительные авиабомбы JDAM (Joint Direct Attack Munition), в-третьих, «мягкие бомбы» или «бомбы затемнения», изготовленные из тончайших электропроводящих волокон. Целью данной статьи заключалось в описании новых боевых средств, применявшихся во время агрессии против СРЮ, и выявлении количества элементов электропроводящих волокон. В данной статье также описан иск Союзной Республики Югославия в Международный трибунал по военным преступлениям в Гааге. Иск был отклонен.

Методы: В ходе исследования были проведены физические и химические исследования волокон. Сканирующий электронный микроскоп JSM Jeol 6610LV использовался для исследования физико-химических характеристик электропроводящих волокон. Он позволил получить информацию о морфологии поверхности образцов, в результате чего было получено изображение высокого разрешения. Микроскоп оснащен детектором рентгеновского излучения (Oxford Instruments X-Max 20 мм2) для проведения энергодисперсионной рентгеновской спектроскопии. Он определяет химический состав материала в анализируемом объеме образца на основании взаимодействия электронного пучка с атомами образца.

Результаты: В статье представлены характеристики самолета-невидимки B-2, бомбившего СРЮ. Бомба JDAM представляет собой усовершенствованную обычную бомбу МК. Она оснащена электронным устройством спутниковой наводки. Полуколичественный анализ волокна был выполнен с помощью СЭМ и подтвердил, что металлический слой волокна преимущественно состоял из алюминия, а большая часть состава неметаллического слоя состояла из диоксида кремния. Соответственно волокна обладали высокой канцерогенной активностью.

Выводы: В 1999 году территория Союзной Республики Югославия являлась полигоном для испытаний новых боевых средств авиации НАТО − B-2 и управляемой бомбы JDAM с наводкой. Бомбы затемнения были сброшены на электростанции и системы

электроснабжения Союзной Республики Югославии, в результате чего вся Сербия оставалась без света по нескольку часов. В результате бомбардировок окружающая среда была подвергнута радиоактивному, химическому загрязнению, а также загрязнению от электропроводящих волокон стекла и алюминия.

Ключевые слова: иск, самолет-невидимка Б-2, проникающие бомбы JDAM, бомбы затемнения, электропроводящие волокна, загрязнение окружающей среды.

Агресија НАТО-а на СРЈ 1999. године: провера ефикасности нових борбених средстава

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ОБЛАСТ: хемијске технологије
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: У време бомбардовања Републике Србије 1999. године, НАТО је користио три нова борбена средства, која су тада први пут испитана. Прво средство је стратешки невидљиви бомбардер Б-2, друго су нове разорне бомбе JDAM (Joint Direct Attack Munition) и, треће, „меке бомбе", или бомбе за замрачивање, од електропроводљивих танких влакана. Циљ рада јесте да се прикажу ова борбена средства и да се квантитативно детектују елементи електропроводљивих влакана. У раду је представљена и тужба Савезне Републике Југославије (СРЈ) Међународном кривичном суду за бившу Југославију (МКСЈ) у Хагу. Тужба је одбијена.

Методе: Извршене су физичке и хемијске анализе влакана. За анализу физичко-хемијских карактеристика електропровидљивих влакана коришћен је електронски микроскоп SEM JSM Jeol 6610LV. Он омогућава добијање информације о морфологији површине узорака, при чему се добија слика високе резолуције. Микроскоп је опремљен детектором X-зрака (Oxford Instrumets X-Max 20 mm^2) за EDS анализу (Energy Dispersive Spectroscopy). Такође, омогућава да се одреди хемијски састав материјала у анализираној запремини узорка, на основу интеракције усмереног електронског снопа и атома узорка.

Резултати: Приказане су карактеристике стелт авиона Б-2 који је бомбардовао СРЈ. Бомба ЈДАМ је усавршена обична бомба МК којој

Anđelković-Lukić, M. et al, NATO attack on FR Yugoslavia in 1999 was used to test the effectiveness of new weapons, pp.274-304

су додати електронски уређаји који је воде преко сателита. Семиквантитативна анлиза влакана урађена је на SEM и потврдила да се метални слој влакна доминантно састоји од алуминијума, а да неметални слој има највећи удео силицијум-диоксида. Влакна су канцерогена.

Закључак: Територија СР Југославије је 1999. године била полигон за испитивање нових борбених средстава НАТО авиона Б-2 и вођене бомбе ЈДАМ. Бомбе за замрачивање бацане су на електро-системе СР Југославије и остављале целу Србију више часова у мраку. Животна средина контаминирана је радиолошки, хемијски и стакло-алуминијумским електропроводљивим влакнима.

Кључне речи: тужба, стелт авион Б-2, пробојне бомбе ЈДАМ, бомбе за замрачивање, електропроводљива влакна, загађење животне средине.

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Variations of physical and mechanical properties of concrete with the height

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Abstract:

Introduction/purpose: Concrete, mortar, and cement pastes are materials that have become central in various fields of construction, structures, and civil engineering. About 7 billion cubic meters of concrete are implemented. Concrete is generally considered a homogeneous material, but that is not always the case given its rheological behavior, which can be due to heterogeneous phenomena of segregation and bleeding.

Methods: The study tested a concrete column's physical and mechanical characteristics and deformation in elevation. The tests included measuring absolute and apparent density, porosity, capillary absorption, permeability, speed of propagation, compressive strength, and static and dynamic modulus of elasticity. For this purpose, the standards of non-destructive testing (sclerometer, ultrasound, etc.) were used to take the average of a series of points located at different levels of the element to be tested.

Results: The results indicate that changes in the column's height affect its physical and mechanical properties, either increasing or decreasing them (such as porosity, absorbency, permeability, compressive strength, and the static and dynamic modulus of elasticity). These changes are influenced by various factors, including the inherent properties of the concrete implementation (such as vibration and curing) and the climate conditions during construction.

Conclusion: The findings of this study emphasize the importance of a nuanced approach to testing and evaluating variations in concrete properties by taking into account the multifaceted impact of changes in column height.

Key words: concrete, porosity, compressive strength, modulus of elasticity, permeability, elevation.

Introduction

Concrete is a composite material, made up of cement, aggregates (gravel and sand), water and possibly additions. Due to its heterogeneity, concrete turns out to be a particularly complex and evolving material: it undergoes profound physicochemical transformations not only when it is subjected to a rise in temperature, but even from the moments following its preparation (especially the hydration reaction and the setting phenomenon). It is therefore essential to fully understand all the parameters that play a role in concrete, in order to be able to understand its behavior.

Ever since its inception, concrete has been the primary material used in building structures across various fields of civil engineering. It has been essential in constructing everything from industrial buildings like factories and warehouses to hydraulic projects such as dams and dikes. It is also integral in vital infrastructures like bridges, tunnels, and urban amenities like aqueducts. Concrete's favor is due to its economy, ease of use, strength against compression, durability, insulation properties for sound and heat, and its ability to enhance architecture with different shapes, textures, and colors (Mani et al, 2021).

However, as construction materials become more diverse, comparing their qualities and performance against the multiple criteria for construction or renovation has become increasingly difficult. Meeting the structural, economic, and environmental requirements has become complex due to a wide range of available composite products (El Mabchour et al, 2020).

The durability of structures is significantly influenced by their environment. It is crucial to enhance the strength of concrete when exposed to external factors such as harsh weather, aggressive soils, and chemically reactive atmospheres.This factor has become increasingly significant, posing a challenge to concrete structures. Among various indicators, permeability stands out as the key factor influencing the long-term effectiveness of reinforced concrete structures (Shi et al, 2012; Teng et al, 2014). The microstructural characteristics, encompassing aspects like the size, distribution, and interconnection of micro-cracks and pores,

play a critical role in determining concrete's permeability (Zhang & Li, 2011).

Nowadays, cementitious materials such as concrete, mortars or cement pastes are materials that have become essential in various fields of construction, engineering structures and civil engineering. Concrete artificial stones are composed mainly of cement and aggregates.

The behavior of concrete depends on the properties of each constituent in its composition. Its properties are determined by methods frequently used in laboratories.

Concrete is generally considered to be a homogeneous material, but this is not always the case given its rheological behavior which can make it heterogeneous due to segregation and bleeding phenomena. Indeed, in a concrete column such as a post, the density can change from one level to another. By this principle, we tried in our study to evaluate the physical and mechanical characteristics of a concrete column in elevation. K.C. Nehar & D. Benamara (2021) investigated and predicted the mechanical performance of high-strength concrete formulated with recycled aggregates.

The examination of the progression of concrete's physical and mechanical properties with regards to height has been the subject of numerous scholarly articles. Zhang et al (2021) conducted a study on the impact of the proportion of reinforced concrete layer height to total height on the mechanical properties of functionally graded concrete (FGC) that incorporated fly ash and polypropylene fiber. Their findings revealed that FGC specimens created with an h/H ratio of 0.50 displayed superior flexural strength, flexural toughness, and compressive strength. Zhang et al (2022) explored the mechanical behavior of concrete under tension at varying levels of water saturation and temperatures. They observed that tension strength and elasticity modulus declined when saturation fell within the range of 35% to 65%, but subsequently increased for higher saturations. Kallel et al (2018) investigated the development of the temperature field, thermal conductivity, specific heat capacity, compressive strength, tensile strength, and elastic modulus in shaft lining concrete as it aged and the thickness of the lining increased. They discovered that compressive strength, tensile strength, and elastic modulus experienced significant growth as the concrete aged.

Aggregates make up the largest portion of concrete, accounting for 60-80% of its volume. It is crucial that these aggregates be appropriately graded to ensure the entire concrete mass acts as a solid, uniform, compact mixture, with smaller particles filling the gaps between larger ones. However, concrete, as a structural material, is not completely solid.

Apart from air porosity, it develops micro-cracks even before being subjected to load. These factors significantly influence the properties of concrete. M. Słowik (2021) shared findings from their numerical simulations, offering a deeper understanding of how the composition affects the fracture characteristics of concrete.

The standard procedure for determining the primary concrete attribute – compressive strength – is well established (Institute for Standardization of Serbia, 2019).

Materials and methods

Materials and preparation of specimens

Concrete specimens were produced using the G. DREUX method for a desired strength of 25 MPa and a slump of 7 cm. The Portland cement used in this study was CEM II/A 32,5 provided by Zahana Cement Plant (Mascara, Algeria) with a 28-day compressive strength of 33 MPa. Blaine fineness of cement is 3100 cm^2/g and its specific gravity is 3.1.

The granular skeleton was composed of fine aggregates (sand 0/4), which generally contain quartz, and coarse aggregates (3/8 gravel), mainly composed of silica and quartz.

Table 1 shows the compositions of the concretes used, for water to cement ratio (W/C) equal to 0.58. Once the concrete was mixed, it was poured into a polyvinyl chloride (PVC) cylinder with a diameter of 40 mm and a height of 750 mm. Compaction is carried out using a vibrating table for 15 seconds.

Table 1 – Formulation of ordinary concrete (Kg/m3)

Component	Sand 0/4	Gravel 3/8	Cement	Water
Quantity (kg)	616	1143	350	202

The PVC tubes containing the samples were covered with plastic film to avoid any water exchange with the external environment and stored in the laboratory environment for 28 days.

Each PVC tube allows us to make up to 7 test pieces (Ø = 40; H = 75 mm) by sawing in a concrete saw as shown in the diagram in Figure 1.

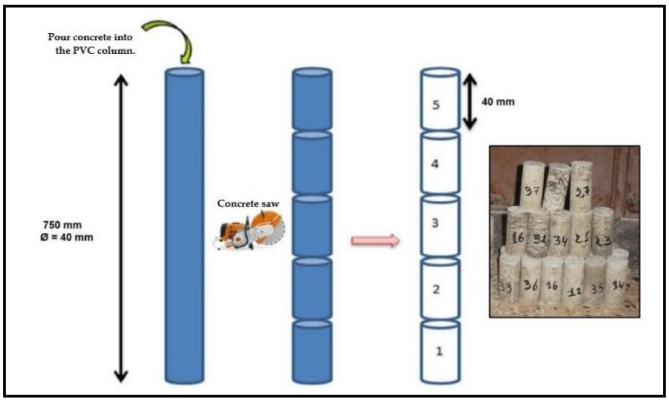

Figure 1 – Sawing of a concrete column

Test procedure

Apparent density (once called volume weight) is defined as the mass "M" per unit volume of the material "V", including pores and water (apparent volume). Therefore, it is measured in kilograms per cubic meter (g/cm3 or kg/m3). This can be represented by the equation:

$$\rho_{app} = \frac{M}{V} \quad (1)$$

The absolute density and the porosity accessible to water was determined in accordance with the recommendations of the AFREM group (RILEM TC 49-TFR, 1984) which predicts the saturation of samples in the single-phase mode (under vacuum). The tests were carried out on cylindrical samples 40 mm in diameter and 80 mm. The samples were then placed under a vacuum bell for 24 hours. Afterwards, they were immersed in water, and then kept under vacuum for 48 hours. It is worth indicating that the sample volume was determined by weighing it in air and then in water using a hydrostatic weighing device. Figure 2 illustrates the experimental setup.

Then, in order to obtain the dry mass, the samples were dried at 105 °C until a constant mass was reached. The absolute density and the porosity accessible to water could then be calculated using the following formulae (2) and (3):

$$\rho_{ads} = \frac{M_{air}}{M_{air} - M_{water}} \rho_{water} \quad (2)$$

$$\frac{M_{air}-M_{dry}}{M_{air}-M_{water}} \times 100 \quad (3)$$

Where Mair is the mass of the sample saturated in air, Mwater is the mass of the sample saturated in water, Mdry is the mass of the sample at the end of drying, and ρwater in the water density at 20 °C.

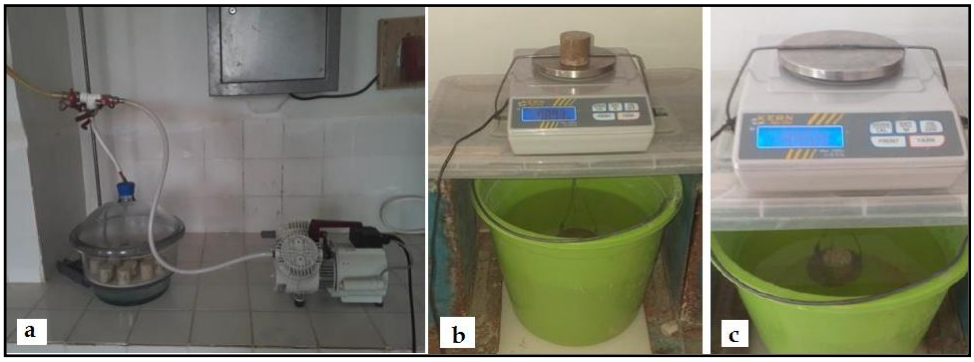

Figure 2 – Porosity tests: (a) vacuum saturation (b) weighed in air (c) hydrostatic weighing

The capillary water absorption test was performed according to ASTM C1585 (ASTM, 2020). Its principle consisted of placing one end of the sample on a support so that the liquid level was constant 1 to 3 mm higher than the bottom of the sample and then measuring the weight gain values of the sample at well-defined time intervals.

In this experiment, before a concrete sample is exposed to water, the sample must be dried in an oven at 105°C to a constant weight. The side faces were waterproofed by molten paraffin wax beforehand (Attolou et al,1989), which forced water to adopt a uniaxial path and prevent the evaporation of water from these faces. Figure 3 illustrates the experimental setup.

The water absorption per unit area of cement-based materials tended to be linearly proportional to the square root of time. This law is also known as the square root law:

$$\frac{d_m}{A} = S\sqrt{t} \quad (4)$$

where dm is the quantity of water absorbed in grams at time t, t is the elapsed time in seconds, A is the bottom surface of the sample in cm^2, and S is the capillary water absorption coefficient.

The amount of water absorbed per unit area after one hour was used as a quantity that represents the volume of the largest capillaries present in the skin area (Hall,1989).

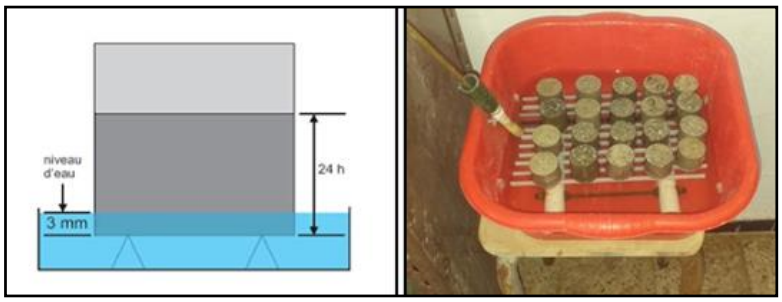

Figure 3 – Capillary water absorption tests

The Ultrasonic Pulse Velocity of concrete cylinders by direct transmission was evaluated using the standard test method (ASTM, 2016). The equipment used was the portable ultrasonic non-destructive digital indicating tester (PUNDIT), shown in Figure 4. In this method, an ultrasonic pulse is generated by a pulse generator and transmitted to the surface of concrete through the transmitter transducer. The time taken by the pulse to travel through the concrete, t (μs), is measured by the receiver transducer on the opposite side. To ensure good contact, a thin couplant (solid Vaseline) was used on the interface between transducers and concrete.

The Ultrasonic Pulse Velocity can be determined with equation (5):

$$V = \frac{L}{t} \tag{5}$$

where V is the ultrasonic pulse velocity (m/s), L is the path length in concrete (mm), and t is the transit time (μs).

The dynamic modulus is linked to the density of the concrete, its Poison's ratio, and pulse velocity according to the following relationship:

$$E_d = \frac{(1+\nu)\cdot(1-2\nu)}{(1-\nu)}\rho \cdot V^2 \tag{6}$$

where V is the ultrasonic pulse velocity (m/s), ρ is the density of concerete in (Kg/m^3), and υ poison's ratio of concrete.

This velocity is then used to calculate the compressive strength of the concrete using the following formula:

$$f_{cj} = 0.08177 \cdot e^{(0.00147 \cdot V)} \quad (7)$$

Figure 4 – Ultrasonic Pulse Velocity tests

The test for compressive strength of cylindrical specimens was performed according to ASTM C39 (ASTM, 2010) using a 1500 kN compression test machine (ELE International). The loading rate was set to 0.2 MPa/s.

Moreover, the instantaneous elastic modulus can be calculated as a function of its compressive strength based on the following empirical model:

$$E_c = 11000\sqrt[3]{f_{cj}} \quad (8)$$

where f_{cj} is compressive strength (MPa).

The dynamic elastic modulus is generally 20%, 30%, and 40% higher than the static elastic modulus for high, medium, and low-strength concrete, respectively (Mehta & Monteiro, 2014). There are several empirical equations that relate Ed and Ec. Lydon and Balendran (1986) proposed the following empirical relationship between Ed and Ec:

$$E_c = 0.83E_d \quad (9)$$

Figure 5 – Compressive strength test tests

Table 2 and Figure 6 present the variation of the apparent and absolute density of the concrete column according to the cutting heights. Each value shown in this graph corresponds to the average of the results obtained on three test specimens. It can be seen that the density, whether apparent or absolute, decreases as the level of the test piece increases. Certainly, this drop in concrete density is attributed to the presence of greater porosity in the specimen. These results are explained by the fact that certain grains, especially denser ones, descend downwards while fine grains remain at the top (due to gravity).

Table 2 – Variation of the apparent and absolute density of the different levels of the concrete column

Level of the specimen in relation to the height (cm)	ρ_{abs} [g/cm^3]	ρ_{app} [g/cm^3]
4	2.259	1.737
12	2.258	1.725
20	2.249	1.705
28	2.233	1.70
36	2.207	1.70
44	2.213	1.7
52	2.205	1.66

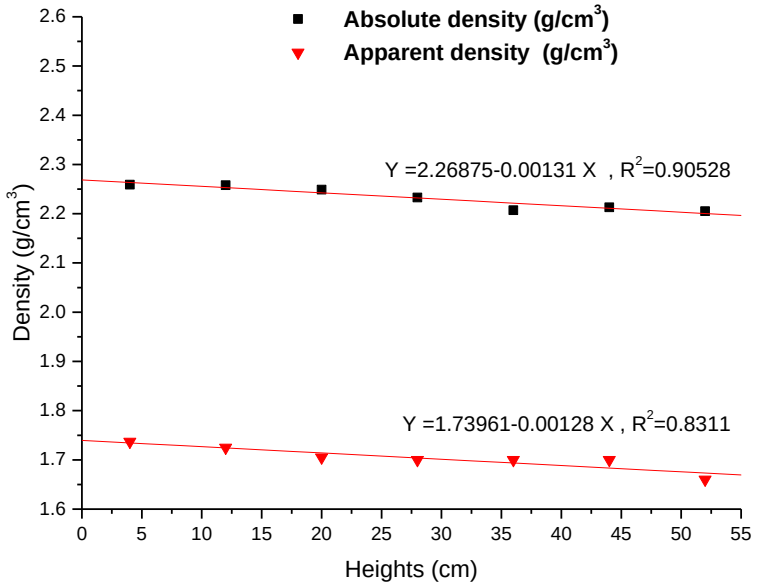

Figure 6 – Variation of the absolute and apparent density of the different levels of the concrete column

Table 3 and Figure 7 illustrate the variation in porosity as a function of the cutting height of the concrete column.

Table 3 – Values of the porosity accessible to water at the different levels of the concrete column

Level of the specimen in relation to the height (cm)	ε [%]
4	15.11
12	15.5
20	16.7
28	16.9
36	17.4
44	17.5
52	17.7

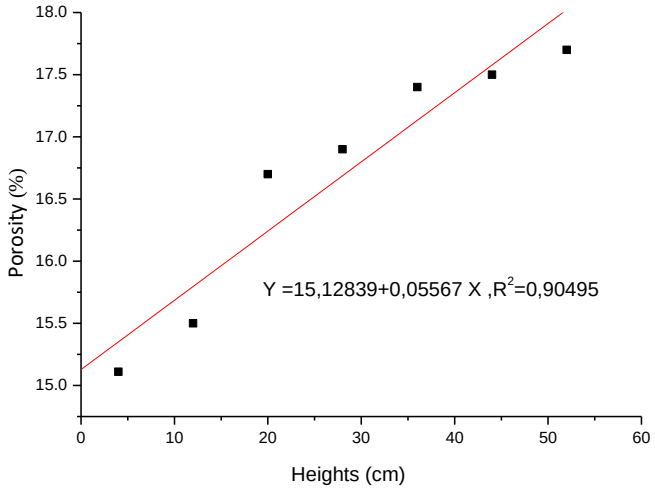

Figure 7– Variation in the porosity accessible to water at the different levels of the concrete column

It can be seen from the curve of evolution of the porosity accessible to water as a function of the cutting height of the concrete column shown in Figure 7 that the porosity evolves in an inverse manner to the density (the porosity increases according to the cutting height). This is explained by the decrease in density which inversely influences the volumes of pores.

The results obtained from the variation (dm/A) according to the square root of time and the different levels of the cut concrete column are shown in Table 4 .

Table 4 – Variation of dm / A according to the time of the different levels of the concrete column

P.H	30 sec	1mn	5mn	15mn	30 mn	1 h	2 h	4 h	7 h	24 h	72h
4	0.0238	0.074	0.1058	0.14	0.158	0.1776	0.1856	0.22	0.2673	0.387	0.517
12	0.0344	0.087	0.1083	0.151	0.171	0.1946	0.1933	0.2546	0.2673	0.4346	0.599
20	0.0344	0.093	0.1163	0.153	0.181	0.215	0.1963	0.2586	0.303	0.4426	0.605
28	0.0344	0.103	0.124	0.164	0.1883	0.23	0.206	0.2586	0.308	0.4773	0.651
36	0.0391	0.104	0.1298	0.164	0.1986	0.231	0.212	0.276	0.321	0.4773	0.666
44	0.045	0.105	0.159	0.193	0.22	0.235	0.2246	0.2953	0.348	0.52	0.689
52	0.0635	0.156	0.1856	0.243	0.2523	0.282	0.2913	0.338	0.3873	0.518	0.689

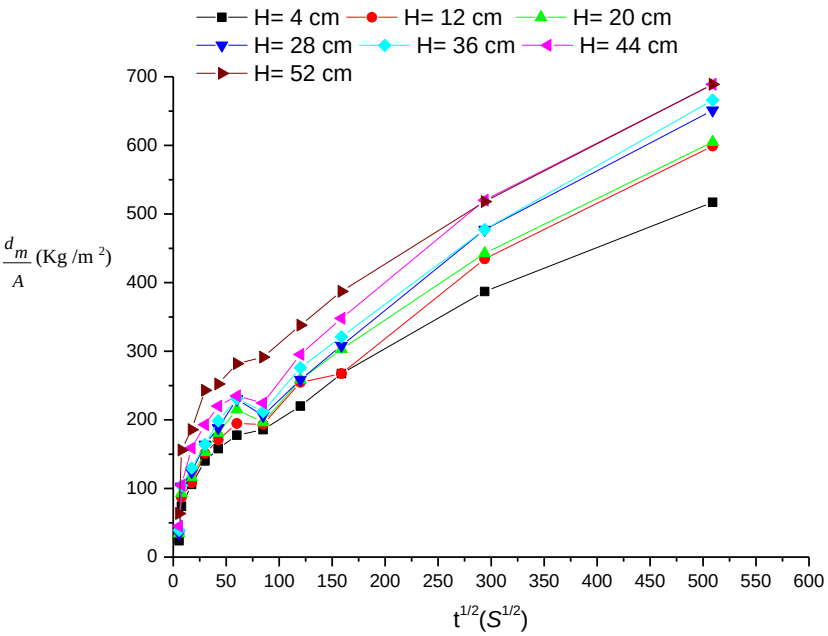

Figure 8 – Absorption kinetics S for the different levels of the concrete column

Table 5 – Measuring values of the absorptivity S of the different levels of the concrete column for t = 1 hour

Level of the specimen in relation to the height (cm)	S(Kg/m^2.S$^{0.5}$)
4	2.960
12	3.243
20	3.583
28	3.833
36	3.850
44	3.917
52	4.700

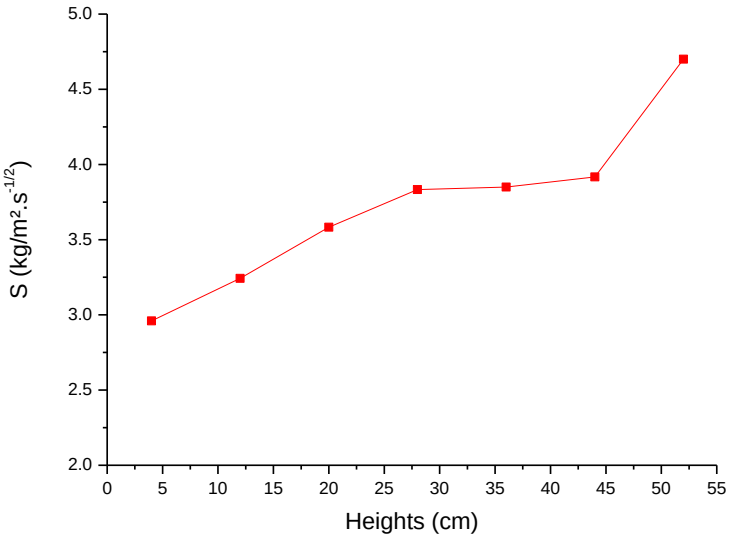

Figure 9 – Variation of absorptivity (S) as a function of the cutting heights of the concrete column for t = 1 hour

Figure 8 shows the absorption kinetics (the variations in the amount of water absorbed per unit area as a function of the square root of time) for different samples taken at different levels of the concrete column. According to Balayssac et al (1993), the water absorption curves make it possible to classify materials in accordance with the average size of the largest capillaries.

The curves in Figure 8, located between 0 and 1 hour, are curvilinear and they reflect the filling of the largest pores. And in the second part of the curves, more linear in appearance, they represent the filling of the finest capillaries. Table 5 and Figure 9 show the change in absorptivity according to the cutting height of the concrete column measured at time = 1 hour. It can be seen that the more the height of the cutting level increases, the more the absorption coefficient increases.

The results of determining the permeability and radius of the capillary pores of the different levels of the concrete column are shown in Table 6 and Figures 10 and 11.

Table 6 – Values of permeability and radius of capillary pores of different levels of the concrete column

Level of the specimen in relation to the height (cm)	V (cm ^{3})	e [%]	r x 10^{-6} (m)	K x 10^{-14} (m^2)
4	0.0022	15,11	1.3760	3.58
12	0.0024	15,5	1.4372	4.00
20	0.0027	16,7	1.5244	4.85
28	0.0029	16,9	1.5798	5.27
36	0.0029	17,4	1.5798	5.43
44	0.0030	17,5	1.6069	5.65
52	0.0035	17,1	1.7356	6.44

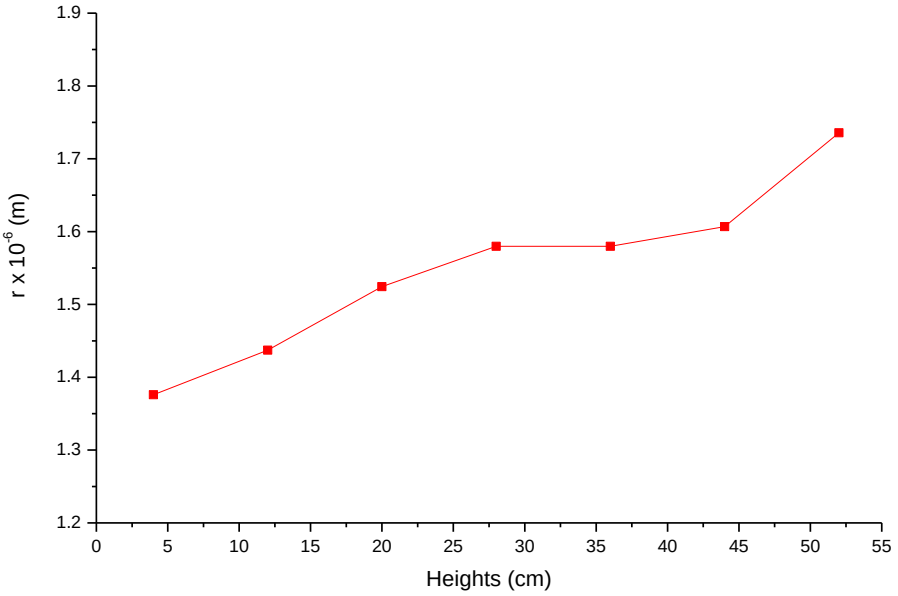

Figure 10 – Variation of the radius of the capillary pores in relation to the different levels of the concrete column

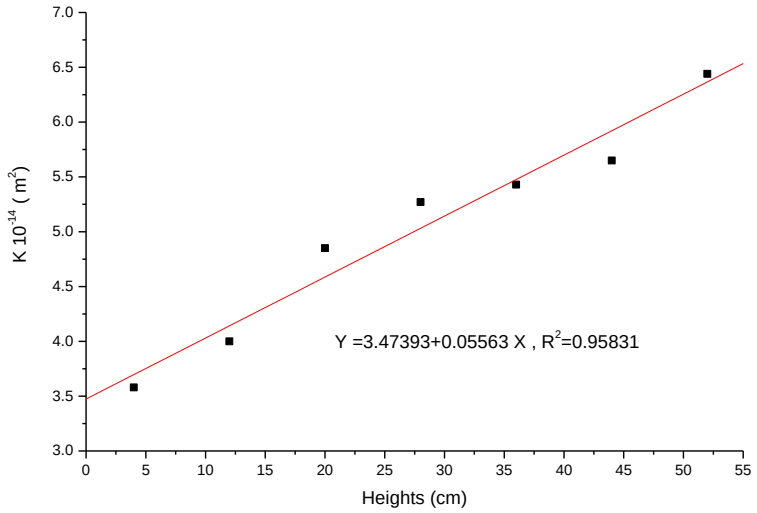

Figure 11 – Variation of the water permeability of the different levels of the concrete column

Calculating the radius of the capillary by the Washburn equation allows the water permeability of concrete to be determined as a function of height. It is observed that the more the level increases, the more the permeability increases. This property depends mainly on the capillary porosity as well as the size and interconnection of the capillary pores. In general, permeability increases with increasing porosity (Ollivier & Torrenti, 2008). The results already observed on the evolution of porosity justified this behavior.

The results of the propagation speed V, the compressive strength RC and the dynamic modulus of elasticity Ed of the different levels of the concrete column are shown in Table 7 and Figures 12 , 13 and 14.

Table 7 – Values of the propagation speed V, the compressive strength R_C and the dynamic modulus of elasticity E_d of the different levels of the concrete column

Level of the specimen in relation to the height (cm)	t.10^{-6} (sec)	V (m/sec)	R_C	E_d (GPa)
4	20.2	3960.39	27.6	31.89
12	20.53	3896.73	25.13	30.86
20	20.6	3883.49	24.65	30.73
28	20.83	3840.61	23.14	29.64
36	20.83	3840.61	23.14	29.30
44	20.93	3822.26	22.53	29.10
52	21.33	3750.58	20.27	27.92

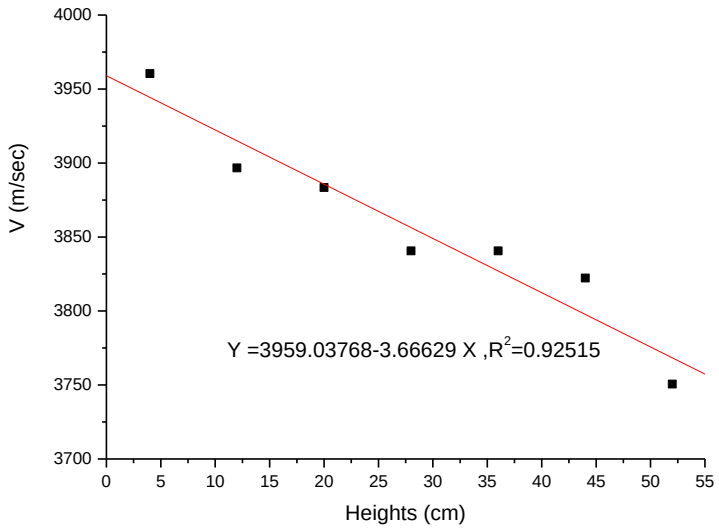

Figure 12 – Variation of the propagation speed of the different levels of the concrete column

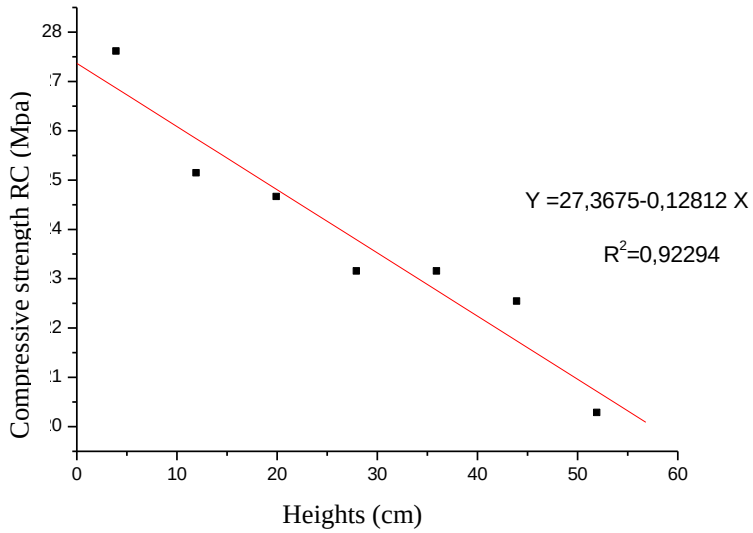

Figure 13 – Variation of the compressive strength RC of the different levels of the concrete column

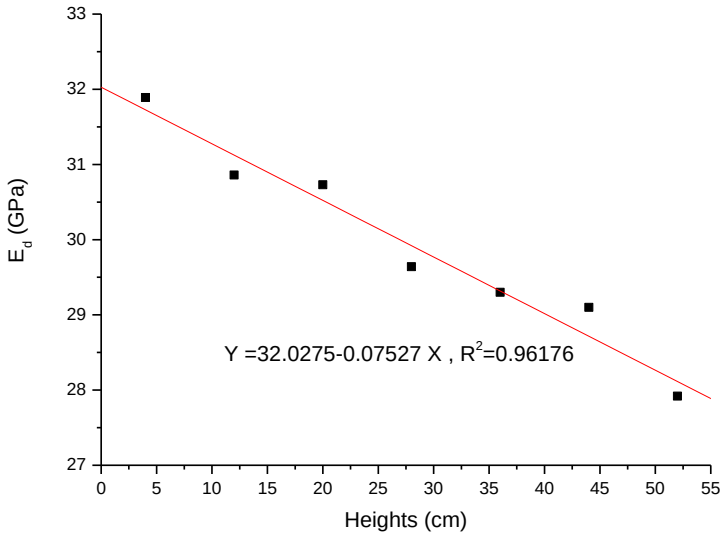

Figure 14 – Variation of the dynamic modulus of elasticity Ed of the different levels of the concrete column

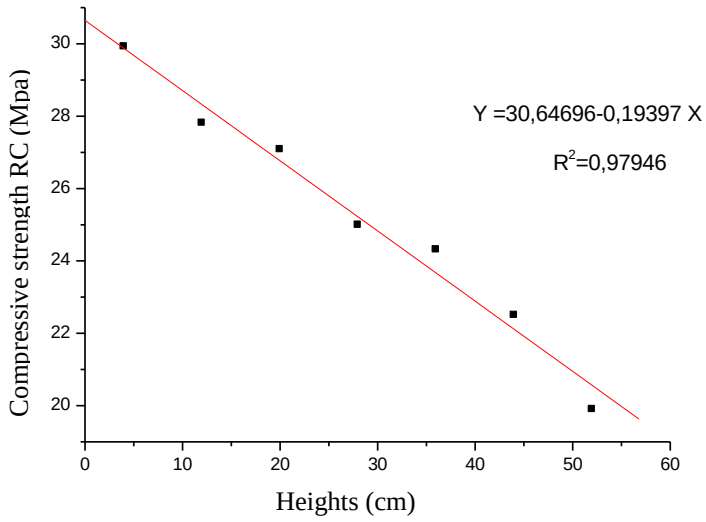

Figure 15 – Variation of the compressive strength of the different levels of the concrete column

Figure 12 shows a decrease in the propagation speed of the sonic wave as a function of the increase in the cutting height of the concrete column, and this is mainly due to the increase in porosity in the concrete confirmed by several authors. The wave propagation speed decreases when the porosity increases (Lafhaj et al, 2006).

The results of the RC specimen crush test are shown in Table 7 and Figure 15.

The values of the static modulus of elasticity Ec and dynamic Ed of the different levels of the concrete column are presented in Table 8 and Figure 16.

Table 8 – Values of the compressive strength RC, the static modulus of elasticity Ec and dynamic Ed of the different levels of the concrete column

Level of the specimen in relation to the height (cm)	R_{C28} (MPa)	E_c (GPa)	E_d (GPa)
6	29.92	34.15	41.14
18	27.81	33.32	40.14
30	27.08	33.03	39.80
42	24.99	32.16	38.75
54	24.31	31.86	38.39
66	22.5	31.05	37.41
78	19.9	29.08	35.04

It can be seen from Figures 15 and 16 that the compressive strength and the elastic moduli decrease with the cutting height of the concrete column and this is due to the increase in porosity and the decrease in density.

These variations in compressive strength and modulus of elasticity can reach 20 to 35%, which is in good agreement with the results in the literature (Giaccio & Giovambattista,1986). It is good, the PT which is at the origin of this phenomenon according to some researchers (Galan, 1981; Lafhaj et al, 2006).

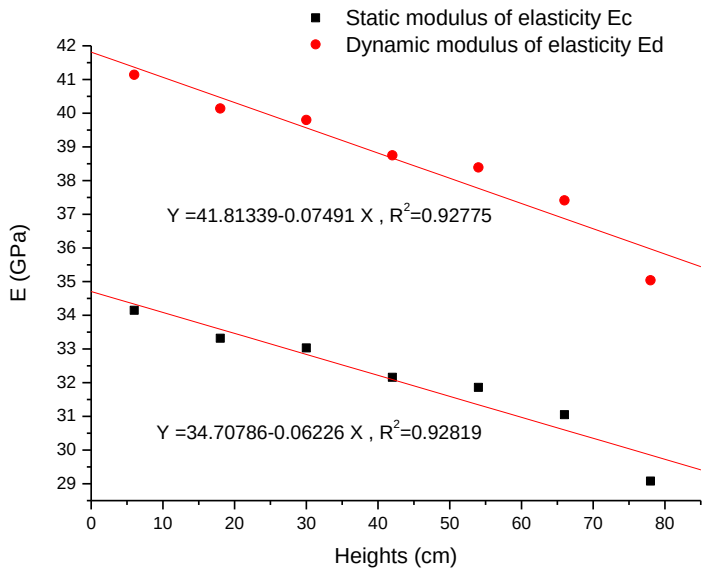

Figure 16 – Variation of the dynamic modulus of elasticity Ed and the static modulus of elasticity Ec of the different levels of the concrete column

Conclusion

The experimental study on the variation of the physical and mechanical characteristics of concrete in a vertical column was carried out using numerous tests.

The different results drawn on the effect of height are summarized as follows:

- A decrease of apparent and absolute density and the speed of sound, and
- An augmentation of porosity, absorbency, permeability, compressive strength and the static and dynamic modulus of elasticity.

All the results show that the variation of the height of the column modifies the physical and mechanical properties either by an increase or a decrease. For this, it is recommended by the standards of non-destructive testing (sclerometer, ultrasound, etc.) to take the average of a series of points located in different levels of the element to be tested.

These variations have consequences for several parameters such as the intrinsic properties of concrete, the implementation (vibration, curing, etc.) and the climatic conditions of the implementation.

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Variaciones de las propiedades físicas y mecánicas del hormigón con la altura

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CAMPO: materiales, ingeniería civil
TIPO DE ARTÍCULO: original de la investigación científica

Resumen:

Introducción/propósito: Las pastas de hormigón, mortero y cemento son materiales que se han vuelto centrales en diversos campos de la construcción, estructuras e ingeniería civil. Se utilizan aproximadamente 7 mil millones de metros cúbicos de hormigón. El hormigón generalmente se considera un material homogéneo, pero no siempre es así dado su comportamiento reológico, que puede deberse a fenómenos heterogéneos de segregación y exudación.

Métodos: El estudio probó las características físicas y mecánicas de una columna de concreto y la deformación en elevación. Las pruebas incluyeron la medición de densidad absoluta y aparente, porosidad, absorción capilar, permeabilidad, velocidad de propagación, resistencia a la compresión y módulo de elasticidad estático y dinámico. Para ello se utilizaron los estándares de ensayos no destructivos (esclerómetro, ultrasonidos, etc.) para tomar el promedio de una serie de puntos ubicados a diferentes niveles del elemento a ser probado.

Resultados: Los resultados indican que los cambios en la altura de la columna afectan sus propiedades físicas y mecánicas, ya sea incrementándolas o disminuyéndolas (como la porosidad, la absorbencia, la permeabilidad, la resistencia a la compresión y el módulo de elasticidad estático y dinámico). Estos cambios están influenciados por varios factores, incluidas las propiedades inherentes de la implementación del concreto

(como la vibración y el curado) y las condiciones climáticas durante la construcción.

Conclusión: Los hallazgos de este estudio enfatizan la importancia de un enfoque matizado para probar y evaluar las variaciones en las propiedades del concreto teniendo en cuenta el impacto multifacético de los cambios en la altura de las columnas.

Palabras claves:. hormigón, porosidad, resistencia a la compresión, módulo de elasticidad, permeabilidad, elevación.

Изменения физико-механических свойств бетона с учетом высоты

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РУБРИКА ГРНТИ: 67.09.33 Бетоны. Железобетон. Строительные растворы, смеси, составы
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Такие материалы, как бетон, строительные растворы и цементные пасты являются главными материалами в различных областях строительства, конструкциях и структурах. Ежегодно используется около семи миллиардов кубометров бетона. Бетон считается однородным материалом, но это не всегда так, учитывая его реологические свойства из-за возможных гетерогенных явлений сегрегации и протечки.

Методы: В ходе исследования были проверены физические и механические характеристики бетонной колонны и ее деформация по высоте. Испытания включали измерение абсолютной и удельной (кажущейся плотности), пористости, капиллярного поглощения, проницаемости, скорости распространения, прочности на сжатие, а также статического и динамического модуля упругости. Были использованы стандартные неразрушающие методы контроля (склерометр, ультразвук и т.д.) для определения среднего значения ряда точек, расположенных на разных уровнях испытуемого элемента.

Результаты: Результаты показывают, что изменения высоты колонны влияют на ее физические и механические свойства, увеличивая, либо уменьшая их (такие, как пористость, поглощение, проницаемость, прочность на сжатие, а также статический и динамический модуль упругости). На эти изменения влияют

различные факторы, включая присущие бетону свойства, такие как вибрирование и отверждение, а также природно-климатические условия во время строительства.

Выводы: Результаты данного исследования подчеркивают важность тщательного подхода к испытаниям и оценке изменений свойств бетона с учетом многогранного воздействия изменений высоты колонны.

Ключевые слова: бетон, пористость, прочность на сжатие, модуль упругости, проницаемость, перепад высот.

Варијација физичких и механичких особина бетона по висини

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ОБЛАСТ: материјали, грађевинарство
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Материјали као што су бетон, малтер и цементне пасте постали су кључни у различитим областима конструкција, структура и грађевинарства. У свету се годишње користи око седам милијарди кубних метара бетона. Обично се сматра да је бетон хомогени метеријал, али, с обзиром на његова реолошка својства услед могућих хетерогених појава сегрегације и цурења, то није увек случај

Методе: Испитиване су физичке и механичке карактеристике бетонског стуба, као и његова деформација по висини. Испитивања су обухватила мерење апсолутне и привидне густине, порозности, капиларне апсорпције, пропустљивости, брзине пропагације, компресивне снаге, као и статичког и динамичког модула еластичности. Коришћене су стандардне методе испитивања без разарања (склерометар, ултразвук, итд.) на серији тачака лоцираних на различитим нивоима испитиваних епрувета.

Резултати: Показано је да промене у висини стуба утичу на физичка и механичка својства бетона, тако што их појачавају или смањују (као, на пример, на порозност, апсорптивност, пропустљивост, компресивну снагу и статички и динамички модул еластичности). Ове промене узорковане су различитим факторима, попут својстава бетона приликом његовог справљања

(нпр. вибрација и умрежавања) и климатских услова током конструкције.

Закључак: Резултати овог рада наглашавају значај изнијансираног приступа испитивању и процени варијација својстава бетона тиме што узимају у обзир вишеструки утицај промена висине стуба.

Кључне речи: бетон, порозност, компресивна снага, модул еластичности, пермеабилност, елевација.

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EEG signal ANFIS classification for motor imagery for different joints of the same limb

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Abstract:

Introduction: The experimental area of brain-computer interfaces (BCIs) is expanding to include movement actions, which play a crucial part in deciphering cognitive processes. Without the need for any kind of exterior stimulation, motor imagining (MI) can be used as a powerful model for brain-computer interfaces (BCIs). A natural method of operating exterior devices is to imagine moving various joints in the same arm. These envisioned motions have similar spatial images in the motor brain, making it difficult to differentiate MI of various joints of the same leg based on EEG data.

Method: A pre-existing data collection of 25 participants was utilized in this study. The participants visualized using their right limbs to carry out three different activities: visualize yourself manipulating your right hand, visualize bending your right arm, and close your eyes while you relax. To assign categories to these impulses, we turned to the adaptive neuro-fuzzy reasoning system.

Results: The average level of accuracy was 90%.

Conclusion: The findings demonstrate that this technique is crucial for correctly categorizing EEG data. The data collection used in this investigation consists of EEG measurements of the same limb used in muscular imaging. The new categorization method will be applied to these signals to draw conclusions.

Keywords: electroencephalography (EEG), classification, ANFIS, wavelet transform, feature extraction, BCI.

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Introduction

Computer Interface (BCI) technology allows for two-way contact and interaction between the brain and the outside world without using any of the body's limbs or sensory organs. Electrode plates (electrodes) are put on the head to record electrical activity in the brain during an electroencephalogram (EEG) examination. Electroencephalography (EEG) is frequently used for BCI due to its high time precision, low expense, mobility, and non-invasive character. Instead of using an external cue to elicit a response, as is the case with steady-state visual evoked potentials (SSVEPs) and P300 potentials-based brain-computer interfaces, motor imaging (MI)-based BCIs depend on the subjects' own conscious control (Ma et al, 2020). MI-based BCI devices have been used for the operation of a wheelchair, an autonomous drone, an upper limb prosthesis, and in post-stroke rehabilitation (Satam, 2022). The classification of EEG patterns has been the subject of a number of studies, most of which have concentrated on determining the intended movement of various body parts (Nazi et al, 2021). To improve MI EEG signal classification forecast accuracy, a random subspace ensemble network with variable-length feature sampling was deployed. The maximum precision of the study was 90%. Another research was implemented by Hafeez and his team (Amin et al, 2017). Pattern recognition was the basis of their study's categorization strategy. As a means of signal decomposition, the DWT was applied to EEG data. The reliability of the study's findings was 99.1 percent. The team in (Hashmi et al, 2021) proposed several machine learning methods, such as linear discriminant analysis (LDA), support vector machine (SVM), multi-layer perceptron, random forest, k-nearest neighbor, and auto encoder with SVM, to classify EEG signal samples of envisioning right-hand movement and rest. When using SVM, the highest accuracy of categorization was 70.4%. Epilepsy could be more easily diagnosed thanks to the EEG's classification. John et al. (Thomas et al, 2018) proposed categorization of epilepsy EEGs was based on IEDs. The proposed method consists of three parts: categorization at the level of the waveform, classification at the level of the EEG, and pre-processing. Convolutional Neural Networks (CNN) and Support Vector Machines (SVM) are used for waveform categorization and EEG classification, respectively. At its best, the technique achieved a precision of 83.86 percent (John Thomas et al.) To reduce the possibility of incorrect classifications, Dongmei et al. (Zhou & Li, 2020) conducted a thorough investigation of epilepsy EEG signals, analyzing the characteristics from both linear and non-linear perspectives before feeding

them into an improved RBF model. S J M Smith (Smith, 2005) gave an example of EEG research that proved the necessity of an EEG in the correct identification and treatment of status epilepticus. EEGs with tracking capabilities should ideally be accessible nonstop. Inggi et al. (Dwi Saputro et al, 2019) explore various Hjorth Descriptor and ICA feature combos for seizure classification. In this research, an accuracy of 91.4% was achieved. Tahereh et al. (Najafi et al, 2022) proposed a model based on the techniques of longitudinal bipolar montage (LB), discrete wavelet transform (DWT), and feature extraction, using statistics for RNN feature selection and a classification model based on extended short-term memory (LSTM). The proposed method achieved 96.1 percent of accuracy. Wen et al. advocated the use of a neural network model for autonomously learning and identifying EEG signals, one that could handle EEG signals of various sampling rates and durations (Wen et al, 2021). The previous work of (Ma et al, 2020) achieved a good accuracy. However, the accuracy can be increased using different methods of classification. In this paper, the ANFIS method was used for (Ma et al, 2020) work to increase the classification accuracy. Multiple signal processing procedures were applied to the EEG data to ensure the highest possible classification accuracy. The procedure begins with a preparation stage for the signal. A lot of noise and anomalies need to be stripped away from the data during this step, so it is crucial. The finest characteristics of the data must be taken, and the Dimension must be decreased through feature selection. The last stage consists of the actual classification procedure. Figure 1 presents the steps in this study.

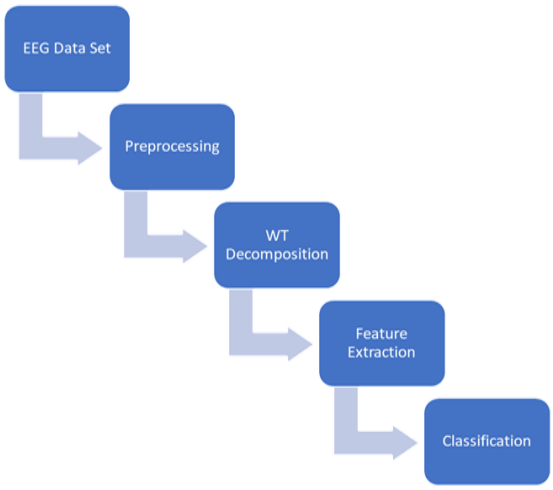


Figure 1 – Process of the study

DataSet

This paper's data were made available by (Ma et al, 2020) and each trial was given the green light by the ethics board at the Institute of Automation, Chinese Academy of Science. A total of 25 healthy, right-handed participants were surveyed (19 Males, 6 Females). There was no Mi-Based BCI information among the participants.

Methods of recording the signals

The data signals were selected from (Ma et al, 2020), (as mentioned in the previous section). It is crucial to mention the method by which the signals were recorded in order to fully understand the situation. The subjects sat in a cozy recliner with their hands lying normally on their legs as they observed the screen from a distance of one meter. (Fig. 2a). As shown in Figure 3, every trial lasted 8 seconds and began with a white circle in the middle of the screen for two seconds. After that, for one second, a red circle appeared as a signal to help people keep their attention on the impending objective. The "Hand" or "Elbow" cue was displayed for 4s before the intended response was required. During this period, the participants were asked to imagine performing the required action with their whole bodies, rather than just their eyes.The participants were instructed to relax their limbs and think about anything they wanted. EMGs were recorded from the participants' right hands and forearms. (Fig. 2b) in order to make sure they were not acting on their own accord (in the EEG preprocessing, the EMG signals were removed). In the end, a "break" of 1s was enough to put a stop to the 8s experiment and the fantasy. The patients were told to relax and minimize ocular and muscle activity during the break.

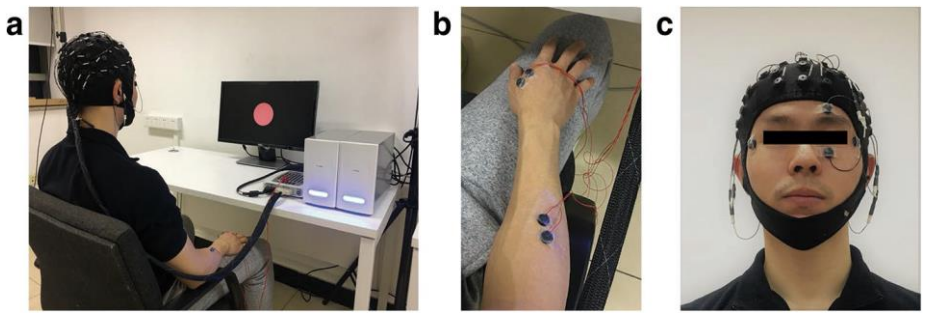


Figure 2 – Data Recording

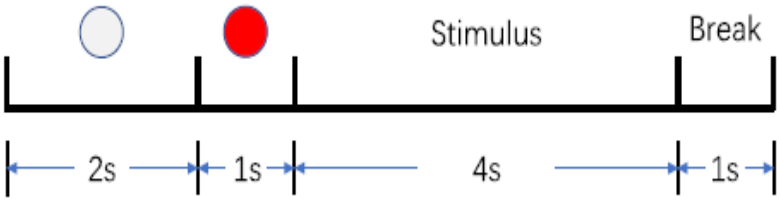


Figure 3 – Time Period for one trial

Event-related synchronization and desynchronization (ERS/ERD) are correlated with alpha (8-13 Hz) and beta (14-30 Hz) motor-related processes. When the actual action is carried out or imagined, ERD appears as a drop in a specific frequency component that is linked to a rise in neural activity. Increase in a specific frequency component is what makes something enhanced frequency sensitive, or ERS. Sometimes it can be observed even when no actual action is being done or envisioned, and this is because it is linked to the inhibition of cerebral activity. In recent years, researchers have discovered a strong link between a specific sense brain region and the ability to imagine moving specific parts of the body (as depicted in Figure 4). According to the image, the dark blue area in the center of the brain is responsible for controlling the limbs' mobility. The pale cyan region is responsible for directing hand motion. When all is said and done, it is the area above the ears that is responsible for moving things like the cheekbones and the mouth. Motor images may cause ERD in the dominant brain and ERS in the nondominant hemisphere. The spectrum strength of the brain frequency ranges is depicted in Figure 5. (marked as red).

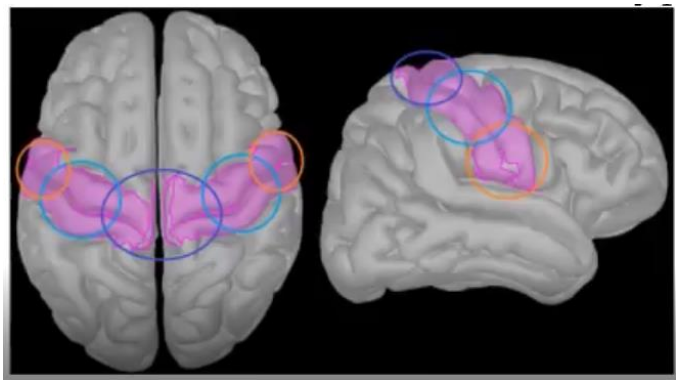


Figure 4 – Region of motor imagery

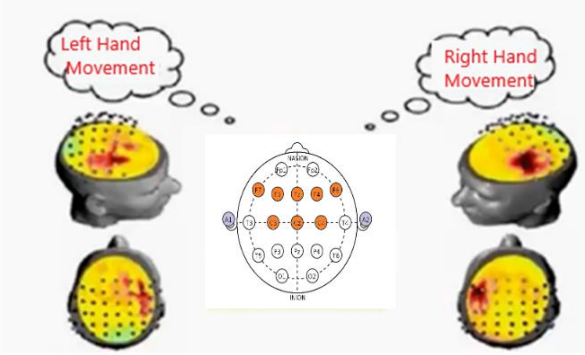


Figure 5 – BCI system for motor imagery signal recording

Preprocessing data signal

The standard 10/20 system was used to capture EEG data at a sampling rate of 1000 Hz using a Neuroscan SynAmps2 amplifier and a 64-channel electrode cover. The left mastoid was used as a standard for the electroencephalogram (EEG) recordings.

Electrode impedances were kept below 10 k ohm throughout the trial. The collected data was cleaned up using the EEGLAB toolkit (v14.1.1_b) in MATLAB (R2015a). In the initial stages of processing, we employed the use of a common average reference (CAR). A 40-hertz low-pass filter and a 0.1-hertz high-pass filter were installed. The input was down-sampled to 200Hz to reduce processing costs. Automatic artifact removal (AAR) was used to clean up the EEG of abnormalities related to the eyes and muscles. The data set had previously undergone preprocessing in (Ma et al, 2020) and was ready for the Extraction feature.

Wavelet transform

The wavelet transform is a tool for non-stationary time-scale analysis that can be applied to EEG data. Having the capacity to analyze non-stationary signals and break them down into their discrete frequency components across a variety of timescales is very useful. With WT, researchers are able to reduce complex biological signals consisting of multiple time-varying data sets to a manageable set of diagnostic factors (Hindarto et al, 2018).

The continuous and discrete wavelet transform formulas are both given in equations (1) and (2)

$$WT_x(a,\tau) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t)\psi * \frac{(t-\tau)}{a} dt \qquad \text{(1) Continuous Wavelet Transform}$$

where a represents the scale displacement, τ represents the time displacement, and ψ is the wavelet basis function, including Hear, db.Series, Coiflet, etc.

$$WT_x(j,k) = \int x(t)\psi^*_{j,k}(t)dt \qquad (2)$$ Discrete Wavelet Transform

The DWT(Discrete Wavelet Transform) is to limit the $a\ and\ \tau$ of the wavelet basis function $\psi(a,\tau)$ to discrete points, that is the discretization of scale and displacement. Figure 6 depicts the breakdown of the DWT of the EEG signal $x(n)$ via the low-pass filter or high-pass filter coefficients. The convolution is a two-function multiplication process that is subsequently processed using own sampling. To down a sample, one must cut the sample signal in half (reduction). Approximations and detail signals are the two forms of wavelet signals. A signal that results from the convolution of the original signal with a low-pass filter is an approximation, whereas a signal that results from the convolution of the original signal with a high-pass filter is a detail. In Figure 6, each output produces a detailed signal D and an approximate signal A, with the most recent one serving as the input for the following phase. The component of the EEG signal with the dominant frequency determines how many levels the wavelet decomposes.

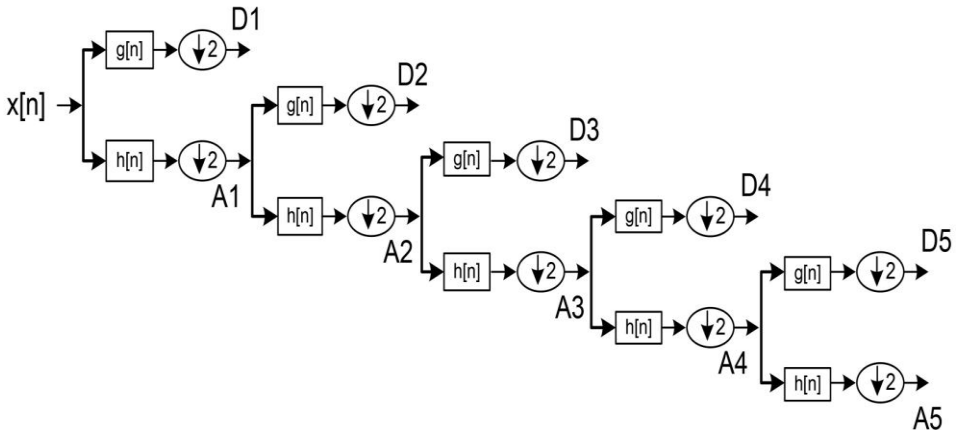


Figure 6 – Wavelet decomposition

The formula of the WT and the filter h is a low pass and can be formulated in the formulation as follows:

$$H\ (z)\ H\ (z\text{-}1) + H\ (\text{-}z)\ H\ (\text{-}z\text{-}1) = 1 \qquad (3)$$

In the above formula, H (z) is used to represent the h, z-transform filter and the complement transformation of this high-pass filter is expressed as:

$$G\ (z) = zH\ (-z\text{-}1). \quad (4)$$

According to the section above, the DWT is used to evaluate the spectrum components of EEG data. EEG signal analysis relies heavily on the WT, specifically a careful selection of a wavelet and the optimal number of breakdown stages. The number of thresholds is calculated based on the primary frequency component of the EEG data. In order to classify signals, the levels are chosen such that the wavelet coefficients maintain a strong connection between the various parts of the signals and the requisite frequencies. The analysis was performed using five distinct degrees of decomposition. Therefore, the EEG data is segmented into D1-D5 details and a final method, A5.

Multiple wavelet varieties are typically tested to find the most effective combination for a particular application. As a result of its Daubechies wavelet feature, the second order (db2) filtering is more adept at detecting variations in the input signal. Therefore, the wavelet coefficients were generated using db2 for this study.

For the Daubechies wavelet of the second order (db2), the band frequencies are as follows, with a sampling frequency of 256 Hz: D1 (64-128 Hz); D2 (32-64 Hz); D3 (16-32 Hz); D4 (8-16 Hz); D5 (4-8 Hz); and A5 (2-4 Hz). (0 - 4 Hz). To determine discrete wavelet values, MATLAB is used. Because even the most effective classifier will fail with a badly selected input feature, this is a crucial factor in the design of artificial neural networks based on pattern categorization. Determining the wavelet discontinuous coefficient provides a representation of the signal's energy across time and frequency. For this reason, the discontinuous wavelet coefficient calculated from the EEG signal of each record serves as the feature vector used to characterize the signal. The size of the recovered feature vector is reduced by using statistics on top of the collection of wavelet coefficients. The temporal frequency distribution of the signals under study is represented by the statistical characteristic listed below:

- Means and standard deviation value,
- Variance,
- Skewness,
- Kurtosis, and
- Root Mean Square.

In this paper, the data needed for the right arm is collected from C3 channel as explained in section 3. In order to retrieve the features for the EEG data prior to classification, a code is developed in MATLAB for this wavelet.

Means and standard deviation value

The definition of the mean is very simple as it is the sum of all the signals divided by the number of the signals.

$$\mu = \frac{1}{N}\sum_{i=0}^{N-1} X_i \tag{5}$$

The expression$|X_i - \mu|$ indicates the difference between the deviation of the sample and their mean. The average deviation can be found by the sum of all the derivatives of the sample signals and divided by the total number of samples. The standard deviation is similar but the average is done by power instead of amplitude as shown in equation (6).

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=0}^{N-1}(x_i - \mu)^2} \tag{6}$$

Variance

It is the variability measure. In order to determine the variance, the average cubed departure from the mean is used as the denominator. The extent of dispersion in data collection can be better understood by examining its variance. The variance from the mean increases as data spreads out.

$$\sigma^2 = \frac{1}{N-1}\sum_{i=0}^{N-1}(X(i) - \mu)^2 \tag{7}$$

Skewness

Skewness is a statistical measure of the degree to which a signal deviates from its mean value. To compute it, divide the cubed standard deviation by the cubed mean variation.

$$\gamma = \frac{1}{(N-1)\sigma^3}\sum_{n=0}^{N-1}(x_n - \mu)^3 \tag{8}$$

Kurtosis

It is the Kurtosis of the signal that determines its Peakedness. More peaks in the waveform correspond to a greater kurtosis number.

$$K = \frac{\frac{1}{N-1}\sum_{i=0}^{N-1}(x_i^4)}{(\frac{1}{N-1}\sum_{i=0}^{N-1}(x_i^2))^2} \quad (9)$$

Root Mean Square

It is a quantitative representation of the signal's intensity. The signal's magnitude is determined using the root-mean-square formula. The strength is represented by the range. The root-mean-square deviation provides a measure of the variability in the system's response to external factors.

$$R.M.S = \sqrt{\frac{1}{N-1}\sum_{i=0}^{N-1} x_i^2} \text{------ (10)}$$

Applications of the ANFIS

The terms "adaptive neuro-fuzzy inference system" (ANFIS) and "adaptive network-based fuzzy inference system" refer to artificial neural networks that are built on the Takagi-Sugeno fuzzy inference system. (ANFIS). This strategy first appeared in the early 1990s. Since it incorporates elements of both neural networks and fuzzy logic, it can reap the benefits of both in a unified system. It can learn and approximate nonlinear functions through a reasoning process that is similar to a set of IF-THEN fuzzy rules. Therefore, the ANFIS is considered a worldwide predictor. The ANFIS can be used more quickly and successfully with the help of the optimal settings found by a genetic algorithm. Possibilities for use include smart energy control systems with context awareness. There are two main components to the network architecture, and they are the foundation and the result. There are a total of five progressively deeper layers in the structure. The input numbers are used by the first layer to determine which membership functions to pick. It is commonly referred to as the "fuzzification layer" (Stefenon et al, 2020). The membership degrees of each function are computed by using the premise parameter set, namely {a,b,c}. The second level is in charge of producing the rule-based discharge rates. The second layer's responsibility is to generate the regulation discharge intensities. We call the second layer the "rule layer" because of the rules it contains. Fuzzification adds a third level of complexity. Layer 4 attempts to standardize the predicted firing strengths by splitting each number by the total firing strength. The fifth layer takes as input the normalized values and the consequence parameter set {p,q,r}. The output is sent using the defuzzified values returned by this component. (Figure 7).

After feature extraction from the EEG data, the ANFIS was applied in MATLAB code for this study, following the addition of registration capabilities. The findings for each topic were derived using the previously stored FIS method.

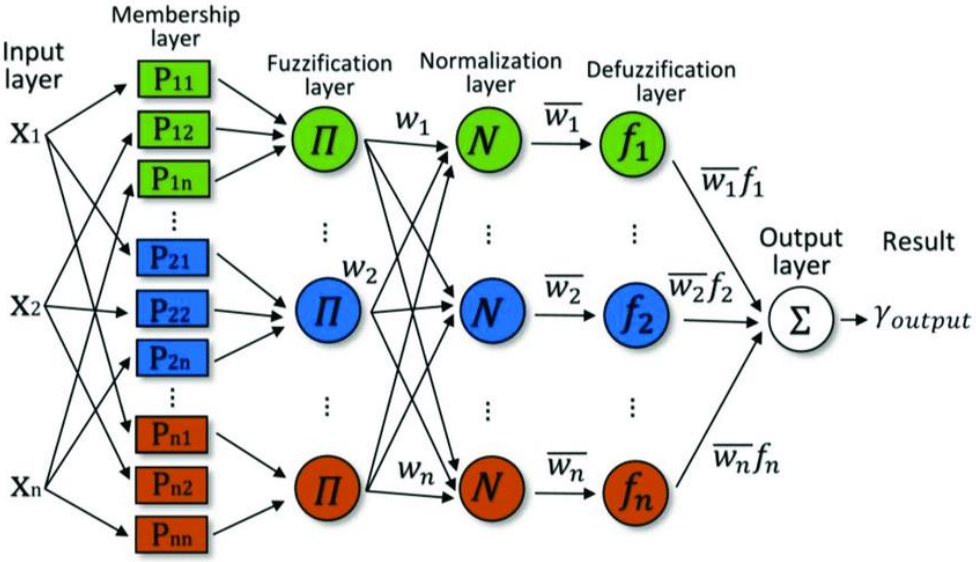


Figure 7 – ANFIS

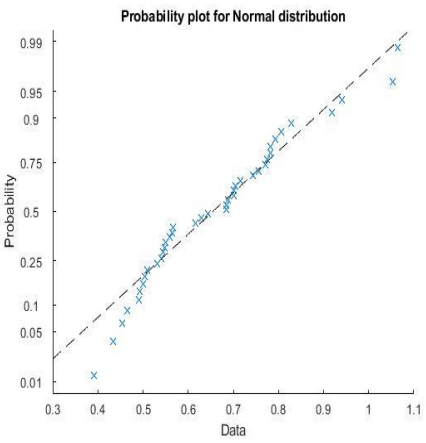
Results

Once the data had been cleaned up, the wavlet transform technique was used to pull out the most useful information. Subject one's characteristics are displayed in a histogram, likelihood, and quantile-quantile figure (a, b, and c, respectively, in Figure 8). The QQ diagram demonstrates that the feature data is normally distributed.

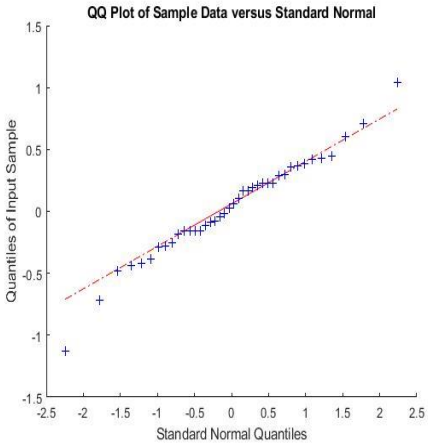
The next step is a classification of the data. To begin, the EEG signals derived characteristics are used to hone the ANFIS classifier's abilities. It is in the ANFIS training setting where the actual learned patterns are created. Then, using the learned patterns as a guide, the ANFIS classifies the derived features from the test EEG data.

The ANFIS classifier categorization method yields a binary output answer, either 1 " Hand " or 2 " Elbow ".

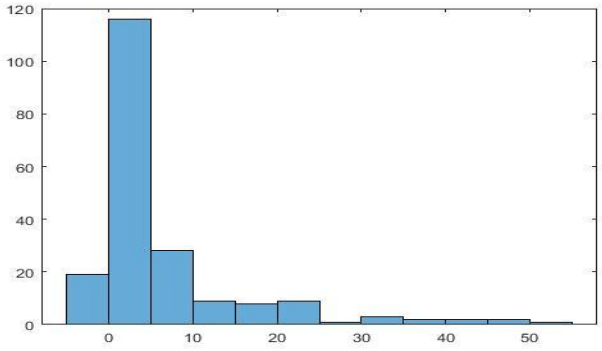
The results of the 25 individuals are displayed in Table 1 below in terms of accuracy, which is compared to the results in (Ma et al, 2020); the results were higher which indicates that the system is reliable.



B. Normal probability



A. Quantile-Quantile plot



C. Histogram

Figure 8 – Characterestics of the processed data of subject 1

Figure 9 shows the ANFIS structure while Figure 10 shows the Fuzzy inference system for the first subject and how the rules are based in order to collect the output.

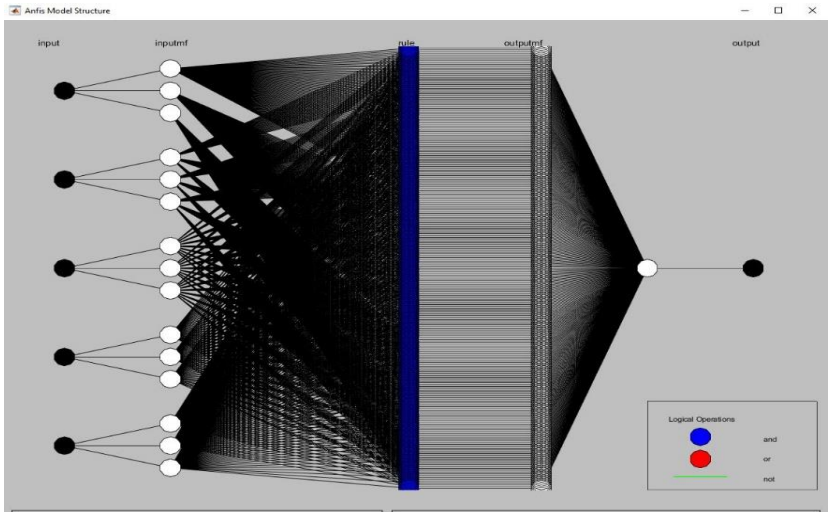


Figure 9 – ANFIS structure

Figure 10 – Fuzzy set for subject 1

Figure 11 depicts the real result of the fuzzy system, which is the application of fuzzy principles to all the samples within each topic. The outcome changes with the characteristics chosen by the WT transform, as demonstrated by the findings.

Figure 12 displays the discrepancy between the real and ideal outputs. The ANFIS algorithm produces results that are within a tolerable margin of error in comparison to the intended results.

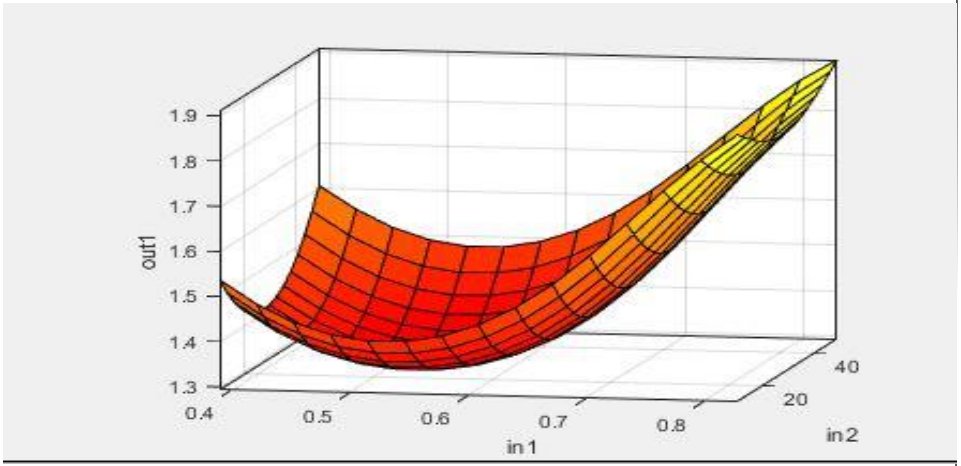


Figure 11 – Fuzzy output

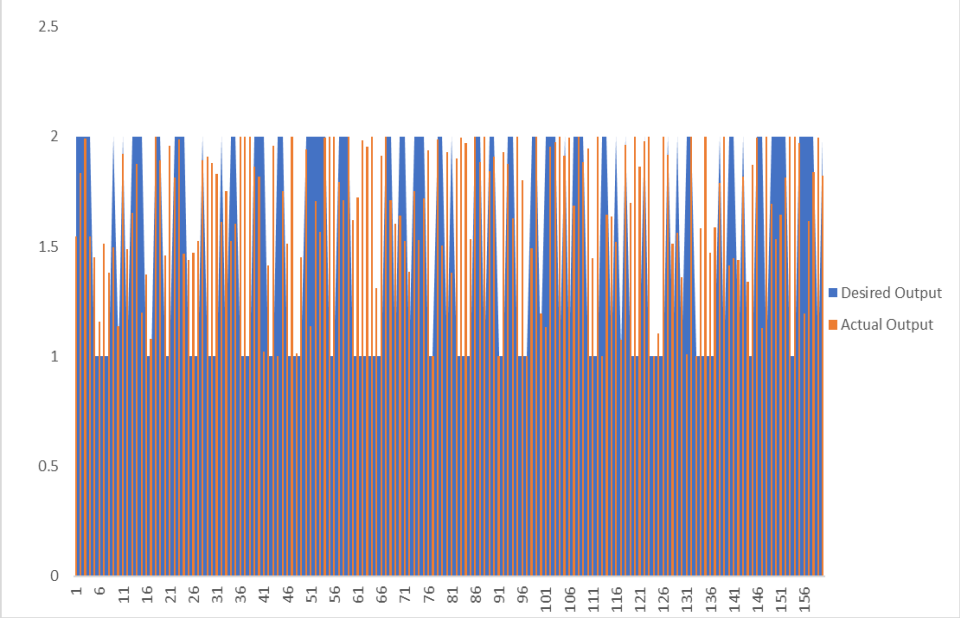


Figure 12 – Subject 1 Output

Table 1 – Accuracy of the ANFIS

No	Accuracy of the ANFIS classification algorithm		
1	85.00%	14	91%
2	95.30%	15	85%
3	86.06%	16	93%
4	96.40%	17	90%
5	99%	18	87%
6	80%	19	95%
7	91%	20	80%
8	88.10%	21	92%
9	88%	22	95%
10	80%	23	96%
11	85%	24	95.00%
12	90.30%	25	96%
13	94%		

Figure 13 given below shows the accuracy achieved in this study compared to the results in (Ma et al, 2020). Due to its superior performance compared to its predecessors, the algorithm is heavily relied upon for signal classification.

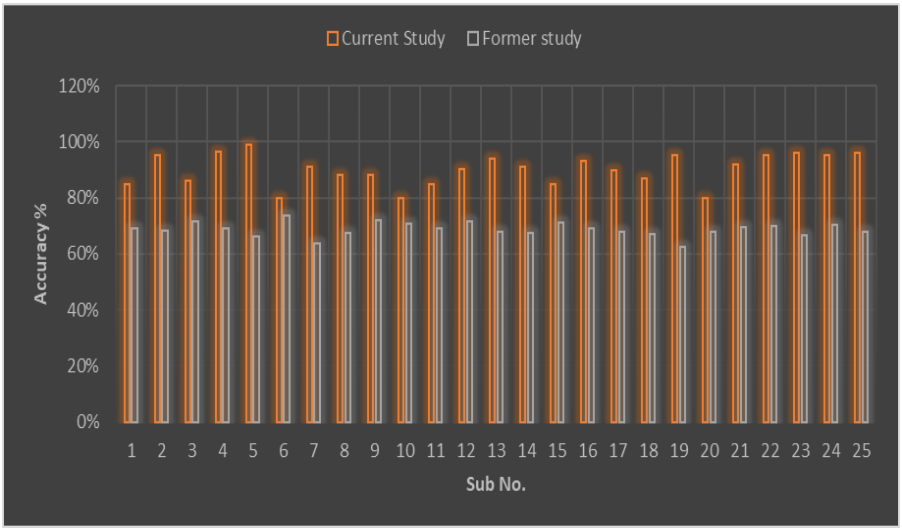


Figure 13 – Accuracy for both studies

Conclusion

In medical contexts, fuzzy set theory is useful for addressing ambiguity and making choices. With the help of fuzzy logic, we were able to incorporate doubt into the classifier architecture, which ultimately led to more trust in the system results. In this work, we introduced an innovative use of the ANFIS: the categorization of EEG data. When the wavelet coefficients of the EEG signals were used as inputs, the ANFIS algorithms were able to distinguish between two groups of EEG signals. Although it will take a long time to process, this can be overcome by using a computer with a high CPU process; the more characteristics pulled from the data, the more efficient the program can be. When using the algorithm to control the motion of a mechanical arm, the varying results increase the likelihood that the arm will be moved by varying the pace at which the elbow and the wrist rotate. The ANFIS was assessed based on the categorization outcomes and data metrics. The overall precision of the ANFIS model categorization was 90.13%. Indicating the algorithm dependability and potential for further uses, the suggested ANFIS model can be used to categorize EEG data.

Appendix

Table 2 – Acronyms

Acronym	Description
BCI	Brain Computer Interface
EEG	Electroencephalography
ANFIS	Adaptive Neuro Fuzzy Inference System
MI	Machine Interface
SSVEP	steady-state visual evoked potentials
DWT	Discreet Wavelet transform
LDA	Linear Discriminant Analysis
SVM	Support Vector Machine
CNN	Convolutional Neural Network
LSTM	Long Short-Term Memory
RNN	Recurrent Neural Network
ERD	event-related desynchronization
ERS	event-related synchronization

QQ	quantile-quantile
MFCC	Mel-Frequency Cepstral Coefficient
CAR	Common Average Reference
ICA	Independent Component Analysis
DWT	Discrete Wavelength Transform
EMG	Electromyography

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Clasificación ANFIS de señales EEG para imágenes motoras de diferentes articulaciones de la misma extremidad

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CAMPO: Bioingeniería
TIPO DEL ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: El área experimental de las interfaces cerebro-computadora (BCI) se está expandiendo para incluir acciones de movimiento, que desempeñan un papel crucial en descifrar los procesos cognitivos. Sin necesidad de ningún tipo de estimulación exterior, la imaginación motora (IM) se puede utilizar como un modelo poderoso para Interfaces cerebro-computadora (BCI). Un método natural para operar en dispositivos externos es imaginarse moviendo varias articulaciones en un mismo brazo. Estos movimientos imaginados tienen imágenes espaciales similares en el cerebro motor, lo que hace difícil diferenciar IM de varias articulaciones de la misma pierna según los datos del EEG.

Métodos: En este estudio se utilizó una recopilación de datos preexistente de 25 participantes. Los participantes debían visualizarse usando sus extremidades derechas para realizar tres diferentes actividades: visualízate

manipulando tu mano derecha. Visualizar doblar el brazo derecho y cierra los ojos mientras te relajas. Asignar categorías a estos impulsos, recurrimos al neuro difuso adaptativo sistema de razonamiento.

Resultados: El nivel promedio de precisión fue del 90%.

Conclusión: Los hallazgos demuestran que esta técnica es crucial para categorizar correctamente los datos de EEG. La recopilación de datos utilizada en esta investigación consisten en mediciones de EEG de la misma extremidad utilizada en imágenes musculares. El nuevo método de categorización se aplicará a estas señales para obtener conclusiones.

Palabras claves: electroencefalografía (EEG), clasificación, ANFIS, transformada wavelet, extracción de características, BCI.

Метод ANFIS в классификации сигналов ЭЭГ при представлении движений разных суставов одной конечности

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Резюме:

Введение/цель: Экспериментальная область изучения интерфейса мозг-компьютер (BCI) распространяется на движения, которые играют решающую роль в расшифровке когнитивных процессов. Без необходимости какой-либо внешней стимуляции воображение движения (MI) можно использовать в качестве мощной модели интерфейса мозг-компьютер. Естественный метод управления внешними устройствами заключается в представлении движения разных суставов одной руки. Эти воображаемые движения создают аналогичные пространственные изображения в моторной коре, и их трудно отличить от воображаемых движений разных суставов одной ноги на основе данных, полученных с помощью ЭЭГ.

Методы: В данном исследовании использовался существующий набор данных, полученный от 25 респондентов, которые представляли, как они используют правую руку при выполнении трех разных команд: 1. представьте, как вы используете правый кулак, 2. представьте, как вы сгибаете правую руку, и 3. закройте глаза и расслабьтесь. Для того, чтобы связать эти импульсы с категориями, мы использовали нейро-нечеткую систему вывода.

Результаты: Средний уровень точности составил 90%.

Выводы: Результаты показали, что данный метод является ключом к правильной категоризации данных, полученных с помощью ЭЭГ. Набор данных, использованный в этом исследовании, состоит из измерения ЭЭГ конкретной конечности при представлении ее движения. При выводе такой новый метод категоризации будет применяться к сигналам ЭЭГ соответствующей конечности.

Ключевые слова: электроэнцефалография (ЭЭГ), классификация, ANFIS, волновое преобразование, извлечение характеристик, BCI.

Метода АНФИС за класификацију ЕЕГ сигнала при замишљању покрета различитих зглобова истог екстремитета

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ОБЛАСТ: биоинжењеринг
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Експериментална област проучавања интерфејса мозак-рачунар (BCI) шири се и на покрете који имају одлучујућу улогу при дешифровању когнитивних процеса. Без потребе за било каквом спољашњом стимулацијом, замишљање покрета (MI) може се користити као моћан модел за интерфејс мозак-рачунар. Природни метод управљања спољашњим уређајима јесте замишљање покрета различитих зглобова исте руке. Ови покрети стварају сличне просторне слике у моторном кортексу и тешко их је разликовати од замишљања покрета различитих зглобова исте ноге на основу података добијених помоћу ЕЕГ-а.

Методе: У студији је коришћен већ постојећи скуп података добијених од 25 испитаника који су замишљали како користе десну руку при извршавању три различите наредбе: у стању опуштања, затворених очију, замишљали су како користе десну шаку и како савијају десну руку. Да би се повезали ови импулси са категоријама, коришћен је адаптативни неуро-фази систем закључивања.

Резултати: Просечан ниво тачности био је 90%.

Закључак: Налази показују да је ова техника кључна за правилну категоризацију података добијених помоћу ЕЕГ-а. Скуп података коришћен у овом истраживању састоји се од мерења ЕЕГ одређеног

екстремитета док се замишља његово покретање. Нов метод категоризације биће примењен на ове сигнале при извођењу закључака.

Кључне речи: електроенцефалографија (ЕЕГ), класификација, АНФИС, трансформација таласића, екстракција својстава, BCI.

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A brief introduction to black holes

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Abstract:

Introduction/purpose: Starting from general relativity, black hole generation and effects are investigated.

Method: Einstein's equation and its Schwarzschild solution are employed to study black holes. Quantum mechanics is used to obtain Hawking's radiation.

Results: Black holes are actually not completely black - they radiate energy during their lifetime.

Conclusions: Black holes could evaporate and this effect is observable if their mass is sufficiently small. Their entropy scales differently with respect to their mass from that of other objects in thermodynamics.

Key words: general relativity, black Holes, Hawking radiation.

General relativity

Special relativity (SR) is a theory that applies to systems moving at a constant velocity. The speed of light c is constant for all observers; space and time are separate and independent dimensions. The metric that defines the distance ds^2 between two points of the four dimensional space is not positive defined:

$$ds^2 = c^2dt^2 - dx^2 \tag{1}$$

The corresponding metric is given by $g_{\mu\nu} = \text{diag}\,(+1, -1, -1, -1)$, $\mu, \nu = 1, \ldots, 4$. In SR the metric tensor $g_{\mu\nu}$ does not depend on the point, and the space is flat. The Lorentz group is the group of spacetime transformations that preserve (1).

General relativity (GR) applies to systems accelerating or under the influence of gravity, which can bend rays of light. This is the case in the presence of very massive objects such as black holes.

In GR, the distance between two points x^μ, x^ν is usually written as

$$s^2 = g_{\mu\nu} x^\mu x^\nu \tag{2}$$

(we use units for which $c = 1$) where $g_{\mu\nu}$ depends upon the spacetime point; therefore, contrary to SR, spacetime is not flat. Curvilinear coordinates are used, where a covariant vector transforms like

$$A^\mu = \frac{dx'^\nu}{dx_\mu} A'_\nu \,, \tag{3}$$

while to obtain a contravariant vector one lowers indices with $g_{\mu\nu}$: $A_\mu = g_{\mu\nu} A^\nu$.

For a vector A, if A^μ is its value at the point x^μ, at its neighbor point $x^\mu + dx^\mu$ will be $A^\mu + dA^\mu$. The total variation of A will be given by coordinates change and a functional variation of A:

$$dA^\mu + \delta A^\mu \,, \tag{4}$$

where

$$\delta A^\mu = \Gamma^\mu_{\rho\sigma} A^\rho dx^\sigma \tag{5}$$

$\Gamma^\mu_{\rho\sigma}$ is the Christoffel symbol that describes the metric g, non flat in GR. This leads to an extension to the concept of derivative, the covariant derivative being defined as

$$D_\mu A^\nu = \partial_\mu A^\nu - \Gamma^\nu_{\mu\rho} A^\rho \,. \tag{6}$$

Observe that this concept is also used in quantum field theories where spacetime is flat in order to describe an “inner” gauge space.

The relation of Γ with the metric g is given by:

$$\Gamma^\mu_{\nu\rho} = \frac{1}{2} g^{\mu\sigma} (\partial_\nu g_{\sigma\rho} + \partial_\rho g_{\sigma\nu} - \partial_\sigma g_{\nu\rho}) \tag{7}$$

The Riemann strength tensor could be expressed by a commutator of covariant derivatives (6)

$$R^\mu_{\nu\rho\sigma} = (\partial_\rho \Gamma^\mu_{\sigma\nu} + \Gamma^\mu_{\rho\tau} \Gamma^\tau_{\sigma\nu}) - (\partial_\sigma \Gamma^\mu_{\rho\nu} + \Gamma^\mu_{\sigma\tau} \Gamma^\tau_{\rho\nu}) \,, \tag{8}$$

and, again, in analogy to it the electromagnetic and chromomagnetic field strength $F_{\mu\nu}$ is written as a commutator of covariant gauge derivatives.

The Ricci tensor is defined by contracting two indices of the Riemann tensor:

$$R_{\mu\nu} = g^{\rho\sigma} R_{\rho\sigma\mu\nu} \ , \tag{9}$$

and the scalar tensor is obtained from the contraction of the remaining two indices of the Ricci tensor:

$$R = g^{\mu\nu} R_{\mu\nu} \ . \tag{10}$$

The action of GR (in absence of matter and a cosmological constant) is obtained by the simplest scalar of the theory (the Ricci tensor) integrated over the spacetime volume

$$S = \int d^4x \sqrt{-g} g^{\mu\nu} R_{\mu\nu} \ , \tag{11}$$

g being the determinant of $g^{\mu\nu}$. This action is known as the Einstein–Hilbert action, to name just a few papers on the subject: (Einstein, 1915a,b; Hilbert, 1915).

In order to obtain Einstein's equation of GR, one has to compute the variation of action (11) which is composed of three terms:

$$\delta S = \int d^4x (\delta\sqrt{-g}) g^{\mu\nu} R_{\mu\nu} + \int d^4x \sqrt{-g} (\delta g^{\mu\nu}) R_{\mu\nu} + \int d^4x \sqrt{-g} g^{\mu\nu} \delta(R_{\mu\nu}) = \delta S_1 + \delta S_2 + \delta S_3 \tag{12}$$

Consider the first term δS_1. For an invertible matrix M, one has $MM^{-1} = I$. It follows that $\delta(MM^{-1}) = 0 = \delta(M)M^{-1} + M\delta(M^{-1}) = 0$. Therefore, $\delta(M^{-1}) = -M^{-1}\delta(M)M^{-1}$ so one obtains

$$\delta(g^{\rho\sigma}) = -g^{\rho\mu}\delta(g_{\mu\nu})g^{\nu\sigma} \tag{13}$$

For the second term δS_2, $\log\det M = \mathrm{Tr}\log M$. Therefore, $\delta(\log\det M) = \delta(\det M)/\det M$, that implies $\delta(\det M) = (\det M)\delta(\log\det M)$, then follows that $(\det M)\delta(\mathrm{Tr}\log M) =$

$(\det M)\,\mathrm{Tr}\,\delta(\log M) = (\det M)\,\mathrm{Tr}(M^{-1}\delta(M))$. We obtain:

$$\delta(\sqrt{-g}) = \frac{1}{2}\sqrt{-g}g^{\mu\nu}\delta(g_{\mu\nu}) \tag{14}$$

For the third term, δS_3, there is a lengthy and not very enlightening calculation. From the Palatini identity

$$\delta R^{\rho}_{\mu\sigma\lambda} = D_\sigma \delta\Gamma^{\rho}_{\mu\lambda} - D_\lambda \delta\Gamma^{\rho}_{\mu\sigma} \tag{15}$$

which stems out when considering locally flat coordinates, that is $\Gamma = 0$ for all indices, and therefore for $\delta R^{\rho}_{\mu\sigma\lambda}$ remain only the parts with derivatives, one obtains for the Ricci tensor

$$\delta R_{\mu\nu} = \delta R^{\rho}_{\mu\sigma\lambda}\,. \tag{16}$$

The result is

$$\delta S_3 = \int d^4x\sqrt{-g}g^{\mu\nu}(D_\sigma\delta\Gamma^{\rho}_{\mu\lambda} - D_\lambda\delta\Gamma^{\rho}_{\mu\sigma})\,, \tag{17}$$

integrating by parts and using the fact that $D_\rho g^{\mu\nu} = 0$ the third term is just a surface term, thus irrelevant.

The final result of the Einstein-Hilbert action variation is thus

$$\delta S = \int d^4x\sqrt{-g}\left[\left(\frac{1}{2}g^{\mu\nu}R\right)\delta(g_{\mu\nu}) + R_{\sigma\rho}\left(-g^{\sigma\mu}\delta(g_{\mu\nu})g^{\nu\rho}\right)\right] = \int d^4x\sqrt{-g}\left(\frac{1}{2}g^{\mu\nu}R - R^{\mu\nu}\right)\delta(g_{\mu\nu}) = 0\,, \tag{18}$$

which has to be true for any $\delta(g_{\mu\nu})$. Therefore, Einstein's equation for GR is given by

$$\frac{1}{2}g^{\mu\nu}R - R^{\mu\nu} = 0\,, \tag{19}$$

for an empty space.

Black holes

Perhaps the first "proto–idea" of a black hole came from Laplace, and independently, from Mitchell (Michell, 1784). He envisaged a Newtonian gravitational field so strong that even the fastest object could not escape

it. If M is the mass generating this particular gravitational field, and m the object that should escape it, then its energy is given by

$$E = \frac{1}{2}mv^2 - G\frac{mM}{r} \tag{20}$$

where G is the gravitational constant. As the maximal possible speed is c, the object will reach its maximal distance r_s from the massive gravitational field for $E = 0$, and from eq. (20) we obtain

$$r_s = \frac{2GM}{c^2} \tag{21}$$

So even the light cannot leave this massive object for a distance larger than $r > r_s$. Therefore, this particular object cannot emit light at a distance, so it appears to be black. This amazing result anticipates by almost two centuries subsequent discoveries of black holes.

Taking Einstein's equation (19) for a massive object and the space with a rotational symmetry, it can be shown that the spacetime metric could be written in the form

$$ds^2 = -\left(1 - \frac{r_s}{r}\right)dt^2 + \frac{1}{\left(1 - \frac{r_s}{r}\right)}dr^2 + r^2(d\theta^2 + \sin^2\theta d\phi^2)\ , \tag{22}$$

that is,

$$ds^2 = -\left(\frac{r - r_s}{r}\right)dt^2 + \left(\frac{r}{r - r_s}\right)dr^2 + r^2 d\Omega^2\ . \tag{23}$$

This is the Schwarzschild solution 1916 (Schwarzschild, 1916a,b; Droste, 1917), and is the only possible spherically symmetric solution. Note that it depends only on the total mass of the body, in complete analogy to the Newtonian theory, because the r_s parameter is the same found by Laplace (21). At large distances from the origin, this metric behaves like

$$ds^2 \simeq ds^2_{Newt} - \frac{r_s}{r}(dt^2 + dr^2)\ , \tag{24}$$

that is, the Newtonian solution plus a perturbation of order r_s, thus at large distances every field appears centrally symmetric. At distances close to r_s, and $r > r_s$, the time slows down because of acceleration due to a strong gravitational field. The boundary at $r = r_s$ is called the event horizon, where the escape velocity is larger than the speed of light, as already seen in (21). If an object, or even radiation, crosses this boundary from the

external space, it can only eventually fall into the black hole. To provide some numbers, the Schwarzschild radius of our Sun is of the order of 3 km, while for the Earth it is less than 1 cm.

Observe that the Schwarzschild solution is singular only by the choice of coordinates that could be seen from the fact that the determinant of metric (23) is actually regular for $r = r_s$. The question was cleared only much later by Kruskal (Kruskal, 1960), where his coordinates are well defined at the event horizon $r = r_s$.

There are other solutions of Einstein's equation (19) that lead to black holes. A nonrotating charged black hole comes from the Reissner–Nordström metric (Reissner, 1916; Nordström, 1918).

Later, a rotating noncharged black hole solution came from the Kerr metric (Kerr, 1963).

Black hole properties

A star is essentially a ball of gas at equilibrium for most of its life. Inside its core nuclear reactions occur, where fusion of H nuclei into He create energy. The gravitation is in equilibrium with internal pressure due to heat as long as there is enough nuclear fuel. At the end of fuel, gravity prevails, the star crushes under its own weight, and a remnant is left.

If the remnant of the star is approximately larger than 3–4 $M_\odot$, the mass of the Sun, it is still too heavy and will eventually collapse to a black hole, with a radius smaller than the Schwarzschild one, $r < r_s$. There is no known mechanism that could prevent this process, not even in neutron stars, except maybe for quark stars, provided they exist at all.

From quantum mechanics (see for instance (Fabiano, 2022) for a discussion of the following subject), the probability amplitude of transition from an initial state $|in\rangle$ to a final state $|fi\rangle$ is given by the matrix element

$$\langle fi|e^{-itH}|in\rangle \ . \tag{25}$$

In thermodynamics, the probability of finding a state $|n\rangle$ of energy E_n at a given temperature T is given by Boltzmann:

$$\frac{\exp(-\beta E_n)}{Z} \ , \tag{26}$$

where $\beta = 1/T$ and Z is the partition function of the quantum mechanical system:

$$Z = \sum_{n=1}^{+\infty} \langle n|e^{-\beta E_n}|n\rangle = \sum_{n=1}^{+\infty} e^{-\beta E_n} = \mathrm{Tr}\, e^{-\beta H} \ . \tag{27}$$

Setting the initial and final states to be the same, i.e. $|in\rangle = |fi\rangle = |n\rangle$, and replacing the time with the inverse of the temperature by means of a Wick rotation, that is, the exchange $it \leftrightarrow \beta$, one could identify the two formulae (25) and (27) to be the same expression. What concerns us most here is that with this procedure the time t becomes periodic and corresponds to an inverse of the system temperature, $1/T$.

Rewrite now the Schwarzschild metric (23) in the following manner. Choose ρ such that $d\rho^2 = r_s/(r - r_s)dr^2$, that is: $\rho^2 = 4r_s(r - r_s)$. Therefore, $\rho^2 d\rho^2 = 4r_s^2 dr^2 = (r - r_s)d\rho^2$.
Near the Schwarzschild radius one obtains:

$$ds^2 \approx -\frac{\rho^2}{4r_s^2}dt^2 + d\rho^2 + r_s^2 d\Omega^2 \ . \tag{28}$$

In Euclidean time, $t_E = it$ so $dt_E^2 = -dt^2$, therefore, the metric will gain all $+$ signs:

$$ds^2 \approx \frac{\rho^2}{4r_s^2}dt_E^2 + d\rho^2 + r_s^2 d\Omega^2 \ . \tag{29}$$

Define ψ such that $t_E = 2r_s\psi$, obtaining finally the metric for $r \approx r_s$

$$ds^2 \approx \rho^2 d\psi^2 + d\rho^2 + r_s^2 d\Omega^2 \ . \tag{30}$$

By inspection of the result, the first two terms are radial coordinates on a plane, (ρ, ψ), ψ having a 2π period, so from its definition follows that t_E has a period of $4\pi r_s$. With the above identification $t_E \leftrightarrow 1/T$, we have the following expression for the temperature of the black hole:

$$T = \frac{1}{4\pi r_s} = \frac{1}{8\pi GM} \ . \tag{31}$$

This is the Hawking temperature (Hawking, 1975, 1974), which is due to a quantum mechanical effect in the region near to the event horizon. Black holes spontaneously emit thermal radiation at this temperature. As seen from the derivation of T, it is due to vacuum fluctuations of quantum fields, which produce pairs of particles; one of them falls inside the black hole, while the other escapes to infinity.

The Hawking temperature increases when the mass of the black hole is smaller, and by radiating the black hole loses energy, i.e. it evaporates. It could be shown that the evaporation time for a black hole scales with the cube of its mass, i.e.

$$t_{evap} \propto M^3 \ , \tag{32}$$

and while a black hole with the mass of our Sun will evaporate for a much longer time than the age of the Universe, a lighter one should still be observable by astronomers while exploding.

From its temperature, it is easy to find out the entropy of a black hole. From the expression of the energy, $E = c^2$M, that implies $dE = TdS = c^2 dM$, thus obtaining the proportionality relations:

$$dS \propto \frac{1}{T} c^2 dM \propto G c^2 d(M^2), \text{ therefore, } S \propto M^2 \ . \tag{33}$$

The entropy of a black hole is proportional to the square of its mass, and from the expression of the Schwarzschild radius (21), $r_s \propto M$, therefore the entropy is proportional to r_s^2, the area of the event horizon:

$$S \propto M \propto r_s^2 = A \ . \tag{34}$$

The entropy is an extensive quantity, proportional to the volume of the system considered. For a black hole, it is not so. The entropy is proportional to its area, not its volume.

This strange result was the inspiration of the so-called holographic principle, first proposed by Hooft and later formalized in string theory by Susskind (Susskind, 1995), for which gravity phenomena in a volume of space are actually projections of a two dimensional space, just like the holograms, which create three dimensional images from a two dimensional plate.

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Una breve introducción a los agujeros negros

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CAMPO: Física
TIPO DE ARTÍCULO: artículo de revisión

Resumen:

Introducción/objetivo: Partiendo de la relatividad general, se investiga la generación y los efectos de los agujeros negros.

Métodos: La ecuación de Einstein y su solución de Schwarzschild se emplean para estudiar los agujeros negros. Para obtener la radiación de Hawking se utiliza la mecánica cuántica.

Resultados: En realidad, los agujeros negros no son completamente negros: irradian energía durante su vida.

Conclusión: Los agujeros negros podrían evaporarse y este efecto es observable si su masa es lo suficientemente pequeña. Su entropía escala de manera diferente con respecto a su masa que la de otros objetos en termodinámica.

Palabras claves: relatividad general, agujeros negros, radiación de Hawking.

Краткое введение в черные дыры

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РУБРИКА ГРНТИ: 29.05.03 Математические методы теоретической физики,
29.05.19 Специальная теория относительности,
29.05.41 Гравитационное взаимодействие. Общая теория относительности
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: В данной статье объясняются образование и влияние черных дыр, начиная с общей теории относительности.

Методы: В изучении черных дыр используются уравнения Эйнштейтна и метрика Шварцшильда в качестве решения этих уравнений. С помощью квантовой механики описано излучение Хокинга.

Результаты: Черные дыры на самом деле не являются полностью черными, они излучают энергию в течение своего существования.

Выводы: Черные дыры могут испаряться. Чем меньше масса черный дыры, тем заметнее ее излучение и исчезновение. Соотношение энтропии и массы черных дыр отличается от соотношения других термодинамических объектов.

Ключевые слова: общая теория относительности, черные дыры, излучение Хокинга.

Основна сазнања о црним рупама

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Београд, Република Србија

ОБЛАСТ: математика
КАТЕГОРИЈА ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: У чланку су објашњени настанак и ефекти црних рупа почевши од опште теорије релативности.

Методе: За проучавање црних рупа искоришћене су Ајнштајнове једначине и Шварцшилдово решење тих једначи-

на. Помоћу квантне механике описано је Хокингово зрачење.

Резултати: Црне рупе нису у потпуности „црне". Оне емитују енергију у виду зрачења током свог века трајања.

Закључак: Црне рупе могу испарити. Овај ефекат би могао бити видљив уколико је њихова маса довољно мала, а њихова ентропија се мења другачије од промене у ма-си у односу на друге термодинамичке објекте.

Кључне речи: општа теорија релативности, црне рупе, Хокингово зрачење.

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The utilization of Solidity programming language in blockchain

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FIELD: computer sciences, IT
ARTICLE TYPE: review paper

Abstract:

Introduction/purpose: This work provides a comprehensive overview of blockchain technology, elucidating its foundational principles and how it ensures transparency, immutability, and decentralization. The integration of Solidity with blockchain is explored through theoretical approach.

Methods: This work meticulously dissects blockchain principles, elucidating transparency, immutability, and decentralization, while exploring Solidity integration in a theoretical framework, ensuring a comprehensive understanding of their intricate relationship and contributing to a broader comprehension of modern distributed ledger technology.

Results: The resulting product of this paper will be getting useful knowledge about the technology that practically shapes the world.

Conclusion: In conclusion, the adoption of Solidity as a programming language in blockchain technology has proven to be pivotal, enhancing smart contract functionality and overall system security. Its specialized features make it an indispensable tool for developers navigating the complexities of decentralized applications.

Key words: blockchain, Bitcoin, Ethereum, Solidity, decentralization.

Introduction

In the continuously evolving landscape of blockchain technology, the emergence of decentralized applications (DApps) and smart contracts has become a focal point of innovation. At the epicenter of this transformative shift lies Solidity, a purpose-specific programming language meticulously engineered for the development of secure and autonomous smart contracts on blockchain networks, prominently exemplified by Ethereum. This scholarly inquiry seeks to systematically investigate the profound implications and nuanced intricacies surrounding the "Utilization of Solidity programming language in blockchain." Throughout this paper, the objective is to delineate the fundamental role Solidity assumes in concretizing the theoretical constructs of decentralized systems into practical, implementable solutions. Through the scrutiny of the syntax, structure, and unique attributes of Solidity, the aim is to provide a scholarly discourse that advances the understanding of the intricate interplay between this programming language and the broader landscape of blockchain technology.

Moreover, this scholarly effort endeavors to dissect the practical implications of Solidity-driven smart contracts, considering their impact across various sectors such as finance, supply chain, and governance. By elucidating the distinct features of Solidity that contribute to the resilience and immutability of smart contracts, the authors aim to provide an explanation of a framework for researchers, developers, and industry practitioners navigating the burgeoning field of decentralized applications. The exploration extends beyond the syntax and semantics of Solidity, encompassing considerations of security measures, standardization, and potential avenues for future enhancements. As the discourse unfolds, the anticipation is to shed light on the challenges inherent in the application of Solidity in real-world scenarios, thereby contributing valuable insights to the ongoing dialogue surrounding the convergence of Solidity and blockchain technology.

Blockchain basics

Understanding the principles on which blockchain resides is not possible without understanding the answers to the following questions:

- What is the purpose of blockchain? and
- Why is blockchain needed for cryptocurrency?

In simple terms, the purpose of blockchain is to have a network of computers agree upon a common state of data (Abou Jaoude & Saade,

2019). Any person or organisation should be able to participate in this process and no person or ogranisation should be able to control this process. This will be explained in the following chapters.

Also, blockchain solves the problem of **trust**. This system is completely neutral and resistant to any censorship or bribe. In 2008, an individual, or a group of people, under the pseudonym of Satoshi Nakamoto released a whitepaper for Bitcoin: "We have proposed a system for electronic transactions without relying on trust." (Nakamoto, 2008)

The system proposed was peer-to-peer network, allowing online payments to be directly sent from one party to another, without going through a financial institution, therefore eliminating the need for trusting someone to make sure your payment goes the way it is meant to.

The Genesis of blockchain

It is impossible to look back at the history of blockchain without looking back at the history of cryptography and its development over the years.

Until the 1970s, cryptography was the study of encrypting messages to the full decryption-proof stadium. It was used for passing confidential information, especially within the military (Ahmad et al, 2021). Substitution ciphers were primarily used – the cryptographical method of encrypting in which units of plaintext are replaced with ciphertext in a defined manner.

As cryptography advanced over the years, more and more complex functions were introduced. The most important leap for blockchain technology, certainly, was the idea of a secret key.

Namely, if two parties can meet prior to their exchange of messages and agree upon a common key for both sides, the message would be encrypted with a mathematical function and that key, creating even more secure encryption. This thus marked the beginning of symmetric-key cryptography.

With the advent of personal computing, cryptographers started to think even further. The idea of secure communication without prior key exchange emerged. In 1976, Whitfield Diffie proposed a concept of PKC (Public Key Cryptography). With PKC, each individual has their own unique key pair, consisting of a public key and a private key. Only the public key needs to be exchanged, eliminating the need for exchanging keys beforehand. If a person's public key is used to encrypt a message, then only their corresponding private key can decrypt it, providing privacy. Likewise, if their private key is used to sign (encrypt) a message, the corresponding public key can authenticate (decrypt) the message. This was the start of assymetric encryption.

Diffie did not have any practical way to make this happen. He had a concept, but the mathematical function with all these properties did not exist back then. Diffie would work with Martin Hellman and Ralph Merkle in search of such a system.

Today, both the RSA (Rivest-Shamir-Adleman) and the ECDSA (Elliptic Curve Digital Signature Algorithm) are two popularly used algorithms for public key cryptography.

The security of the RSA algorithm relies on the practical difficulty of factoring the product of two large prime numbers - "the factoring problem". An RSA user creates and publishes a public key based on two large prime numbers, along with an auxiliary value. The prime numbers are kept secret, messages can be encrypted by anyone, via the public key, but can only be decoded by someone who knows the prime numbers. This algorithm is relatively slow, but there are no published methods to decypher this system if a large enough key is used.

The ECDSA uses elliptic curves. It can provide the same level of security as other public key algorithms with smaller key sizes, which is the reason of its popularity. This is the Digital Signing Algorithm used by Bitcoin, specifically the secp256k1 curve.

Consensus mechanisms

Blockchain networks are essentially distributed and decentralized databases consisting of many nodes (computers). In a decentralized environment, common issues are:

- How do all nodes agree on what the current and future state of user account balances and contract interactions is?
- Who gets to add new blocks/transactions to a chain? How do we know any blocks added are "valid"?
- How is this system coordinated without any official coordinator?

All of this is done thanks to consensus mechanisms.

The blockchain consensus mechanism typically means that at least 51% of nodes are in agreement over the current global state of network (Ahmad et al, 2021). Essentially, these are rules that distributed, decentralized blockchain follows in order to stay in agreement over what is considered valid. There are many consensus mechanisms, but the two most famous ones are: proof-of-work (PoW) and proof-of-stake (PoS).

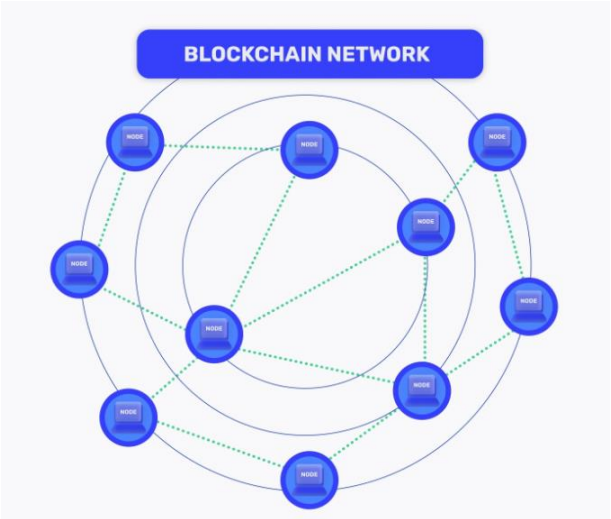

Figure 1 – Abstract scheme of the blockchain network

Proof of work & mining

Proof-of-work is the consensus mechanism that allows decentralized networks like Bitcoin and (previously) Ethereum to come to consensus, or agree on things like account balances and the order of transactions (Ali et al, 2023). This prevens "double spending" and ensures the followin of the blockchain rules, making the PoW network resilient to malicious attacks.

The main consensus rules for the PoW are the following:

- There must not be double spending, and
- The "longest" chain will be the one the rest of the nodes will accept as the one "true" chain - Nakamoto Consensus.

The consensus mechanism ends up being the security mechanism the network needs, because it ensures that every node on it is following the consensus rules. In PoW, mining represents the work.

Mining is the process of creating a block of transactions to be added to blockchain.

In proof-of-work consensus, nodes in the network continuously attempt to extend the chain with new blocks - these are the miners, nodes that contain mining software (Antonopoulos & Wood, 2018). Miners are in charge of extending a blockchain by adding blocks that contain "valid" transactions. In order to add a block, the network will ask miners for their "proof-of-work".

A proof-of-work-based system will typically require miners produce an output in a very difficult-to-get target range. Valid proof-of-work once looked like this in the Bitcoin network:

```
00000000000000000043f43161dc56a08ffd0727df1516c987f7b187f5194c6
```

Figure 2 – The look of once valid proof-of-work in the Bitcoin network

To get an output like this, automated mining software does the following: takes a piece of data (i.e. the previous block header + new transactions to add to a chain) and hashes it. If the hash output is bellow a target difficulty, then the miner has found the answer to the puzzle: a valid proof of work.

The proof-of-work shown above has 19 leading zeroes, and since the range of each possible character per space is in hexadecimal, this means that there are 1/16 character possibilities per space.

The hash outputs for SHA-256 are in hexadecimal, which means there are 1/16 possible characters per space - a-f in letters and 0-9 in decimals = 16 total possibilities. This means that finding one 32-byte SHA-256 output that has just one leading zero will take on average 16 tries (Banerjee et al, 2018).

Finding an output with 2 leading zeros increases the average number of attempts to 256 - 16 possible characters in the first spot * 16 possible characters in the second spot. Finding 19 leading zeros will take, on average, 16^{19} attempts, which equals to 755578637259143234191360000000000000000000 attempts.

Proof-of-work networks will typically have some sort of target_difficulty. In order for a miner to add a new block, they must find a proof-of-work lower than the network target difficulty. Finding such a difficult-to-find output is proof enough that a miner expended considerable resources to secure the network.

The proof-of-work mining algorithm looks like this:

- Take current block's block header, add mempool transactions
- Append a nonce, starting at nonce = 0
- Hash data from #1 and #2
- Check hash versus target difficulty (provided by protocol)
- If hash < target, puzzle is solved! Get rewarded.
- Else, restart process from step #2, but increment nonce

The miner nodes in a proof-of-work network will perform this algorithm regularly. This gives the network a way to recognize the true state and the validity of the proposed transactions following the consensus rules. As long as the majority of nodes on the network follow the consensus rules, the blockchain remains secure and resistant to attacks, ensuring that only valid and verified transactions are added to the distributed ledger, thus maintaining its integrity and trustworthiness. In exchange for large amounts of energy and hardware upkeep required to run mining software, miners receive currency as a reward.

Blockchain structure

A blockchain is a distributed database of a list of validated blocks (Bashir, 2018). Each block contains data in the form of transactions and each block is cryptographically tied to its predecessor, producing a "chain". Each blockchain consists of nodes.

A blockchain has nodes scattered all over the world all acting together in real-time. There is no central administrator, say a "supernode", responsible for verifying any changes to the state of data, all nodes are equal members of the network. This means that the network will perform the same, no matter what node is interacted with to update data. In other words, blockchains are peer-to-peer networks.

A valid hash for a blockchain is a hash that meets certain requirements. The number of leading zeros required is the difficulty. The process of finding valid hash outputs, via changing the nonce value, is called mining. A miner starts a "candidate block" with a nonce of 0 and keeps incrementing it by 1 until it finds a valid hash.

Since data is an input variable for the hash of each block, changing the data will change that block's hash. Blockchains like Bitcoin and Ethereum, protect the integrity of any data held inside blocks in their chains: manipulating data in a block that has been nested deeply in the chain is almost impossible.

In Bitcoin, Merkle trees are used to store every transaction mined on the Bitcoin network. Merkle tree is a data structure that represents a collection of hash values reduced to a single hash.

Each letter represents a hash. The combined letters represent concatenated hashes that have been combined and hashed to form a new hash.

Over a series of steps, the eight leaf hashes A, B, C, D, E, F, G, and H are combined to create a single, unique hash that allows efficient checking for inconsistencies without having to look at each individual data point.

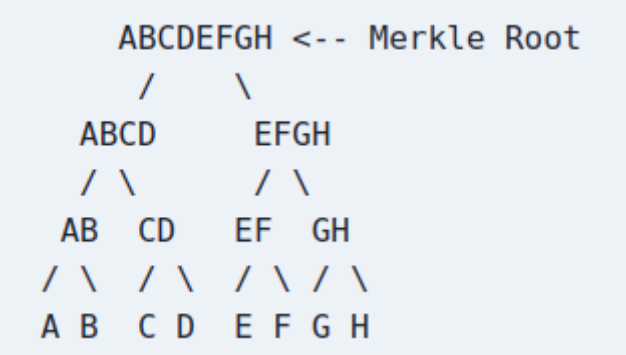

Figure 3 – Visual representation of Merkle tree

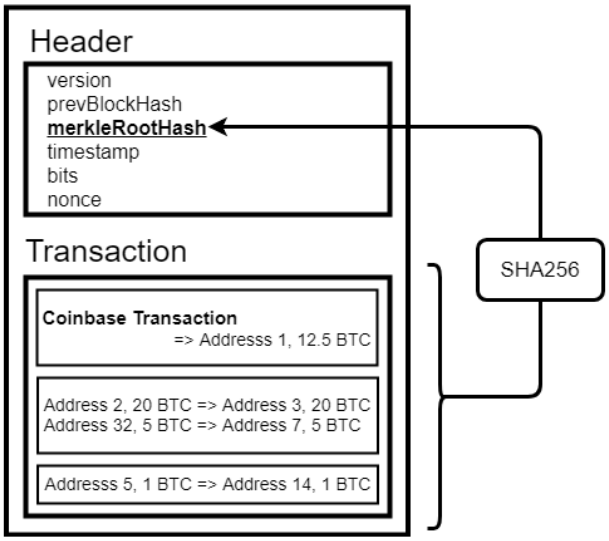

Figure 4 – The architecture of a Bitcoin block

The figure above shows the architecture of the Bitcoin block. All of the transactions per block are arranged into a big Merkle tree. Merkle tree's root hash actually gets commited into the block.

By committing the root hash of the tree, the transaction data can be stored off-chain (full nodes, for example, store these transaction records on a LevelDB integrated into all full nodes).

A main design purpose behind using Merkle trees to commit a lot of data elements (typically transactions) per block is to keep the size of the

blockchain as small as possible. Given the nature of their usage, blockchains grow perpetually. Keeping the blockchain size from becoming bloated means more people can support running full nodes which helps network decentralization (Dabbagh et al, 2019).

UTXO & account models

With traditional web2 server based platforms, keeping track of user data and information is actually a lot easier than it is on the blockchain. This is because there is a single centralized server that stores the state of user accounts. There is no need for consensus or resolving discrepancies since there is only one central place that stores information.

However, when moving to a decentralized system, the problem of storing user balances becomes complicated. Decentralized networks like Bitcoin and Ethereum need specific models for keeping track of the state of users. Bitcoin uses the UTXO (Unspent Transaction Output) model to keep track of user balances. Ethereum and other EVM chains use the account model to keep track of user balances.

The account model tracks the balances of users based on their overall account state, without knowing what constitutes the actual balance itself. This model is a lot like a classical bank account model.

In the account model, the ownership of cryptocurrency is determined by the account's private key, which corresponds to a unique public key or address. When a user initiates a transaction, they sign it with their private key to prove ownership and authorize the movement of funds from their account. This model simplifies the transaction process and is more intuitive for developers building decentralized applications, as it resembles the familiar ledger system used in traditional banking. However, it also comes with challenges, such as the need for more complex protocols to prevent issues like double-spending. The choice between the UTXO and account models reflects different design philosophies and trade-offs in the realm of blockchain architecture (Buterin, 2013).

The Unspent Transaction Output (UTXO) model is a fundamental concept underpinning the functioning of the Bitcoin blockchain. In the Bitcoin network, transactions are represented as a chain of inputs and outputs. Each output of a transaction is a certain amount of bitcoin, and these outputs serve as the inputs for future transactions. The UTXO model is designed to keep track of the ownership of Bitcoin and prevent double-spending. In simple terms, a UTXO is essentially an unspent output of a transaction that can be used as an input for a new transaction. This model contrasts with the account-based model used by traditional banking

systems, where an account balance is maintained, and transactions involve debiting and crediting these balances.

In the UTXO model, the ownership of Bitcoin is determined by the ability to provide a valid digital signature corresponding to the public key associated with a UTXO. When a user initiates a transaction, they must reference one or more UTXOs as inputs, providing the required digital signatures to prove ownership. The outputs of this transaction become new UTXOs, which can be spent in future transactions. This model adds a layer of security to the Bitcoin protocol by ensuring that every transaction input is indeed an unspent and valid output from a previous transaction. It also contributes to the decentralized and trustless nature of the Bitcoin network, as the entire transaction history is publicly accessible and verifiable by anyone on the blockchain (Buterin, 2013).

Ethereum

Bitcoin was the first blockchain-based decentralized network ever. It popularized the use of Merkle trees for scalable transaction inclusion. Ethereum also uses Merkle trees but since Ethereum is a completely different design, it also uses one other important tree data structure for some of its data storage needs: Patricia Merkle Tries. Unlike Bitcoin, Ethereum uses the Keccak256 hash function.

Ethereum is a deterministic but practically unbounded state machine, consisting of a globally accessible singleton state and a virtual machine that applies changes to that state (Dange & Nitnaware, 2023).

Essentially, Ethereum can be seen just like any other computer in the world. This computer has some major features that make it unique:

- It is the first global singleton machine ever, that fundamentally is not localized (not located on any physical machine in the world). Ethereum does not reside in any single machine, with no physical presence anywhere.
- Ethereum is totally censorship resistant. No authority, government, corporation or a group of individuals is behind the Ethereum computer. No one owns it, can shut it off or can us it as a privileged user.
- Ethereum is ubiquitous and accessible anywhere there is Internet connection.
- Natively multi-user, with a practically infinite range possible for account creation - 2^{160} accounts.

Since Ethereum keeps track of a larger amount of state data than Bitcoin, its block architecture is completely different.

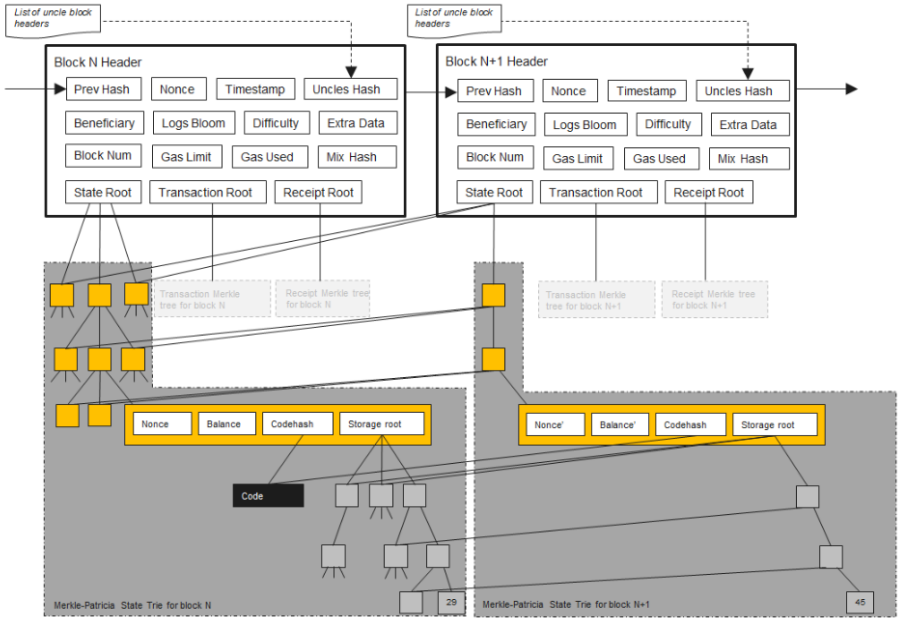

Figure 5 – The architecture of the Ethereum block

Ethereum makes use of a data structure called radix trie (Patricia trie, radix tree) and combines it with the Merkle tree structure to create a Patricia Merkle Trie.

Trie comes from the word "retrieval", meaning that radix trie is a tree-like data structure that is used to retrieve a string value by traversing down a branch of nodes that store associated references (keys) that together lead to the end value that can be returned.

A Patricia Merkle trie (PMT) is a data structure that stores key-value pairs, just like a hash table. In addition to that, it is also used verify data integrity and the inclusion of a key-value pair. PMTs groups similar-value nodes together in the tree. That way, searching for "HELP" leads you along the same path as searching for "HELLO" - the first three letters are shared entries of different words. It is very good for space efficiency and read/write efficiency. Patricia is an acronym: P - Practical; A - Algorithm; T - To; R - Retrieve; I - Information; C - Coded; I - In; and A - Alphanumeric.

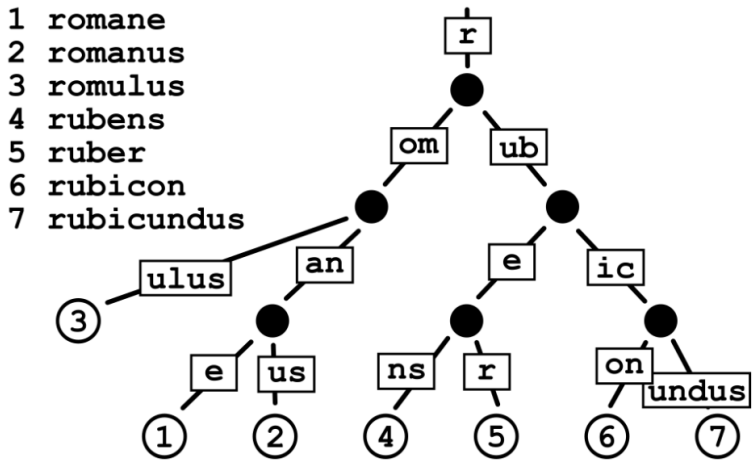

Figure 6 – An example of the radix trie data structure

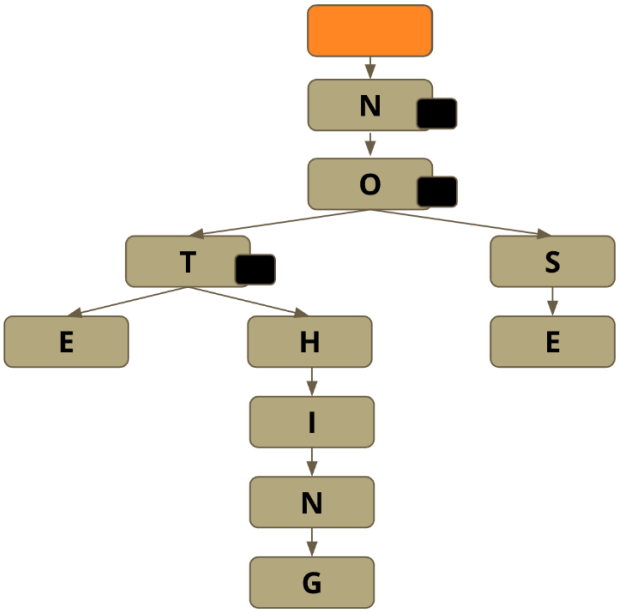

Figure 7 – An example of the Patricia Merkle trie data structure

Ethereum stores two types of data: permanent and ephemeral. It makes sense that permanent data, like mined transactions, and ephemeral data, like Ethereum accounts (balance, nonce, etc), should be stored separately. Merkle trees are perfect for permanent data. PMTs are perfect for ephemeral data, which Ethereum is in plenty supply of.

Unlike transaction history, the Ethereum account state needs to be frequently updated. The balance and nonce of accounts is often changed, and what is more, new accounts are frequently inserted, and keys in storage are frequently inserted and deleted.

The Ethereum block header contains many pieces of data.The block header is the hash result of all of the data elements contained in a block. It is like a gift-wrap of all the block data.

Looking at the Ethereum architecture diagram at the beginning of this chapter, the block header ends up hashing all of the data properties of the block. It also includes:

- State Root: the root hash of the state trie,
- Transactions Root: the root hash of the block's transactions, and
- Receipts Root: the root hash of the receipts trie.

The state trie acts as a mapping between addresses and accounts states. It can be seen as a global state that is constantly updated by transaction executions. All the information about accounts is stored in the world state trie and information can be retrieved by querying it.

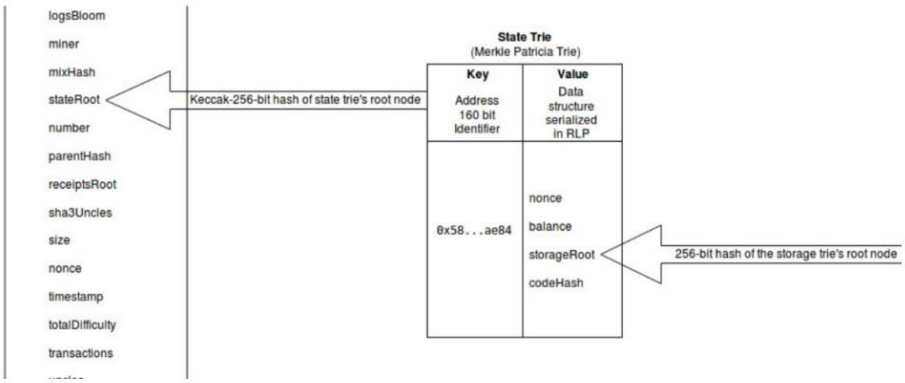

Figure 8 – An example of the state trie and its integration with the Ethereum block

The transaction trie records transactions in Ethereum. Once the block is mined, the transaction trie is never updated. Each transaction in

Ethereum records multiple pieces specific to each transaction such as gasPrice and value.

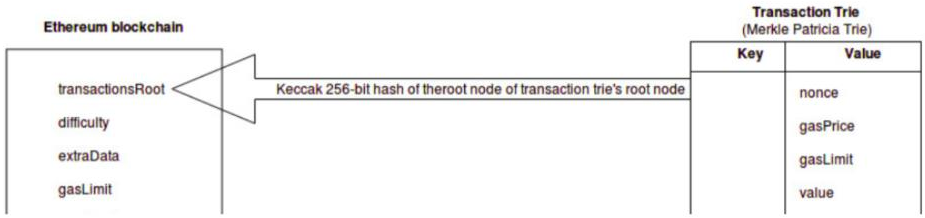

Figure 9 – An example of the transaction trie and its integration with the Ethereum block

The transaction receipt trie records receipts (outcomes) of transactions. It contains data including gasUsed, logs and events emitted. Once the block is mined, the transaction receipt trie is never updated.

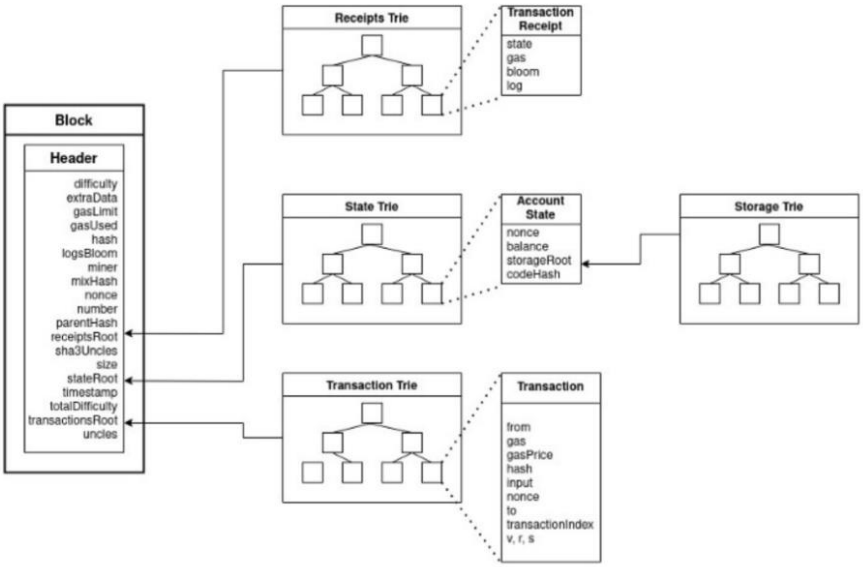

Figure 10 – Visualizaton of how the tries end up being commited in every block via their root hash

Proof of stake

Ethereum transitioned to PoS on September 15th, 2022. This transition is known as "The Merge". This was a massive migration that was always in the roadmap and original planning for Ethereum, but required coordination from the entire network to execute.

Proof-of-stake is a totally different mechanism than proof-of-work that enables Ethereum to be more secure, less energy intensive and more scalable.

In order to become a miner in PoW, there are large energy requirements, which makes it difficult for any individual to compete with the existing mining warehouses that are dedicating millions of dollars of resources to mining. However, in proof-of-stake, the energy requirement to become a validator is much lower and can be done by individuals without a high overhead energy cost. This encourages more users to become validators, decreasing the centralization risk, and thereby increasing the security of the network.

Instead of using mass amounts of electricity, validators are required to stake 32ETH by depositing it into a contract to have the ability to validate blocks. This staked ETH is used as collateral against bad actors in the network. If any given validator acts dishonestly or maliciously, they put themselves at risk of losing their staked ETH.

Rather than all validators competing at the same time for the next block, the network randomly selects a validator to propose a block every 12 seconds, all the other validators verify that the proposed block is correct, and the cycle repeats (Stanišić, 2023).

One of the largest ways that PoS affects Ethereum developers is with a new framework for block finality. Finality in blocks refers to how confident you are that the given block will not change or get forked away. For blocks that have been on the network for a very long time (older blocks), it is extremely unlikely that it will be removed from the canonical chain and therefor has high finality.

Proof of stake introduced 2 new levels of finality that developers should consider when requesting data from the network: safe and finalized. Here is an overview of all “block tags”:

- earliest: The lowest numbered block the client has available. Intuitively, you can think of this as the first block created.
- finalized: The most recent crypto-economically secure block, that has been accepted by >2/3 of validators. Typically finalized in two epochs (64 blocks). Cannot be reorganized outside manual intervention driven by community coordination. Intuitively, this block is very unlikely to be reorganized.
- safe: The most recent crypto-economically secure block, typically safe in one epoch (32 blocks). Cannot be re-orged outside manual intervention driven by community coordination. Intuitively, this block is unlikely to be re-orged.

- latest: The most recent block in the canonical chain observed by the client, this block may be re-orged out of the canonical chain even under healthy/normal conditions. Intuitively, this block is the most recent block observed by the client.
- pending: A sample next block built by the client on top of latest and containing the set of transactions usually taken from local mempool. Intuitively, you can think of these as blocks that have not been mined yet.

Gas on Ethereum

The cost of operations on Ethereum are fixed and measured in a unit called "gas". The price of gas is what constantly changes. This means that the energy requirements to mine any given block are significantly lower than that of PoW.

In August 2021, there was an Ethereum Improvement Proposal (EIP) to improve the calculation of gas prices on Ethereum, known as EIP-1559. Historically, gas prices on Ethereum have been unpredictable and at times astronomically high, making transactions inaccessible to most people. EIP-1559 changed the mechanism for setting the gas price, making participating in Ethereum blockchain accessible to pretty much everyone.

Just like every currency in the world, Ethereum also has different denominations thar are used to express smaller values. 1 ether is equal to 10^{18} wei (the smallest denomination of ether) or 10^{9} gwei.

Unit	Wei Value	Wei
wei	1 wei	1
Kwei (babbage)	1e3 wei	1,000
Mwei (lovelace)	1e6 wei	1,000,000
Gwei (shannon)	1e9 wei	1,000,000,000
microether (szabo)	1e12 wei	1,000,000,000,000
milliether (finney)	1e15 wei	1,000,000,000,000,000
ether	1e18 wei	1,000,000,000,000,000,000

Figure 11 – Table with relevant denominations for ether

Every block has a maximum amount of gas that can be used within it. This is how a number of transactions included within a block are determined. Every block has the capacity to use 30 million gas but has a

target of 15 million gas total. The price of gas is determined by the amount of demand for transactions (or block space), where demand is measured by how filled the previous block was relative to the target gas.

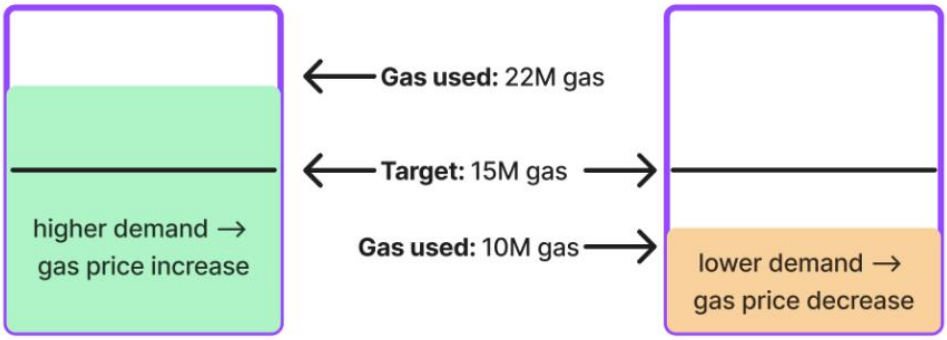

Figure 11 – Example of two different blocks with different demand quantity

The network first sets a base fee; in an ideal world, this base fee would result in 15 million gas getting used in a block, no more, no less. However, what happens in practice is the actual gas can be above or below the target gas.

When blocks are above the target, the gas price (or base fee) is automatically increased, increasing the cost and barrier to entry for sending transactions and thereby reducing the number of people who are competing to fill the block. When the block is below the target, the base fee is lowered to incentivize people to transact by lowering the barrier to entry for paying for a transaction.

This base fee helps users select an efficient gas amount that is likely to get their transaction mined rather than wasting tons of money on unnecessarily high gas prices like in the past. These mechanisms also make it easy to predict future gas prices by looking at how “full” the previous blocks were.

Instead of going straight into the miners pocket, the base fee actually gets burned. There are several reasons why the base fee is burned instead of being given to the miner:

- This prevents the miner from circumventing the payment of the base fee since they have to pay at least base fee times the number of transactions for the block that the mine, and
- Burning ether also creates a deflationary pressure on ether as an asset since supply is taken out of the market.

Since the base fee is entirely burned, the new incentive for miners is now known as the miner tip. In a perfect world, the miner tip is the minimum amount that the miner is willing to accept in order to execute the transaction. This tip was originally set as 1gwei but can fluctuate depending on how full blocks are. Since the target gas value in blocks is 15M, in general, so long as blocks are hitting or near the target amount, there will always be room to add more transactions within a block. This is why the miner tip does not need to be insanely high to get some transaction included.

Solidity

Solidity is an object-oriented, high-level language for implementing smart contracts. It is a language that closely resembles other popular programming languages like C++, Python and JavaScript. Solidity is statically-typed (variables must be defined at compile time) and supports inheritance, libraries and complex user-defined types. It is a programming language used to write smart contracts.

A smart contract is a set of promises, specified in a digital form, including protocols within which the parties perform on these promises (Szabo, 1996). Basically, smart contracts are typical contracts, but in a digital form, and they have stronger enforcement parameters (Szabo, 1997).

A smart contract is simply a program that runs on the Ethereum computer. More specifically, a smart contract is a collection of code (functions) and data (state) that resides on a specific address on the Ethereum blockchain. These are written in Solidity which means they must be compiled into bytecode first in order to be Ethereum compatible.

Smart contracts are permisionless (anyone can deploy them to Ethereum) and composable (they are gloably available via Ethereum).

```
// SPDX-License-Identifier: MIT
pragma solidity ^0.8.4;

address public owner;
bool public isHappy;
uint public x = 10;
int public y = -50;

contract MyContract {
    constructor(address _owner, bool _isHappy) {
        owner = _owner;
        isHappy = _isHappy;
    }
}
```

Figure 12 – A sample of a Solidity smart contract

The features of Solidity will be explained on the example listed as Figure 12.

Line 1: Specifies what type of license will be used and determines what license rules fall on that specific smart contract.

Line 2: The word **pragma** defines the version of Solidity that will be used for writing the smart contract. Solidity uses semantic versioning.

Lines 4-7: Define state variables that will be used throughout the writing of the smart contract. Variables in Solidity can have private, public and internal visibility. Numbers in Solidity can be **int** (interger) and **uint** (unsigned integer).

Lines 9-14: The scope of the contract. The contract keyword behaves very simliar to the class keyword of JavaScript.

Lines 10-13: The **constructor()** function is called only once during deployment and completely discarded thereafter. It is used to specify the state when deploying a contract.

There are many data types in Solidity: boolean (**bool**), **string**, integers (**uint** and **int**), **bytes**, **enums**, **arrays**, **mappings**, and **structs**.

A solidity-specific type of variable is called **address**. There are two types of this variable: **address** and **address payable**. These two types are more than just some string holding Ethereum address value, they are first-class types, meaning that they have a number of methods and function that can be called upon them.

Integration with Ethereum Virtual Machine

The Ethereum Virtual Machine (EVM) is a runtime environment that executes smart contracts on the Ethereum blockchain. The Ethereum Virtual Machine is a crucial component of the Ethereum network, enabling the execution of decentralized applications (DApps) by processing and validating smart contracts code. It plays a central role in ensuring the decentralized and trustless nature of the Ethereum platform by allowing participants to execute code without the need for a central authority. Smart contracts written in languages like Solidity are compiled into bytecode that can be executed by the Ethereum Virtual Machine.

After a contract has been compiled, the bytecode of that contract is sent to the EVM. For a contract containing a simple while loop that increments a variable of type integer five times, the bytecode looks like this:

```
6080604052348015600f57600080fd5b5060a58061001e6000396000f3fe6080604052348015600f57600080fd5b50
600436106028576000356e01c8063a92100cb14602d575b600080fd5b60336049565b604051808281526020019150
5060405180910390f35b60008060009050600080905b6005821015606757818101905060565b80925050509056
fea2646970667358221220058d7e11ff1d36fc53779562e305af3c9180b2ab8dccfe6d234fa50420908a5d864736f6c
63430006030033
```

Figure 13 – The bytecode of the while loop

The bytecode contains opcodes and operands. This bytecode looks like this after looking up the EVM operation codes:

```
PUSH1 0x80 PUSH1 0x40 MSTORE CALLVALUE DUP1 ISZERO PUSH1 0xF JUMPI PUSH1 0x0 DUP1 REVERT
JUMPDEST POP PUSH1 0xA5 DUP1 PUSH2 0x1E PUSH1 0x0 CODECOPY PUSH1 0x0 RETURN INVALID PUSH1 0x80
PUSH1 0x40 MSTORE CALLVALUE DUP1 ISZERO PUSH1 0xF JUMPI PUSH1 0x0 DUP1 REVERT JUMPDEST POP
PUSH1 0x4 CALLDATASIZE LT PUSH1 0x28 JUMPI PUSH1 0x0 CALLDATALOAD PUSH1 0xE0 SHR DUP1 PUSH4
0xA92100CB EQ PUSH1 0x2D JUMPI JUMPDEST PUSH1 0x0 DUP1 REVERT JUMPDEST PUSH1 0x33 PUSH1 0x49
JUMP JUMPDEST PUSH1 0x40 MLOAD DUP1 DUP3 DUP2 MSTORE PUSH1 0x20 ADD SWAP2 POP POP PUSH1 0x40
MLOAD DUP1 SWAP2 SUB SWAP1 RETURN JUMPDEST PUSH1 0x0 DUP1 PUSH1 0x0 SWAP1 POP PUSH1 0x0 DUP1
SWAP1 POP JUMPDEST PUSH1 0x5 DUP3 LT ISZERO PUSH1 0x67 JUMPI DUP2 DUP2 ADD SWAP1 POP PUSH1
0x56 JUMP JUMPDEST DUP1 SWAP3 POP POP POP SWAP1 JUMP INVALID LOG2 PUSH5 0x6970667358 0x22 SLT
KECCAK256 PC 0xD7 0xE1 0x1F CALL 0xD3 PUSH16 0xC53779562E305AF3C9180B2AB8DCCFE6 0xD2 CALLVALUE
STATICCALL POP TIMESTAMP MULMOD ADDMOD 0xA5 0xD8 PUSH5 0x736F6C6343 STOP MOD SUB STOP CALLER
```

Figure 14 – The look of the bytecode after transposing the values of opcodes and operands

Conclusion

In the ever-evolving landscape of blockchain technology, the significance of the Solidity programming language is underscored by its integral role in platforms like Bitcoin and Ethereum. Bitcoin, the pioneering cryptocurrency, employs a blockchain data structure to create a secure, decentralized ledger of transactions. Solidity, however, takes the concept of blockchain a step further within the Ethereum ecosystem, enabling the development of smart contracts. These self-executing contracts, written in Solidity, automate and enforce predefined rules, facilitating a wide array of decentralized applications. Ethereum's versatility, driven by Solidity, extends the capabilities of blockchain beyond a mere medium of exchange, transforming it into a decentralized computing platform with applications spanning finance, gaming, and decentralized finance (DeFi).

As industries recognize the potential benefits of blockchain, its integration is becoming increasingly prevalent across sectors. From enhancing the traceability of goods in supply chain management to revolutionizing traditional financial systems through decentralized finance applications, the transformative impact of blockchain is gaining

momentum. Solidity's role in facilitating the creation and execution of smart contracts plays a crucial part in this evolution, offering developers a powerful tool to build decentralized applications that foster trust, transparency, and efficiency. The ongoing convergence of Solidity, blockchain data structures, and real-world applications suggests a promising future where decentralized technologies redefine how industries operate and interact.

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La utilización del lenguaje de programación Solidity en cadena de bloques (blockchain)

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CAMPO: ciencias de computación, IT
TIPO DE ARTÍCULO: artículo de revisión

Resumen:

Introducción/objetivo: Este trabajo proporciona una descripción general completa de la tecnología blockchain, aclarando sus principios fundamentales y cómo garantiza la transparencia, la inmutabilidad y la descentralización. La integración de Solidity con blockchain se explora a través de un enfoque teórico.

Métodos: Este trabajo analiza meticulosamente los principios de blockchain, aclarando la transparencia, la inmutabilidad y la descentralización, mientras explora la integración de Solidity en un marco teórico, asegurando una comprensión integral de su intrincada relación y contribuyendo a una comprensión más amplia de la tecnología moderna de distribuición de registros.

Resultados: El producto resultante de este artículo será la obtención de conocimientos útiles sobre la tecnología que prácticamente da forma al mundo.

Conclusión: En conclusión, la adopción de Solidity como lenguaje de programación en la tecnología blockchain ha demostrado ser fundamental, ya que mejora la funcionalidad de los contratos inteligentes y la seguridad general del sistema. Sus características especializadas la convierten en una herramienta indispensable para los desarrolladores que navegan por las complejidades de las aplicaciones descentralizadas.

Palabras claves: blockchain, Bitcoin, Ethereum, Solidez, descentralización.

Применение языка программирования Solidity в технологии blockchain

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РУБРИКА ГРНТИ: 20.15.05 Информационные службы, сети, системы в целом,
81.93.29 Информационная безопасность. Защита информации

ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: В данной статье представлен всесторонний обзор блокчейн технологии, разъясняются ее основополагающие принципы и то, как она обеспечивает прозрачность, неизменность и децентрализацию. Интеграция Solidity с блокчейном исследуется с помощью теоретического подхода.

Методы: В данной статье представлены принципы blockchain технологии. Теоретический подход и фрагменты кода на практике показывают, как Solidity сочетается с этой технологией и почему она является фундаментом развития современных технологий и многих отраслей промышленности.

Результаты: В результате исследования получены полезные сведения о технологии, которая встречается практически во всех сферах современного мира.

Выводы: Внедрение Solidity в качестве языка программирования в блокчейн технологию оказалось ключевым фактором в повышении функциональности смарт-контрактов и общей безопасности системы. Его специальные характеристики делают его незаменимым инструментом для разработчиков, занимающихся сложностями децентрализованных приложений.

Ключевые слова: блокчейн, биткоин, Ethereum, Solidity, децентрализация.

Примена програмског језика Solidity у *blockchain* технологији

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ОБЛАСТ: рачунарске науке, ИТ
КАТЕГОРИЈА (ТИП) ЧЛАНКА: прегледни рад

Сажетак:

Увод: У раду је представљена blockchain технологија, њени основни принципи и начин на који се осигурава транспарентност, непроменљивост и децентрализација. Интеграција програмског језика Solidity са blockchain технологијом објашњена је теоријским приступом.

Методе: Расветљени су принципи blockchain технологије. Теоријским приступом и исечцима кода показано је како се Solidity интегрише са овом технологијом и зашто представља стуб развоја савремених технологија и многобројних индустријских грана.

Резултати: Добијене су корисне информације о технологији која је примењена у свим областима данашњег света.

Закључак: Усвајање програмског језика Solidity у blockchain технологији показало се кључним, јер побољшава функционалност паметних уговора и укупну сигурност система. Његове специјализоване карактеристике чине га неопходним алатом за програмере који се крећу кроз комплексност децентрализованих апликација.

Кључне речи: blockchain, Bitcoin, Ethereum, Solidity, децентрализација.

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Information system to support the operation of the car park

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Abstract:

Introduction/purpose: Information systems represent a set of people, data, processes and information technologies related to the purpose of data collection, processing, storage and their filtering into useful information needed for supporting organizations or decision making. The information system is developed as a Web application with the help of the Javascript programming language, Node.js, and React.js, while in the background it relies on data storage and communication with the SQL database.

Methods: Modern web application development tools are used and tested on low budget hardware.

Results: Effective software for a car park with low maintenance cost and great reliability has been developed.

Conclusion: The software made work easier, increased access to data and facilitated data review, reducing the possibility of error. The application described in this article and made for research shows how modern commercial technologies can be used for military purposes.

Keywords: software, solution, car park, JavaScript, node, SQL, military, technology.

Introduction

The constant improvement and expansion of technology has led to the fact that there is almost no sphere (social, economic, military, etc.) that has remained immune to its implementation and application. The potential for application is significant and there are no limits to the depth to which technology will reach into people's lives. The key part is the development of software which people come in contact with in their daily activities and which has become their tool for doing business. In this paper, an Information System will be presented for the needs of operating a car park. (Kaplanović, 2023)

Used technologies

Agile method in IS development

The agile development method consists of phases, but the entire project is executed through cycles (sprints) that have some of the required system functionalities as the end product. Cycles are iterative, adaptive, divided in time, fast and flexible to new requirements or changes. The method requires continuous communication with users and developers who develop the solution. After each cycle, there is a consolidation with the already completed part of the solution from the previous cycles. Unfinished solutions are handed over to users for use and testing at a certain point in time. The received feedback from users affects the modification of the product of a certain cycle (part of the solution) which will be performed in one of the following cycles.

Used information technologies for development

Node.js is an open source environment, implemented in the JavaScript programming language. JavaScript as a relatively new programming language has brought convenience in writing codes because it can be used on both the client side and the server side. Node.js is platform independent and it is intended for the development of scalable network applications. Its architecture is event-driven and contributes to the ability of input/output operations to be executed in real time. It allows writing command line tools and scripts as well as running on the server side. The manager package provides access to a huge database of packages. It also supports boot chaining projects. By using the HTTP1 package, a simple web server can be created very quickly.

Some of the typical web tasks are not directly supported by Node. To add specific request handling, URL paths, or dynamically creating server responses, it is necessary to write a code or facilitate the work by using one of the web frameworks. Express is one of the most popular and minimalist ones. In this paper, it was used for processing HTTP requests (GET, POST, UPDATE, DELETE) from different paths.

Sequelize is a library for Node.js that provides work with relational databases. It uses ORM (Object-Relation Mapping) functionality which manipulates the database using objects and the very methodology of object-oriented programming. The benefit is that there is no need to write raw SQL. It supports work with databases such as MySQL, PostgreSQL, SQLite, and Microsoft SQL Server. The developer defines the models that represent the tables in the database and the relationships between them.

Models are used to create, read, update, and delete (CRUD operations) a data base. This approach allows the same code to be used over and over again and to access any SQL database without changing the query. (Pundsack, 2023)

The React JavaScript library was used to create the user interface. React creates components (tables, buttons, forms, menus) that are modular code pieces and whose community constitutes the user interface. The point is to make such components that they can be used multiple times without retyping their code. It is not necessary to reload the page for changes to occur. React is based on the principle of the virtual DOM (Virtual Document Object Model). It allows monitoring the state of certain components and updating only those that have changed. This allows for better performance and more efficient display updates. The data itself is transferred from the top to the bottom of the hierarchically organized components. This is made possible by using unidirectional binding which also makes it easier to follow the flow of data. (Grebe, 2019)

Analysis of the requirements for an ideal solution

The driving force behind the development of this information system is the desire to facilitate and automate the process of vehicles entering/exiting to/from a military facility, to monitor their conditions and to organize drivers. The information system for supporting the car park operation is designed to consist of two groups: guards and administrators. There is information on each vehicle: vehicle brand, vehicle type, vehicle status, registration number, and VIN number. The guard user group is obliged to keep records, enter data on which driver leaves or enters the facility with which vehicle, with which travel order number, and on which date. The group of administrators is responsible for entering, updating, or deleting data on vehicles, drivers and records, as well as entering user accounts and maintaining them. In the security service, in the analysis of the existing organization, the potential for speeding up work and increasing efficiency was noticed, and it was chosen as a priority for the development of the first version of the application. A client-server architecture was chosen as a solution. A centralized server with a database allows users to simultaneously access data with different devices. (Ellk et al, 2020)

The idea of improving the existing working method

When a vehicle enters a military facility or exits from it, a certain procedure must be followed. The method of operation is as follows:

• the vehicle approaches the gate,

• the guard approaches the vehicle, takes the license plate number from the driver,
• enters the security facility and enters data into the record book,
• returns to the driver and returns the documents, and
• opens the gate for the vehicle to leave the facility.

The mentioned process can be improved based on the following:
• the vehicle approaches the gate,
• the guard approaches the vehicle,
• the guard enters the data into the application (which vehicle, which driver and the number of the travel order) using a portable device, and
• opens the gate and the vehicle leaves the facility.

The importance of the mentioned procedure is noticeable especially when multiple vehicles leave or enter a facility where there is a shortage of available time for performing such actions. The system can also be applied in conditions where the guard does not have to be at all next to the vehicle. The entire process can be monitored from a remote facility.

The suggested procedure is as follows:
• the vehicle approaches the gate,
• the security service records the driver and the vehicle with a video from the cameras, and
• remotely opens the gate and the vehicle leaves the building. (Fadeev, 2022)

The way of using the developed IS may differ depending on military facilities, their organization and techniques at their disposal. The system requires any device that can access the network where the application is located and which has the ability to work with the Internet browsers. This system enables all the benefits of digitalization such as: authentication and user authorization, authenticity of entered data, insight into the current state, easier access to information, and storage of copies. These benefits are very difficult to achieve by applying the old approach of manual data entry into record books. The concept of an individual at the gate recording who enters and exits is outdated and prevents the security service from performing their duty of guarding the object. Access to data kept in a record book is limited to the shift guard responsible for keeping it. However, data entered into the application with a centralized database are available to authorized users online. This enables users whose duties are related to the organization to autonomously seek information about currently available manpower or technology. Users who need such information do

not have to call the security service, thus disrupting their work and wasting the time of the duty officer who has to browse the records and search for requested information. The diagrams in the text describe the usage of the application. The elements of the diagram are: actors (users), use cases that describe the tasks that the system performs, links that connect actors and use cases. Figure 1 shows a diagram of the use cases. (Ádám et al, 2021)

Figure 1 – Use case diagram

An activity diagram consists of different elements:

1. Activities: these are tasks or operations performed in the system. They are represented inside a rectangle and named after the actions they represent.

2. Transitions: show a change in activity and indicate the flow of control or data flow. They are represented by arrows that connect activities and contain conditions related to their execution.

3. Decisions: represent the points in the diagram where the system must make decision on what next step to take. They are marked with

diamonds and contain the conditions that determine which transition will occur.

4. Synchronization: represents events that are executed in parallel, and then connected at one point in the diagram. It is used when necessary to ensure that activities are completed before proceeding to the next step.

5. Initial and final node: the initial node marks the beginning of the activity diagram, while the end point marks the end of the execution of the diagram. Both points are represented by circles.

The activity diagram contributes to a better understanding of complex processes and helps in their implementation, analysis and optimization. The following text describes an activity diagram (Figure 2) of user registration.

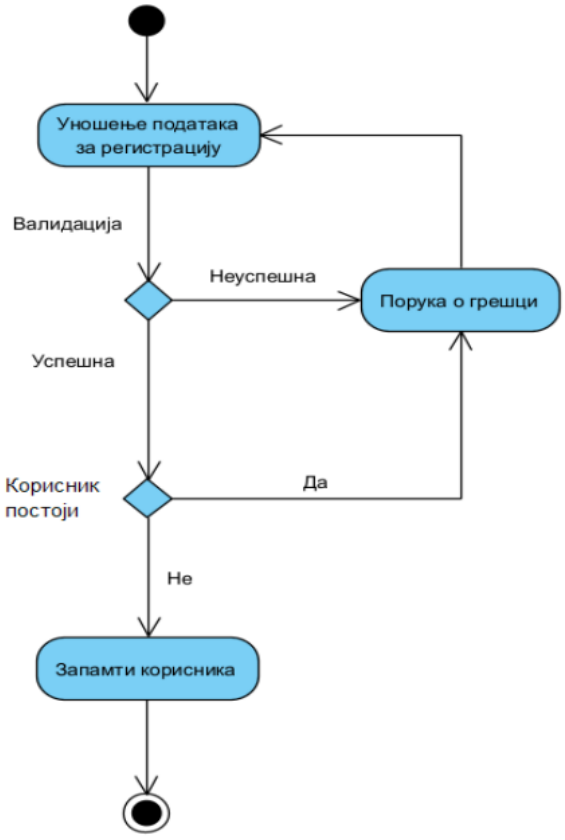

Figure 2 – Activity diagram

The registration activity consists of the following steps:

1. The user enters his username and password into the system.
2. After the username and the password are entered, the system performs a validity check of the entered data. If some of the validation requirements (e.g. password length) are not met, the system displays an error message and prompts the user to re-enter correct credentials. The application performs the check on the client side, thus reducing the task of the server to reject requests that do not meet the condition.
3. If the entered data is valid, the system checks the status of the user in the database data. If the user does not exist in the database, the system updates the database and registers a new user.
4. If a user with the same username already exists in the database, the system displays an error message, informing the user that the account already exists.

The data entry activity is shown in a diagram (Figure 3). The diagram shows the data entry in the record table. The activities are the same for each entry in the application. The following is a description of the diagram from Figure 3:

1. Upon the access to the application, it is checked whether the user is registered for work. If yes, the page for data entry is displayed; if not, the user is redirected to the login page.
2. Enter the data in the input form. Data validation is synchronized with the input. While data entry is ongoing, data validation is ongoing.
3. If the entered data is valid, it is possible to send data to the server.
4. The content of the form is removed. A clean form for a new entry is immediately available thus speeding up user's work.

Figure 4 represents a sequence diagram that shows how the client-side of the application sends a request to the server-side of the application to get the data to display. (Stawowy et al, 2023)

By clicking on the link to display the page, the user sends a request to display it. An example in Figure 4 shows the user accessing the page where the data about drivers is displayed. This is made possible with the help of the Navigate() function which assigns the URL for the corresponding page, and calls for the React Router library that routes the users based on URLs. Specific content related to the defined address route is then displayed. The components of a particular page have functions related to the page load event (onLoad). The function starts to be executed while loading the bound component, in this case the component in charge of display of driver data (mainTable).

The component sends a request to get data using Sequelize. The query is executed in the server part of the application over the database data and returns the requested data as a result. The client side formats and displays the data that the user can see.

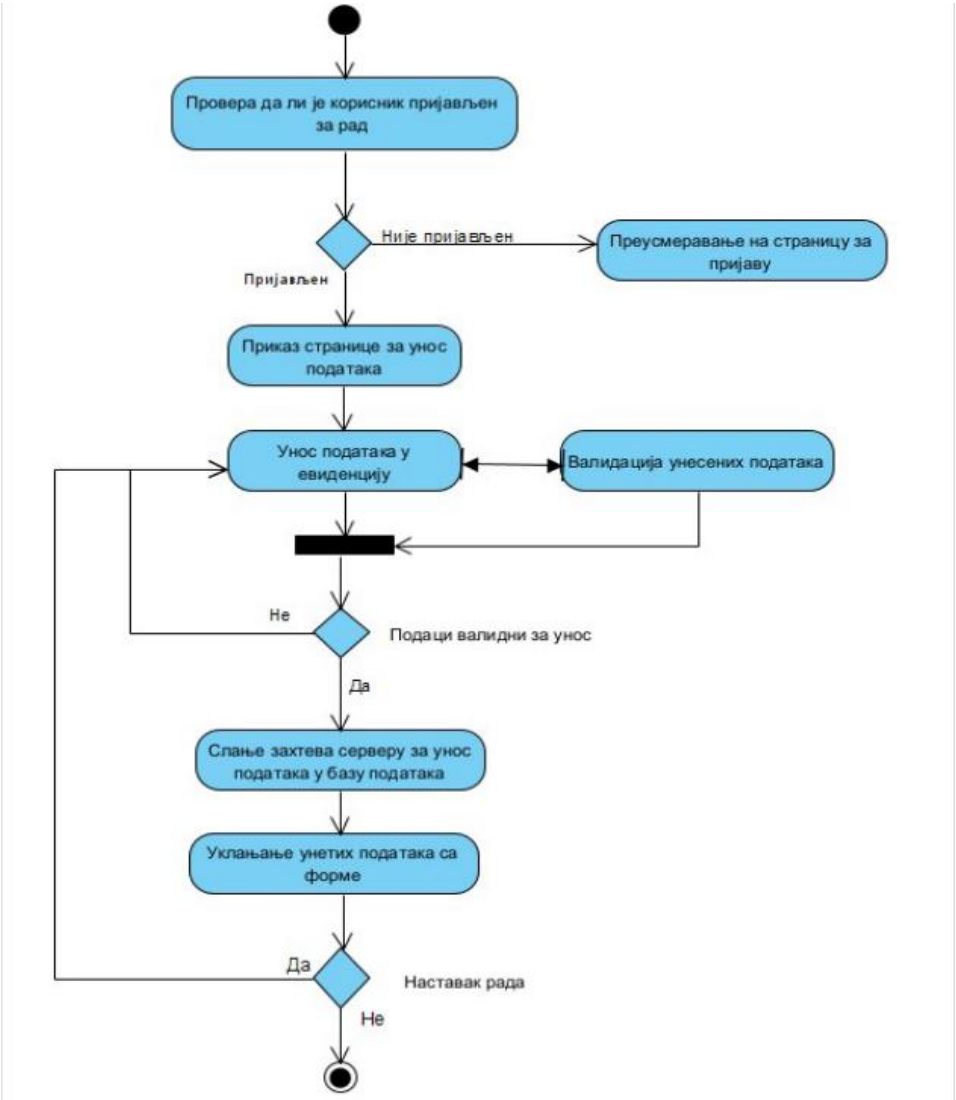

Figure 3 – Diagram of the data entry activities

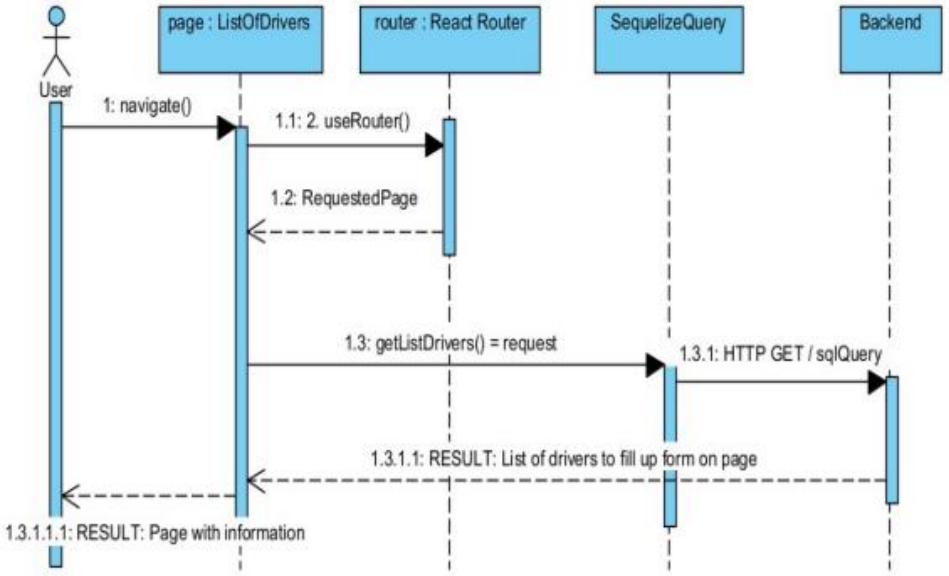

Figure 4 – Diagram of the data filling sequences on pages

The database is created in MySQL, a free open-source software. The chosen system has proved to be highly manageable in data manipulation, fast and efficient. The big advantage is that it can work on multiple platforms (Windows, Linux, macOS, etc.) where the independence from the platform for the operation of the application and its configuration has been acquired.

In Figure 5, a logical model of the database is shown. A logical model consists of entities, attributes, and relationships between them. This model is an approximate representation of a system or process that serves to understand the system and its changes and managing methods. In the relational database, the main entities presented are Vehicles, Records, and Drivers.

The other entities refer to vehicle types, vehicle statuses, vehicle brands and ranks, representing codes that are not commonly changed.

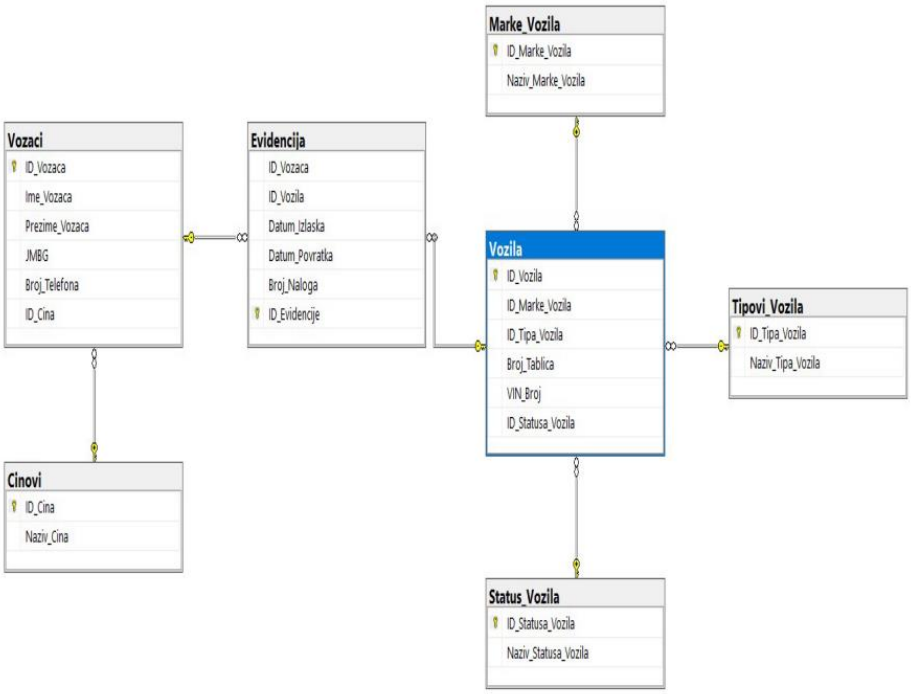

Figure 5 – Database model

Implementation of solutions

Application solution implementation is the process of translating the design and application requirements into a real code and functionalities that work within the web environment. This includes client and server side application programming, database usage, environment configuration and testing. The development of the user interface and functionality on the user's browser are part of the client-side application. The user interface is an important aspect of every application because most users rate the application mostly based on of their subjective feeling gained by using it. Users get in touch with the application only through the interface. It is important that the user's work itself be intuitive. Whether or not an app gets adopted depends more on its design than on its functionality. In practice, applications with poorly designed user interfaces rate much lower even though they have more functionality or a higher speed of operation than those applications that are appealing to the eye. To create the user interface of the test application, React.js was used.

Another part of the solution is programming the server side of the application. Node.js was used for the development of communications with the database, processing of client requests, and data processing. Security is one of the priorities of developing server-side applications. The data is the most valuable resource that attracts potential attackers. The degree of security and the level of investment in application security depends on the data value. Of course, it is important to implement protection on the client side as well, but only after implementing adequate protection on the server side. There are many examples of bypassing client-side protection where attackers manage to send written requests and talk to the server without authorization. This leads to attackers coming into contact with the data and the database itself without being authorized. There is a data leak, sabotage of the application, and it can also result in hardware damage.

Figure 6 shows an example of the model implementation for Sequelize. To create a model, it is necessary to define a table with the attributes. Each attribute is defined by the properties such as data type, whether it can be "null", whether it is a primary key or a foreign key for the table, etc. When working with relational databases, it is also necessary to define relations over certain attributes in the model. The relations that Sequelize supports are basic and refer to one-to-one, one-to-many and many-to-many. For defining these relations, it is necessary to combine the four associations that Sequelize offers: HasOne, BelongsTo, HasMany, BelongsToMany. In the example in Figure 6, in the first part of the code, under the method sequelize.define(), the primary key IDVozaca is defined in the Vozaci model. Once the model definition is complete, its relations with other models are established. Vozaci.associate() is a function that defines the relationship between models over certain attributes.

An example of the code for processing requests on the server side is given in Figure 7.The import of the MarkeVozila model provided the methods that come with Sequelize and make it easier to work with the database without writing queries but by calling the methods on models that change queries. The methods shown in Figure 7 are: findAll(), create(), and findByPk().

In Figure 7, the input requests (POST request) in the database and data withdrawal are processed (GET request) from the database. Asynchronous functions are used, which as a result return data to the JSON format.

```sequelize
module.exports = (sequelize, DataTypes) => {
  const Vozaci = sequelize.define("Vozaci", {
    IDVozaca: {
      type: DataTypes.INTEGER,
      allowNull: false,
      autoIncrement: true,
      primaryKey: true,
    },
    ImeVozaca: {
      type: DataTypes.STRING(20),
      allowNull: false,
    },
    PrezimeVozaca: {
      type: DataTypes.STRING(20),
      allowNull: false,
    },
    JMBG: {
      type: DataTypes.STRING(13),
      allowNull: false,
    },
    BrojTel: {
      type: DataTypes.STRING(12),
      allowNull: false,
    },
  });

  Vozaci.associate = function (models) {
    Vozaci.belongsTo(models.Cinovi, {
      foreignKey: {
        name: "IDCina",
        type: DataTypes.INTEGER,
        allowNull: false,
      },
      onDelete: "CASCADE",
      onUpdate: "CASCADE",
    });
    Vozaci.hasMany(models.Evidencija, {
      foreignKey: {
        name: "IDVozaca",
        type: DataTypes.INTEGER,
        allowNull: false,
      },
      onDelete: "CASCADE",
      onUpdate: "CASCADE",
    });
  };

  return Vozaci;
};
```

Figure 6 – Sequelize example of the Vozaci (Drivers) model

```express
const express=require('express');
const {MarkeVozila}=require('../models');
const router=express.Router();


router.get("/", async(req,res)=>{
    //res.send('Hi');
    const listOfMarke=await MarkeVozila.findAll({
        order:[['NazivMarke','ASC']]
    });
    res.json(listOfMarke);
});

router.post("/", async(req,res)=>{
    const data=req.body;
    await MarkeVozila.create(data);
    res.json(data);  //potvrda
});

router.get("/edit/:id",async(req,res)=>{
    const id=req.params.id;
    const mark=await MarkeVozila.findByPk(id); //findOne({where:{idMarke:id}})
    res.json(mark);
})
```

Figure 7 - Sample request processing code

Application operation

At the start of the application, the home page is displayed. The home page contains a message and a login button. Its role is to inform the user who accesses it that the system is operational and in function. When being logged out of the account, the user will be automatically redirected to the home page. (Jakovljević et al, 2022)

Figure 8 – Welcome screen

By clicking the "Log in" button, the user is redirected to the login page on which there are the fields for entering the username and the password. If valid data is entered, the user is redirected to the home page for work. Attempts to log in with incorrect information will result in displaying a warning to the user (Figure 9) and the user remains on the login page.

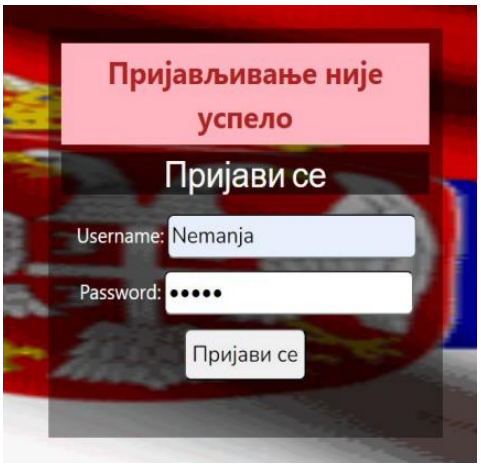

Figure 9 – Log In tab

The appearance of the home page after login differs from the appearance when the user logs into the application. This is achieved by following the application based on the type account and its privileges show the options available to user in the navigation menu through the application. In the continuation of the text, the images of the menus for privilege users are given as "Administrator" (Figure 10) and as “Duty Officer“ (Figure 11). If the user tries to access the page, by manually entering the URL, for which there is no privilege, the application will redirect him to the home page.

Figure 10 – Administrator menu

Figure 11 – Duty officer menu

By clicking on the menu option, the user goes to the page for working with the selected data. The key functionality of the application is recording the entry or exit of the vehicle, and it is accessed through the "Evidencija" option in the menu (Figure 12).

The records page displays a sub-menu containing functionalities related to working with data related to the selected page - on the page for working with records, it is the "Unesi novu evidenciju" option.

The data in the records are displayed in the form of a table with columns and rows. The data that require attention are marked in red. Each row, in addition to the columns that display the information about the data, also contains a column with a button for changing and deleting data. When the driver finishes task and returns, its return time is entered by pressing the "Izmeni" button. After the return time is entered, the data will no longer be displayed in red. Pressing on the "Brisi" button opens a window for deleting the data. Data search is enabled by the "Pretraga" field in which the user enters a term for search. It is not necessary to select a search category because the search is performed through all categories.

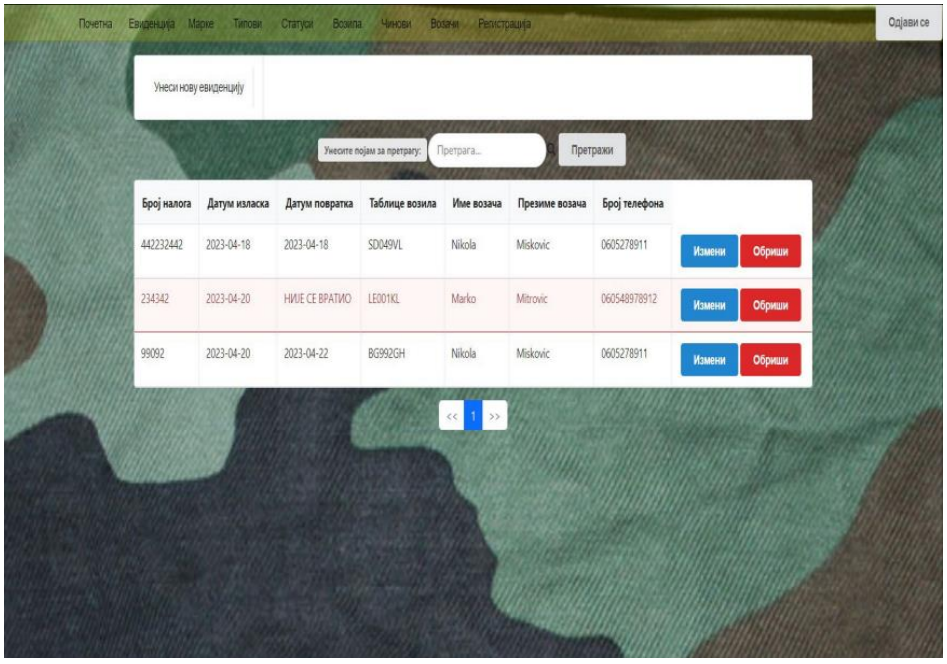

Figure 12 – „Evidencija“ page

The layout of the pages for displaying data, entering new data, changing and deleting data about drivers, vehicles, vehicle types, status of vehicles, brands of vehicles and their ranks follows the same template as the pages for working with records.

Pressing the "Unesi novu evidenciju" option opens a page to enter data in the records. Filling in the fields is done by choosing one of the offered options or manually. The validation of the entered data is performed when the "Enter" button is pressed. A validation example in Figure 13 shows an appropriate message with a description of the error that needs to be corrected to enter the data.

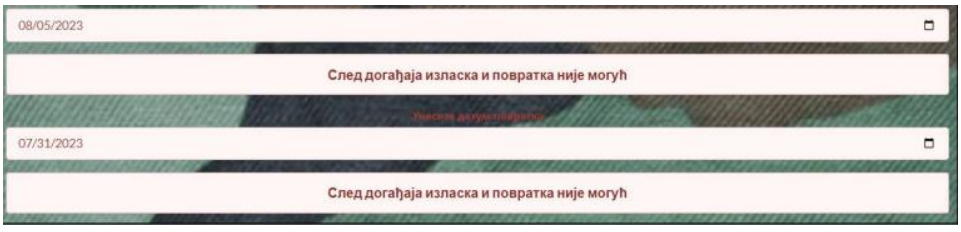

Figure 13 – Fields to enter new data and errors

Possibility of further expansion of the system

The conceptual solution was given and realized by the author; therefore, there is room for refinement of current functionalities and addition of new ones. To begin with, it is necessary to form a group of different specialists in order to carry out the assessment of the application and its testing in real conditions. After that comes a creation of a newer version of the application that would represent a revision of the existing one. It is desirable that the same expert group continue improving the application and at the same time conduct training for the application maintenance. Further extensions may refer to the introduction of new account types such as "Mechanic". The role of the mechanic would be to enter data about functioning, defective and available vehicles. Thus, the solution would include other structures. The ultimate goal would be a system that links together the entire work of a military facility. It would enable the entry of employees who come to work on a particular day. There would be an exact list of people and vehicles currently available, thus the person responsible for assigning tasks can easily connect available drivers with ready and free vehicles and assign them a task. And guards themselves would find it easier to record the entry and exit of vehicles. Monitoring the operation of one facility would make work easier and more organized. The idea that would arise from this way of solving the problem would influence the improvement of work automation. What complete automation means is that all human actors are replaced by sensors. The solution is presented below. The driver comes to work with his own identification card (ID) which contains a chip, and he scans the ID thus becoming visible for task assignment. The mechanic ensures that the vehicles condition data are accurate and entered in time. The commander connects the driver and the vehicle through the application and assigns a task. The driver goes to perform the task, takes over the assigned vehicle and drives to the exit gate. A camera with a sensor reads the license plates of the vehicle and compares them with the available vehicles, the driver approaches the point and reads his ID. The system checks the camera data and the ID data, verifying whether there is a task assigned to that particular driver with that particular vehicle. If it finds a match, the gate opens and the vehicle leaves. The information about that exit appears in the records. When the vehicle returns, it repeats the same procedure as when exiting. The camera reads the license plates, the driver is authenticated via the reader of smart cards. If there is a match in the records that that driver with that vehicle left the facility, the gate opens, the vehicle enters and the records become completed with his return time. (Karakebelioglu et al, 2021)

Conclusion

The application developed aims to improve the current method of executing the actions related to the process of vehicle entry and exit from a military facility. Developing modern web applications that help with everyday activities is at the very top of people's interests. Adaptive applications such as those created in web technologies are intended for any device type or screen size. The advantage is that they do not need to be already installed: all that is necessary is a web browser and access to the network where the application is located. The goal of this paper is to bring people closer to the idea of using smartphones or other smart devices for something useful at their work.

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Sistema de información de apoyo al funcionamiento del estacionamiento de coches

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CAMPO: IT
TIPO DE ARTÍCULO: artículo de revisión

Resumen:

Introducción/objetivo: Los sistemas de información representan un conjunto de personas, datos, procesos y tecnologías de la información relacionados con el propósito de la recopilación, el procesamiento, el almacenamiento de datos y su filtrado en información útil necesaria para apoyar a las organizaciones o a la toma de decisiones. El sistema de información se desarrolla como una aplicación Web con ayuda del lenguaje de programación Javascript, Node.js y React.js, mientras que en segundo plano se basa en el almacenamiento de datos y la comunicación con la base de datos SQL.

Métodos: Se utilizan y prueban herramientas modernas de desarrollo de aplicaciones web en hardware de bajo presupuesto.

Resultados: Se ha desarrollado un software eficaz para un estacionamiento de coches con bajo coste de mantenimiento y gran fiabilidad.

Conclusión: El software facilitó el trabajo, aumentó el acceso a los datos y facilitó la revisión de los mismos, reduciendo la posibilidad de error. La aplicación descrita en este artículo y realizada con fines de investigación muestra cómo las tecnologías comerciales modernas se pueden utilizar con fines militares.

Palabras claves: software, solución, estacionamiento, JavaScript, nodo, SQL, militar, tecnología.

Информационная система управления автопарком

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РУБРИКА ГРНТИ: 20.23.25 Информационные системы с базами знаний
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: Информационные системы представляют собой: совокупность персонала, данных, процессов и информационных технологий, связанных с целью сбора, обработки, хранения данных

и их фильтрации в полезную информацию, необходимую для поддержки организаций или принятия решений. Информационная система разработана в качестве веб-приложения с помощью языка программирования Javascript, Node.js, и React.js, в то время как в фоновом режиме она полагается на хранение данных и связь с базой данных SQL.

Методы: В данной статье на бюджетном оборудовании применены и протестированы современные инструменты разработки веб-приложений.

Результаты: Разработано эффективное программное обеспечение для автостоянки с низкими затратами на обслуживание и высокой надежностью.

Выводы: Разработанное программное обеспечение облегчило работу, расширило доступ к данным и упростило их просмотр, снизив вероятность ошибки. Приложение, описанное в данной статье, было специально разработано для исследований. Оно доказывает, что современные коммерческие технологии могут применяться в военных целях.

Ключевые слова: программное обеспечение, решение, автостоянка, JavaScript, узел, SQL, вооруженные силы, технология.

Информациони систем за подршку рада ауто-парка

Немања Д. Капламовић

Војска Србије, Центар за командно-информационе системе и информатичку подршку (ЦКИСИП), Београд, Република Србија

ОБЛАСТ: информационе технологије
КАТЕГОРИЈА (ТИП) ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: Информациони системи представљају скуп људи, података, процеса и информационих технологија чији је циљ прикупљање, обрада, складиштење података и филтрирање у корисне информације потребне за подршку организацији или доношење одлука. Информациони систем је развијен као веб апликација уз помоћ програмског језика Javascript, Node.js, React.js, а у позадини се ослања на складиштење података и комуникацију са СКЛ базом података.

Методе: Користе се и тестирају савремени алати за развој веб апликација на нискобуџетном хардверу.

Резултати: Развијен је ефикасан софтвер за паркинг са ниским трошковима одржавања и великом поузданошћу.

Закључак: Софтвер је олакшао рад, повећао приступ подацима, олакшао њихов преглед и смањио могућност грешке. Описана апликација намењена је истраживању и показује како се модерне комерцијалне технологије могу користити у војне сврхе.

Кључне речи: софтвер, решење, аутo-парк, JavaScript, node, SQL, војска, технологија.

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Analysis of packet switching in VoIP telephony at the command post of tactical level units

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FIELD: computer sciences, telecommunications, IT
ARTICLE TYPE: review paper

Abstract:

Introduction/purpose: This paper conducts a comprehensive analysis of a potential implementation of Voice over Internet Protocol (VoIP) systems, focusing on network architecture, VoIP phones, and servers. The study explores potential vulnerabilities and proposes solutions. The paper concludes by advocating for a holistic approach to securing VoIP systems, incorporating supplementary services to ensure the confidentiality, integrity, and availability of voice communications in the digital landscape.

Methods: Review of the underlying theory, analysis of the end-user needs and potential solutions, practical viability assesment.

Results: The theoretical points discussed were proven in practice, using commercially available resources. Communication was established in an expected manner.

Conclusions: Implementing solutions similar to the one presented in the paper would be a relatively inexpensive way to make diverse improvements to the operation of tactical level units, both in peacetime and during war.

Key words: VoIP, real-time communication, voice sessions, computer networks, SIP.

Introduction

Commutation, or redirection, of telephone signals had a long development. From manual switching, through the automation of telephone switchboards, to today's packet switching in digital Internet protocol systems, which will be the topic of this paper.

VoIP (Voice over Internet Protocol) telephony, the most modern form of voice transmission, is the result of the convergence of telephone and computer systems. In this form of communication, digitized voice is placed in packets, units of information of the third network layer of the OSI (Open Systems Interconnection) reference model. It enables the transmission of speech over the network infrastructure used in computer networks, which is especially convenient in the case of communication over long distances. VoIP telephony enables many more new functionalities (Ahmad et al, 2015) compared to the telephone systems that are currently in use, some of which will be mentioned in this paper.

The components necessary for the realization of a VoIP phone system are similar to those of other types of telephony. These are telephones, transmission medium, switching devices and telephone switchboard. This paper will describe the configuration of commercial devices to fulfill these functions.

This modern type of telephony would find its place in the Serbian Army. Lower cost of system implementation, greater possibility of integration with realized solutions applied in data transmission, simpler installation and the possibility of traffic management and monitoring are just some of the advantages of adopting such a system. Through this paper, one of the variants of the use of this system will be analyzed, using the example of the command post of a tactical level unit.

Network scenario

The starting point for designing a computer network is the user's needs (Fayyaz et al, 2016). This system is intended for use at the battalion level, the basic modular unit of the Serbian Army, and higher units. The battalion is the smallest unit that has headquarters in its formation, which represents the largest group of users of the implemented system. The users of this system are the heads of groups and sections within the command of the unit, the commander and the deputy commander of the unit. The system at the local level also supports the connection of other users from the unit, which would be tactically meaningful only in peacetime conditions. Each user has his own workplace, within which a computer and

a VoIP phone are of interest for this work. The role of this system is to enable communication between users at different workplaces.

In the implementation of this work, the task was defined as the establishment of communication at the command post of two battalions in the premises and their connection. The computer network realized for the execution of the task (Figure 1) can be divided into a local network and a network of large areas.

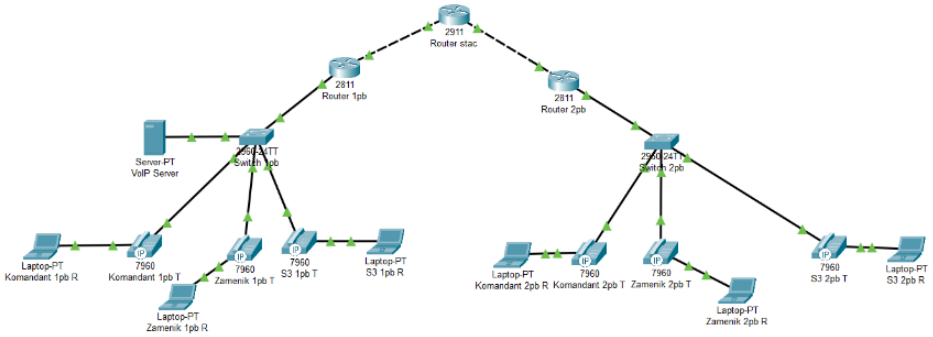
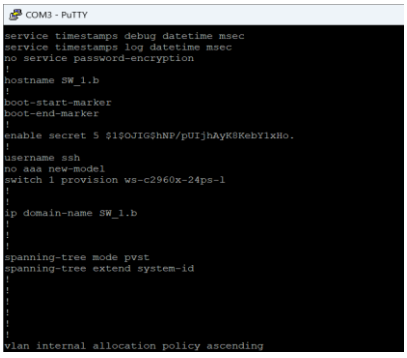
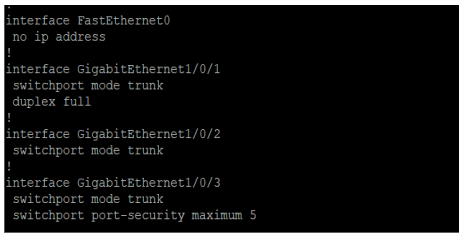


Figure 1 – Logical network topology

Switch configuration

The configuration of the switch, as well as the router, was performed using the PuTTY desktop application. It is an SSH (Secure SHell)/Telnet client through which the Command Line Interface (CLI) is accessed. In the command line, commands are entered for the general setting of the switch, as well as for individual interfaces, lines, VLANs (Virtual Local Area Network) and the like.





Figures 2 and 3 – Part of the running configuration of the 1st battalion switch shown in the CLI

Access router configuration

The access router is the last device in the local network, and the boundary between the local network and the WAN. Each router interface is on a separate local area network, which is why routers are said to restrict local area networks. Due to technical limitations, access routers and one central router were used. In reality, there are a number of routers between the two command posts, but they are under the jurisdiction of the stationary component of the SAF's TcIS (Telecommunication Information System of the Serbian Armed Forces). (Marković, 2023)

In this paper, the OSPF routing protocol was used because it is used in the SAF. On the edge router, which is located between the stationary component of the SAF and the Internet provider, it may be necessary to configure BGP as well.

The general settings of access routers are similar to those of other network devices. They are assigned a name, an IP domain name to enable SSH and Telnet, a password for privileged access, and virtual lines. The difference between configuring a router and a switch is the interface. The C2620 router has only FastEthernet interfaces. Each of the router's interfaces is automatically disabled, and can be enabled by configuring the IP address. One of the capabilities of a router is to divide one physical interface into several logical subinterfaces. The use of subinterfaces is reflected in the definition of virtual local networks. In Cisco's 12.0(7) IOS (Internetwork Operating System), which is very outdated, the first virtual network must not belong to a subinterface, which is a difference from the configurations used in practice today. This restriction means that the native virtual local network (Native VLAN) must be the first VLAN used. This makes traffic isolation difficult and prevents the use of a "guest local area network".

Each of the interfaces has a defined IP address and netmask. The netmask determines the number of users in the local network. In this configuration, each of the VLANs on the access interfaces has 16 possible addresses, the first of which is the network address and the last is the broadcast address. This means that the maximum number of IP devices in each virtual network is 14. Subinterfaces must be assigned a VLAN tag. It is inserted into the Ethernet header to separate the associated VLAN (Ghini et al, 2009). The tags must match the VLAN number defined on the switch.

The last interface of interest is Serial0/0 (s0/0). Connecting the DCE/DTE cable connects the serial interfaces of the two routers. These types of interfaces have not been used for years, but due to technical

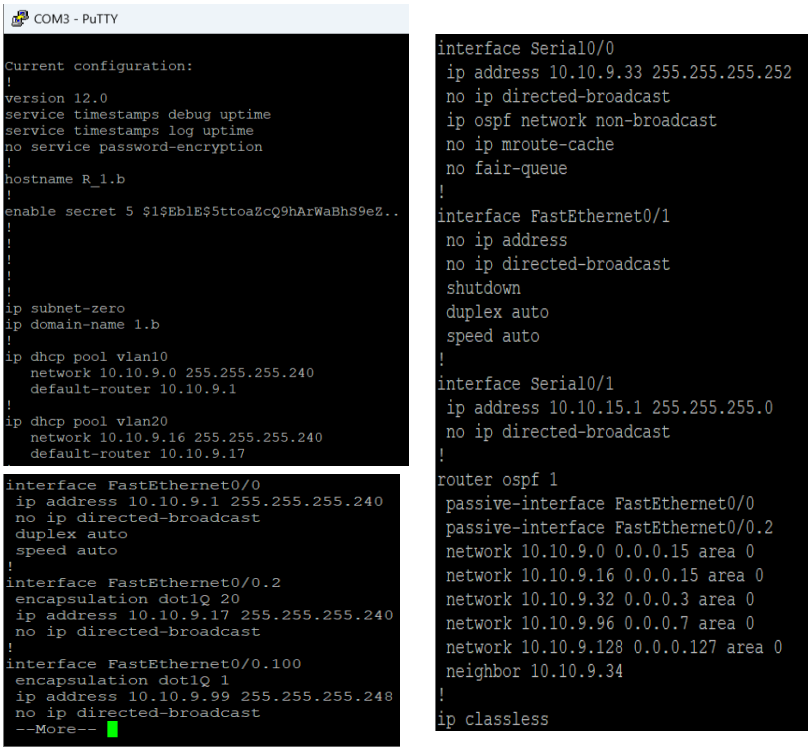
limitations of routers they are used in this system. The local area network of this interface is of size 4, which means that there can be two devices in it. It is the optimal network size for the case where two routers are connected.

DHCP (Dynamic Host Configuration Protocol) is configured on routers in the access plane. It assigns IP addresses at the request of the user, which is desirable in such systems. The method of determining the IP address is configured on the user's device, and in most cases it is desirable that it be dynamic. The exception in this system is the VoIP server itself, whose address is static. The address is dynamically assigned to other terminal devices. Considering that each user has two devices and the fact that the size of the subnet is 16, we reach a conclusion that the maximum number of workstations is 7. The size of the local network itself can be changed simply, but in this example the goal was to use the IP range in an efficient way. In addition to assigning IP addresses on the terminal device, DHCP can be used to configure over 100 parameters (DHCP options). We are also interested in the default gateway parameter. It is the IP address of the device used to exit the local network, in this case the router interfaces.

The last necessary option is to configure the routing protocol. The used routing process is assigned the number 1. In the configuration of the OSPF protocol, it is necessary to define the addresses and sizes of all directly connected local networks with the associated areas, and the address of the neighboring router. Area 0, the so-called "backbone" area, and 1 are assigned to local networks in this project. By assigning different areas, the router bordering the two areas would become an ABR (Area Border Router) and perform link aggregation. It would group local network addresses into one network, which it would advertise to the neighboring area. Link aggregation in an incorrect configuration leads to the creation of loops in routing, therefore care should be taken when planning the WAN.

One detail of good practice is to define passive interfaces in the routing process. The OSPF protocol only exchanges messages with devices of the same protocol, where some other conditions, such as the matching of the Hello timer, must be met to establish an OSPF adjacency (Strzeciwilk, 2021). To prevent unnecessary traffic, router interfaces can be marked as passive, and they will then not send Hello packets. This is to be applied to access interfaces, interfaces that are connected to the local network.

The complete view of the router configuration can be found in Figures 4, 5 and 6.



Figures 4, 5 and 6 – Access router configuration

Distributive and edge router configuration

Distribution routers are located outside the command post of the unit and are under the jurisdiction of the stationary component of TcIS. In the laboratory implementation, it was necessary to configure one such router.

The difference between access and distribution routers is the size of the local area network that they are directly connected to. Unlike access routers, distributive plane routers are connected only to neighboring routers. This reduces the complexity of the configuration, considering that only individual interfaces and the routing protocol need to be configured. The configuration of these parameters is similar to the parameters of access routers.

A specific case of distribution routers are edge routers. They are located on the border between our network and the network of other TcIS owners (telecom, post office, etc.). In addition to one of the internal routing protocols, these routers must also have an external routing process running. BGP (Border Gateway Protocol) configured on this router would

summarize the entire address range of the internal network and forward it as such to the neighboring BGP router. A higher level of protection is introduced on these routers, most often by using a Firewall. The system implemented in this work could be connected to the Internet, which will be discussed in the fourth thesis. Part of the configuration of the distribution router used in the implementation of this work can be found in Figure 7.

```
interface FastEthernet0/0
 no ip address
 no ip directed-broadcast
 shutdown
 duplex auto
 speed auto
!
interface Serial0/0
 ip address 10.10.9.34 255.255.255.252
 no ip directed-broadcast
 ip ospf network non-broadcast
!
interface Serial0/1
 ip address 10.10.9.37 255.255.255.252
 no ip directed-broadcast
 ip ospf network non-broadcast
!
router ospf 1
 network 10.10.9.32 0.0.0.3 area 0
 network 10.10.9.36 0.0.0.3 area 1
 neighbor 10.10.9.33
 neighbor 10.10.9.38
!
ip classless
```

Figure 7 – Distribution router configuration

VoIP service

The network infrastructure implemented in the second point of this paper can be used for data exchange between users, but it is insufficient in itself for the operation of a VoIP system. The missing elements will be described at this point.

The function of a network is to provide communication between devices. In a VoIP system, these devices are servers and phones (Ali et al, 2013). The VoIP server plays the role of a telephone switchboard in a classic telephone system. It assigns telephone numbers, establishes and terminates telephone connection, performs remetering and switching, and enables monitoring and management of telephone traffic. Servers are often expensive devices that are placed in tightly controlled physical conditions. They are most often accessed via the Internet, and are often not owned by the organization that uses them to provide a specific service. This type of server is called a cloud server. VoIP services are often run on this type of server. However, the function of a server for certain services can also be performed by a personal computer located in a local network. Due to the nature of the information exchanged in the Serbian Armed

Forces, and other limitations, such a solution was chosen for the realization of this work.

In this work, the role of the server is performed by a virtual machine. It is a software emulation of a physical computer system. A virtual machine is allocated the hardware resources of the physical machine on which it is running. It is possible to run multiple virtual machines on a single physical machine. Processes within a virtual machine are isolated and independent, so a virtual machine can have its own operating system. The software layer that manages the virtual machine is called a hypervisor. Its role, among other things, is the allocation of hardware resources.

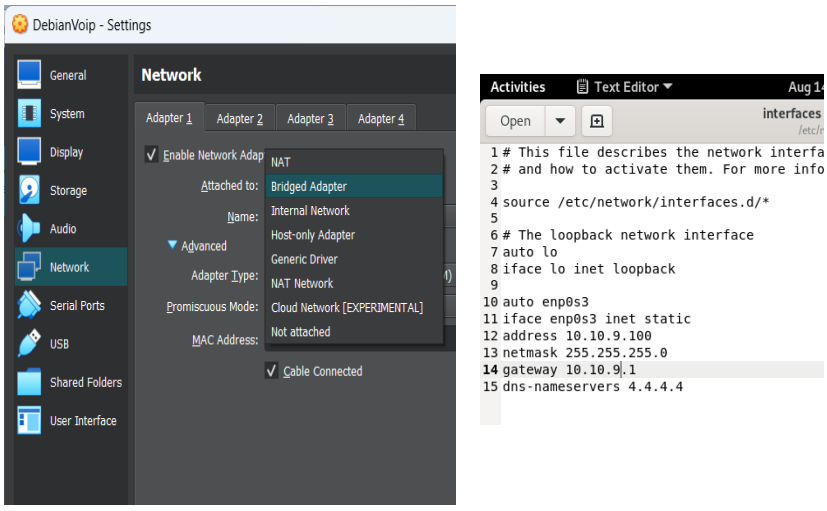
VoIP services use many protocols, but they can be said to be based on SIP and RTP (Abualhaj et al, 2021). SIP (Session Initiation Protocol) is a protocol whose role is to establish, modify and terminate a communication session. In its essence, it is a signaling protocol and its functions include the agreement of the codec used and the selection of the network path for data transmission. It is also active during call management, such as placing a listener on hold, redirecting and establishing a conference. The second protocol, RTP (Real-time Transport Protocol), is responsible for the transfer of packets after the connection is established. Some of its roles are packetizing the voice, assigning a sequence number to the packet, and reorganizing it in order of sending at the receiving end. It eliminates problems caused by jitter, delay and packet loss. It is also used in other real-time communications, such as video streaming and gaming.

Virtual machine

For the purposes of this work, a virtual machine built on the open-source application VirtualBox, from Oracle, was used. VirtualBox is installed on the Windows 11 operating system, which means that the virtual machine will be based on a type 2 hypervisor. VirtualBox offers various options for configuring and using virtual machines, such as machine cloning, machine state memory, folder sharing, and more. Of greatest interest for this paper are the virtual machine's network settings, shown in Figures 8 and 9. The virtual machine is configured to have its own network outlet that behaves as a separate device from the point of view of the rest of the network. The virtual machine is assigned 4 GB of RAM (Random Access Memory) and one logical processor core. Allocation of resources to virtual machines is done before startup. If necessary, more hardware resources can be allocated, where it is recommended to leave at least 30% of RAM and half of the logical processor cores to the physical machine. The virtual machine is running a

64-bit Debian operating system. It is a free, open-source operating system that offers various benefits for running servers over Windows. Less use of hardware resources, greater protection and ease of software installation are just some of them.

On the virtual machine, two lines of code are only needed to be entered into the terminal to install FusionPBX. To act as a server, a virtual machine must be connected to the rest of the network. A virtual Ethernet interface is configured for this purpose. The rest of the server settings are performed via the web interface, by connecting to the server's IP address.



Figures 8 and 9 – Network adapter configuration

FusionPBX VoIP server

FusionPBX is free, open-source software that serves as a switchboard for a wide range of communications. It is based on FreeSWITCH software, on which it builds a web GUI (Graphical User Interface). Another well-known derivative of FreeSWITCH is BigBlueButton, which is used on the distance learning platform in the SAF. FusionPBX enables VoIP, voicemail, fax, conference calling and many other services. It can also be used for traffic monitoring and management. It is used in commercial environments due to its large number of functionalities and ease of implementation. There are paid versions of the software that offer additional services such as notifying waiting users of their position in the waiting queue, sending emails to users upon

registration, and others. However, the biggest benefit of paying for this software is access to official "training recordings" and documentation that serves as a guide to the switchboard operator. The software is complex and contains too many functionalities that are not well documented in the software itself. Therefore, despite the price ranging between one hundred and one thousand dollars per month, a large number of companies that use this software have several subscribers. The $1,000 per month offer offers a maximum of 6 hours of customer support per month.

An important term in this software is domain. Domain is the name for all software processes related to one system (company, neighborhood, etc.). A single server can serve multiple systems, but each system will have its own domain. The only priviledge level valid for multiple domains within a server is the superadmin operator. Operator levels are divided into superadmin, admin and user. The superadmin has the ability to configure all domains on the server, the authority of the admin is limited only to a certain domain, and the other groups of operators have different restrictions within their domain.

Configuration is done through the web interface. In order to access the web interface, it is necessary to enter a URL (Uniform Resource Locator) link in case there is a DNS (Domain Name System) server, or a specific IP address as is the case in this paper.

After the operator logs in, the information about the operator and the system is displayed on the home screen of the website, such as received messages, the percentage of hardware resource utilization, the number of registered users, and the like. The following is an explanation of the individual settings.

User configuration

User management is done in the Extensions window. First it is necessary to add users. In the add user window, there are many options, such as recording the call, sending an e-mail after a missed call, even selecting music for other users in the call waiting queue. Of interest for this work are the configuration of password, domain, name on caller ID and phone number. It is possible to add multiple users at the same time, where they share the basic settings after adding, which can be changed separately by configuring the individual user. It is also possible to assign a specific MAC address to the user, whereby he will be automatically registered when connecting a device with a defined MAC address. After adding a user, it is possible to view the list of possible users, which can be seen in Figure 10.

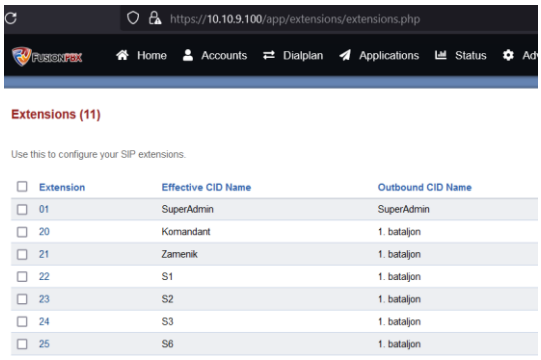


Figure 10 – User configuration

SIP profile configuration

This software handles calls based on four SIP profiles. The internal profile for IPv4 is of greatest interest for this paper. There are 137 configurable options within this profile. They include settings for TLS or SSL (Secure Sockets Layer), certain timers, call forwarding and the like, but in this work it is necessary to change only a few parameters. The SIP socket configured in this section must be identical to the configurations of other VoIP devices. Figure 11 shows current SIP processes and possible profiles. The SIP protocol usually uses UDP (User Datagram Protocol) on the transport layer, but it can also be configured for TCP WebSocket and WebSocketSecure, the last two of which are upgrades to HTTP and HTTPS (HyperText Transfer Protocol Secure) respectively. In this work, a standard configuration was used. Configured profiles must be run. The operator has the possibility to cancel the registration of all users registered on one profile at the same time.

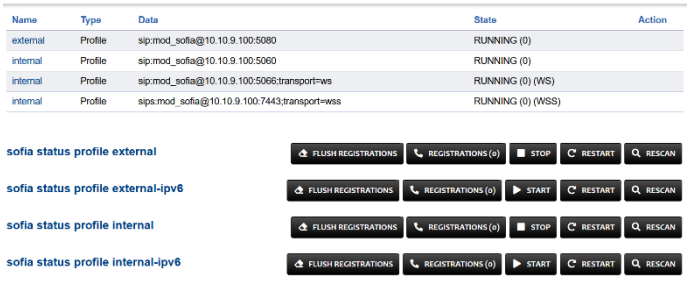


Figure 11 – SIP profiles and processes

Useful administrative views

FusionPBX, as previously mentioned, offers a great degree of control over all aspects of interest to a telephone exchange. Special attention in this paper will be devoted to the possibilities of monitoring and managing the operator. The operator, depending on the level of his account, in addition to the configuration of the user, has complete insight into the activities related to the users. Busy time, call list, e-mail list, redirects; all this is only part of the user data over which the operator has an overview. An operator with a superadmin level account in standard configurations has as many as 762 "permissions", while an ordinary user has less than 100, which include calling, adding to a conference, activating redirection, reading his voicemail, and the like. It is important to mention that the operator can even record calls between participants, listen to other people's voice mail and read other people's electronic mail. Figures 12 and 13 show some views that operators of a certain level have access to.

Figure 12 – Registered MAC addresses

Ext.	Domain	Caller Name	Caller Number	Caller Destination
21	10.10.9.100	S1	22	21
22	10.10.9.100	S1	22	22
21	10.10.9.100	S1	22	21
22	10.10.9.100	Zamenik	21	22
23	10.10.9.100	Zamenik	21	23
23	10.10.9.100	Zamenik	21	23
23	10.10.9.100	Zamenik	21	23
21	10.10.9.100	S2	23	21
21	10.10.9.100	Komandant	20	21

Figure 13 – Global call list

Panasonic KX-HDV430X VoIP phone

A VoIP phone, one of the basic components of a VoIP phone system, differs from analog and ISDN (Integrated Services Digital Network) phones. In order for the user to access the telephone system, it is necessary to configure the telephone itself. In this paper, only network settings are of interest, attention is not paid to user settings such as ringtone volume and the like. It is important to note that these phones are powered by an adapter from the mains or via Ethernet when connected to a PoE (Power over Ethernet) switch. The phone used in this system is accessed physically, using a touch screen, and using a web interface. The settings necessary for logging into the telephone exchange are located on the web interface. The phone's physical settings are low-level settings and must be set before accessing the web interface. VLAN, IP address can be configured physically/statically (Figure 14) and via DHCP (Dynamic Host Configuration Protocol), CDP (Cisco Discovery Protocol), LLDP (Link Layer Discovery Protocol) and Embedded Web. In this paper, the IP address and Embedded Web are physically set, which enable access to the web interface.The phone also has the ability to send echo request packets of the ICM protocol (Internet Control Message Protocol) (Figure 15).

Figure 14 – Manual IP configuration

Figure 15 – Ping response

The rest of the necessary configuration was performed via the web interface (Figure 16). In order for the user to register to the VoIP server, he needs to configure his phone number, authentication identification number, password, IP address, port and domain of the server. All the mentioned settings are located within the line window of the SIP window.

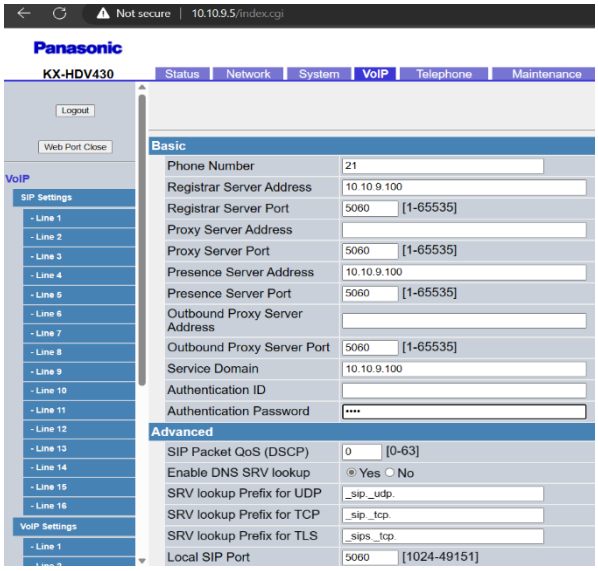


Figure 16 – Client-side SIP configuration

It is also possible to configure the IP address of the phone itself, caller ID, DNS and other options. This phone supports simultaneous use for a maximum of 16 user accounts, i.e. 16 phone numbers, which can also belong to different domains. One line is configured. After the configuration, the phone will automatically log on to the VoIP server. The settings remain saved in the phone's memory, and it is possible to delete them using the web interface or by typing a certain number on the phone itself. This function, similar to USSD (Unstructured Supplementary Service Data) codes in mobile telephony, should not be known to ordinary users.

After performing all the mentioned configurations, the system is ready for operation.

Additional services

The configurations realized in parts 2 and 3 of this paper are sufficient for the operation of one VoIP phone system. As part of this work, additional

functionalities have been implemented, and the addition of services and functionalities that were not implemented either due to time or technical limitations will be theoretically considered. Advantages in the application of the described solutions are reflected in the spheres of efficiency, protection, provision of redundancy and scalability. They are also important for the operator because they enable faster and easier installation and management of the system.

SSH

SSH is a cryptographic network protocol used to access, manage, and exchange data with remote computer systems. It was developed as a replacement for insecure protocols like rlogin and Telnet. The purpose of using SSH in this paper is to enable remote configuration of network devices. This protocol is based on key exchange. After accessing the network device through the terminal, in this case Command Prompt on the Windows operating system, it is necessary to agree on the key exchange method and the encryption algorithm. After exchanging the keys and confirming the matching of the hashed authentication parameters, an SSH connection is established to transmit commands to the network device. The user can then access the device in the same way as they do via console port and flat cable with RS (Recommended Standard) 232 connector. The routers used in this paper do not support SSH because they were manufactured in 1998, so SSH is configured only on the switch. To log in using the SSH algorithm, one needs to know the IP address of the device, the username for SSH access, and the access password, which is configured in the second chapter of this paper. In this example, the Diffie-Hellman cryptographic algorithm for key exchange and the AES (Advanced Encryption Standard) encryption algorithm with a key length of 256 bits were used.

DNS

The role of the DNS service is to translate domain names into IP addresses. DNS servers work like a phone book. Most services that rely on computer networks communicate based on IP addresses. Users, on the other hand, do not have an easy time remembering IP addresses. When a user makes a request to a browser or other application for a resource on the Internet, that request is forwarded to a DNS server that will translate the requested domain name into an IP address. The translated IP address is returned to the user's device, and it becomes a parameter for establishing communication between the user and the requested resource. DNS servers can be of different hierarchical levels, and store different

types of data. Most often, the Internet provider has its own DNS resolver that stores data about frequently used domains and IP addresses. When a request is made to the DNS resolver for an unknown domain, it forwards the request to higher-level DNS servers.

The purpose of using a DNS server in this system would be reflected in the case of expansion of this type of telecommunication system. Introducing a local DNS server would make logging in and administration of this system easier. For example, in the event that the same VoIP server is shared by all units of a reinforced brigade-level tactical group, each subordinate unit would have to remember the exact IP address of its domain on the VoIP server. Using a DNS server, instead of remembering an IP address, users and operators would log in using a domain name like "komandant.1pb@1br.tg1". This type of name is similar to an email address. All email services address users by name and associated domain. Without the DNS service, the e-mail address of a gmail user would look like "username@177.217.9.219".

Soft VoIP phones

Soft phones are applications that allow users to use VoIP telephony services without a physical phone. Depending on the software itself, they offer a number of benefits and improvements over physical VoIP phones (Singh et al, 2014). They reduce system cost, facilitate configuration and remote management, and can be integrated with other applications. They can be installed on computers, mobile phones, tablets and similar devices.

Use on mobile phones, with appropriate expansions of the network infrastructure (WLC (Wireless LAN Controller) and multiple wireless access points) would enable user mobility at the command post, while retaining all the good features of the basic system. A mobile phone without a SIM (Subscriber Identity Module) card does not connect to the civil mobile communications network. Even with the card, it is possible to turn off the transmission power of the mobile phone by entering the appropriate configuration window, using a certain USSD code defined by the operator (Bhattacharjee et al, 2010). By turning off the transmission power for the mobile network, the phone becomes invisible to the adversary. The advantage of VoIP telephony is that it relies on the Internet, so mobile phones can rely on a local Wi-Fi (Wireless Fidelity) network that would originate from wireless access points at the command post. A Wi-Fi signal has a much shorter range than a cell phone signal, so it would be very difficult for a potential enemy to detect. Such an upgrade of the implemented system would retain the features of anti-electronic protection, along with the great benefits offered by mobility.

The software phone was very useful in the realization of this work, due to the technical limitations of the laboratory and the existing VoIP phones. The MicroSIP application is installed on the server computer. It is free, open-source software that supports all the functionality of physical phones, except for video calls. In addition, it offers the possibility to configure protection at the transport layer of the OSI reference model using TLS and SRTP protocols.

The configuration of MicroSIP is simpler than the configuration of a physical phone, and is done in just one window, which is shown in Figure 17. It should be noted that to use this application it is not necessary to be connected to the Internet, and it only takes a few MB of memory space. From that aspect, and bearing in mind that the application is open-source, it can be concluded that the use of this application does not represent a security risk.

Figure 18 shows the appearance of the application after the call is made.

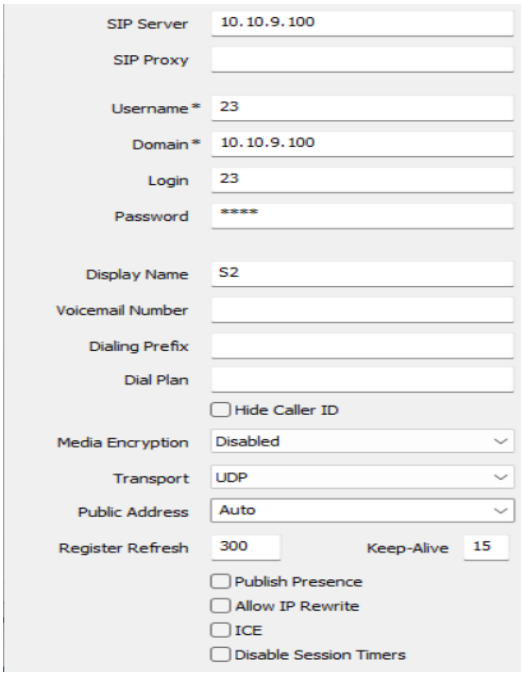


Figure 17 – MicroSIP configuration

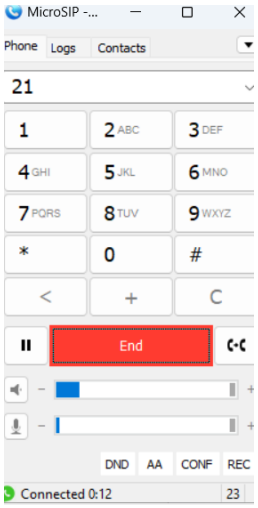


Figure 18 – Call established using MicroSIP

Redundancy and load balancing

The implemented system, in the topological sense, has a centralized structure. In the case of application during combat operations, this type of implementation may adversely affect the continuity of communications (Thirunavukkarasu & Karthikeyan, 2015). Therefore, it is necessary to implement certain solutions that ensure redundancy. These solutions increase the complexity and cost of the system, but are necessary in the case of more mass use of the system.

In an organizational sense, some kind of redundancy would be provided by defining the rank of the unit running its own VoIP server. Battalion-level units already possess technical resources for the implementation of such a system, in the form of PKČb (Serb. Battalion Mobile Switching Hub). The lower the rank of the unit that implements such a system, the more resistant the entire telecommunications system is to interruptions. In the event of the loss of its VoIP server, provided the switch is still functional, the unit could rely on the other unit's server with negligible configuration changes, providing a high degree of redundancy. Connecting several such systems is simple from a technical point of view, and does not require any hardware additions compared to separate systems, but due to technical limitations it was not realized in this work.

Technical measures to ensure redundancy can be implemented at several levels. Today's commercial servers have multiple network cards,

which can be connected to different switches. Such an implementation would ensure that the immediate consequences of the loss of one switch are reflected only on the users connected to that switch, and not on the entire system. The process of deciding which path the server will choose is configurable, and can be static (one switch is primary and the other is backup) or involve load management based on certain metrics. Some other advantages of a server with multiple NICs are link aggregation and QoS filtering, which are not of interest in this paper.

The last level of redundancy relates to the router. Configuring HSRP, VRRP, or GLBP allows a group of routers to share a single virtual IP address. The first two protocols work in a similar way. They assign a virtual IP and MAC address to one physical router according to a certain metric, which all other network devices use in communication. The biggest difference between HSRP and VRRP is that the first protocol is proprietary to Cisco, while the second is an open standard for all manufacturers. GLBP is an improvement over these two protocols, as it also offers the possibility of load management. The main router (AVG (Active Virtual Gateway)), selected according to a certain configurable metric, assigns virtual MAC addresses to other routers (AVF (Active Virtual Forwarder)), which forward the traffic on. AVG is responsible for the resolution of ARP requests that are directed to a shared virtual IP address. Based on certain metrics and network conditions, it assigns different virtual MAC addresses to different routers. An AVG router can be an AVF router at the same time. In addition to these two types of routers, there is also an SVF (Standby Virtual Forwarder) router, whose task is to monitor the state of the AVF router and, if necessary, take over part of the traffic.

Security

Information security features are an important indicator of the quality of a TcI system. In an ideal TcI system, organizational, technical and other protection measures are implemented at all levels of the OSI reference model. In the previous chapters, some protection measures were mentioned, such as TLS, SSH, WSS (Web Socket Secure) and others. In this part of the paper, the technical protection measures implemented on the second and third layers of the OSI model are of interest.

Data link layer protection techniques often include device MAC addresses. Protection at this level is mainly implemented on the switch. Apart from the division into virtual local networks, which in itself carries some features of protection by isolating groups of users, port security measures (Port Security) were implemented in the realization of this system. Traffic filtering by known MAC addresses is enabled on the

switch's access interfaces. Considering that each device has its own unique MAC address, the interfaces are configured to protect the network from access by unknown devices. It is possible to define the exact MAC address of the allowed device before access itself, or with the sticky command allow the addresses of devices connected to the interface to be automatically remembered. In this system, the security implemented is configured to allow access to the first five devices that connect to this interface. In case of unauthorized access, it is possible to completely disable the interface of the unauthorized device or automatically reject traffic without disabling it. An operator accessing the switch in privileged mode can see statistics related to protection of this type. The switch protection configuration used in this work is shown in Figure 19.

Greater diversity in protection is possible at the network layer of the OSI model. The basic form of protection at this layer is the use of an access control list (ACL). The traffic parameters that will be forwarded or rejected are defined within the ACL. AC lists are divided into standard and extended. The first type makes a decision based only on the source IP address. They are simpler to configure but offer an unsophisticated form of protection. Extended AC lists allow or deny traffic based on source and destination IP address, port, and protocol type. They allow for more precise traffic control. It is important to note that the criteria (rules) defined in the list are applied hierarchically. If the lower-numbered criteria in the list allow traffic, the higher-numbered criteria are not considered. The practice is to enter the command deny 0.0.0.0 at the end of the list, which prohibits all traffic. In this way, it is ensured that the network device does not forward traffic that was not previously defined by the operator.

Protection of a certain level can be configured on any device, but there are also devices for which protection is the main task. A firewall is a device or software that monitors, filters, and controls traffic between two devices. It is placed between a protected and an unprotected network, and makes decisions based on predefined criteria. Their functioning is not limited to one layer of the OSI model, and the possibility of traffic inspection even allows the interruption of the traffic flow upon detection of a prohibited string of characters within the text file. The firewall analyzes the traffic according to various parameters, which makes the effective use of these devices very complex. Protection as well as the attacks are becoming more and more complicated, especially with the introduction of artificial intelligence in this fight. The analysis of techniques that can be applied in protective walls will not be covered in this paper.

Traffic often goes beyond the reach of the locally owned network. In the event that sensitive information must be transmitted through a part of

the network over which we have no control, that traffic needs to be protected. The set of protocols of the third layer of the OSI model used for these purposes is called IPSec (IP Security). It has a dual function: it confirms the identity of the other communication participant and ensures that the traffic between the two participants remains unknown to all other devices that forward that traffic. The first function is provided by the Authentication Header protocol. AH prevents data from packet headers from being altered and verifies the identity of the other participant using a hash calculated based on the original header and a key known only to the end participants. The key exchange algorithm (IKE (Internet Key Exchange)) will not be given attention in this paper. The role of traffic encryption is performed by the ESP (Encapsulating Security Payload) protocol. It can be realized in two ways. It is possible to encrypt only the useful information without the header or the entire packet. These two modes of operation of the IPSec group of protocols are called transport type and tunnel type. In addition to encryption, ESP also offers authentication. The difference between AH and ESP is that the first protocol performs authentication taking into account the content of the entire packet, while the second protocol uses only information from the header for authentication. IPSec is the basis for various implementations of VPNs, which will be discussed in the next chapter.

```
!
interface GigabitEthernet1/0/3
 switchport mode trunk
 switchport port-security maximum 5
 switchport port-security
 switchport port-security violation restrict
 switchport port-security mac-address sticky
 switchport port-security mac-address sticky bcc3.4252.8c68
!
interface GigabitEthernet1/0/4
 switchport access vlan 10
 switchport mode access
 switchport port-security maximum 5
 switchport port-security
 switchport port-security violation restrict
 switchport port-security mac-address sticky
 switchport port-security mac-address sticky bcc3.4252.8c7a
!
```

Figure 19 – Switch security configuration

VPN tunneling and the Internet

A virtual private network (VPN) is a technology that allows users to protect and hide traffic passing through an unprotected part of the network. It is based on the principles of authentication and encryption, functions for

which implementation uses different protocols. The most famous VPN solutions basically work on IPSec, SSL/TLS, OpenVPN and WireGuard protocols (Singh et al, 2014). In this paper, their specificities will not be considered.

VPNs are used for various purposes, such as providing anonymity on the Internet, bypassing location restrictions, remote access, and the like. In this paper, attention is paid to VPN tunneling, i.e. establishing a protected connection between two devices connected by an unprotected network. VPN tunnels can be established with or without a VPN server. By using a VPN server, the system is centralized, but also easier to configure. This is the most common implementation of virtual private networks. The server establishes tunnels, encrypts and decrypts traffic between users. VPN servers can be run on the Internet or independently. OpenVPN is one such software, offering the option of using their own servers or running your own. It is an open-source application, which means that it can also be used for military purposes without security risks[1], with prior testing and modification of the algorithm for additional protection. Depending on the amount of traffic that passes through the VPN server, the function of the server can also be performed by a personal computer. In the case of tunnel implementation using a server, the traffic of all computers in the local network that communicate with devices at another location through the Internet would be processed in the server. This implementation is called a "site-to-site" VPN tunnel. Another way of using it is called "point-to-point". In this embodiment, each user establishes its own tunnel with another user. The advantage of this method is that it is not necessary to use a server computer, but configuring individual tunnels is more complex. The use of the Internet to transmit military traffic using upgraded commercial technologies to achieve secure tunnels is already widespread in foreign militaries, depending on the cryptographic value of the traffic.

Conclusion

In this paper, the implementation of a VoIP phone system is analyzed and demonstrated. The system was implemented using commercial solutions of newer and older production. During the realization of the

[1] The TETRA radio system, used by many government institutions around the world, including the Ministry of Defense, has an encryption algorithm that was publicly revealed at the end of 2020. In January 2021, a team of researchers discovered a number of risks, perhaps the most dangerous of which is a backdoor. Exploitation of this "deliberate" security flaw weakens the 80-bit key to just 32 bits, allowing even commercially available systems to "break" the encryption with a brute-force attack in less than a minute

system, due to technical and time constraints, it was not possible to implement certain functionalities, which were therefore considered from the theoretical side. The implemented system represents the basis for the development of new and complex solutions that would increase the properties of scalability, protection, redundancy, ease of installation and administration, and introduce many other benefits. By analyzing existing commercial solutions, one can create an insight into the advantages, disadvantages, challenges and limitations that the introduction of such a system into use in the Serbian Armed Forces would achieve.

The existing telephone system in the Serbian Army is a mixture of analog and ISDN systems. VoIP telephony represents a step towards a future that brings better quality, more efficient communication. This path to the future is not without its challenges, both of a technical, organizational and logistical nature. The current infrastructure of the stationary component of the telecommunications and information system of the Serbian Army does not support the introduction of such a system in its entirety, but with certain adaptations, this system would be easily adapted to the existing solutions implemented in the mobile component, i.e. PKČ. Bearing in mind that there is already an L3 (Layer 3) switch and a computer located in the vehicle cabin, for the implementation of this system, depending on the number of users, there would be no need for any hardware changes. This system is very flexible, to use the basic telephone service, only one switch is needed, a computer that would function as a server, and a VoIP phone or a combination of a handset and a microphone in case of running a software phone on the user's computer. To implement more advanced functionalities, it would be enough to add one router, switch and firewall to the vehicle.

Within the existing computer network, the only requirements before introducing such a system would be operator and user training. The system is highly modular and can be run on a variety of hardware, which is another logistical benefit. The protection of such a system can be achieved on different layers, by combining different technologies. The ability to safely use existing civilian infrastructure for military communications purposes is an enticing aspect of this project that also deserves attention.

Introducing VoIP telephony in the SAF will be a big and challenging feat. However, following the trends in the development of commercial solutions and systems of foreign armed forces, such a feat seems inevitable. The purpose of this work is to serve as an introduction and basis for that technological transformation.

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Análisis de la conmutación de paquetes en telefonía VoIP en el puesto de mando de unidades de nivel táctico

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CAMPO: ciencias de computación, IT
TIPO DE ARTÍCULO: artículode revisión

Resumen:

Introducción/objetivo: Este artículo realiza un análisis integral de una posible implementación de sistemas de Voz sobre Protocolo de Internet (VoIP), centrándose en la arquitectura de red, los teléfonos VoIP y los servidores. El estudio explora posibles vulnerabilidades y propone soluciones. El documento concluye abogando por un enfoque holístico para proteger los sistemas VoIP, incorporando servicios complementarios para garantizar la confidencialidad, integridad y disponibilidad de las comunicaciones de voz en el panorama digital.

Métodos: Revisión de la teoría subyacente, análisis de las necesidades del usuario final y posibles soluciones, evaluación de la viabilidad práctica.

Resultados: Los puntos teóricos discutidos fueron probados en la práctica, utilizando recursos comercialmente disponibles. La comunicación se estableció de la manera esperada.

Conclusión: Implementar soluciones similares a la presentada en el documento sería una forma relativamente económica de realizar diversas mejoras en la operación de unidades de nivel táctico, tanto en tiempos de paz como durante la guerra.

Palabras claves: VoIP, comunicación en tiempo real, sesiones de voz, redes informáticas, SIP.

Анализ коммутации пакетов VoIP-телефонии в командном пункте тактического подразделения

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РУБРИКА ГРНТИ: 20.15.05 Информационные службы, сети, системы в целом
49.33.29 Сети связи
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: В данной статье проводится всесторонний анализ потенциального внедрения системы передачи голоса по интернет-протоколу (VoIP). В статье особое внимание уделяется сетевой архитектуре, телефонам VoIP и серверам. В статье исследуются потенциальные недостаткти и предлагаются определенные решения. В заключении отстаивается целостный подход к обеспечению безопасности системы VoIP, включающий дополнительные услуги для обеспечения конфиденциальности, целостности и доступности голосовой связи в цифровой среде.

Методы: В данной статье применены следующие методы: обзор основной теории, анализ потребностей пользователей, анализ потенциальных решений, оценка практической устойчивости.

Результаты: Обсуждаемые теоретические положения были подтверждены на практике при использовании имеющихся в продаже ресурсов. Связь была налажена в соответствии с ожиданиями.

Выводы: Внедрение решений, аналогичных представленному в статье, было бы относительно недорогим способом повышения эффективности деятельности тактических подразделений как в мирное время, так и во время войны.

Ключевые слова: VoIP, коммуникации в режиме реального времени, голосовые сеансы, компьютерная сеть, SIP.

Анализа пакетске комутације у VoIP телефонији на командном месту јединица тактичког нивоа

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ОБЛАСТ: рачунарске науке, телекомуникације, ИТ
КАТЕГОРИЈА (ТИП) ЧЛАНКА: прегледни рад

Сажетак:

Увод: У раду је спроведена темељна анализа могуће имплементације система Voice over Internet Protocol (VoIP), уз фокус на мрежну архитектуру, VoIP телефоне и сервере. Истражене су потенцијалне рањивости и предложена решења. Такође, препоручује се целисходан приступ обезбеђивању VoIP система, укључујући додатне услуге како би се осигурала поверљивост, интегритет и доступност гласовних комуникација у дигиталном окружењу.

Методе: У раду су презентовани: преглед основне теорије, анализа потреба крајњих корисника и потенцијалних решења, као и практична процена одрживости.

Резултати: Теоријске тачке о којима се расправљало доказане су у пракси, коришћењем комерцијално доступних ресурса. Комуникација је успостављена на очекиван начин.

Закључак: Имплементација решења сличних оном представљеном у раду био би релативно јефтин начин да се створе различита побољшања у деловању јединица тактичког нивоа, како у миру, тако и у рату.

Кључне речи: VoIP, комуникације у реалном времену, гласовне сесије, рачунарске мреже, SIP.

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Review of 5G and 6G applications for mobile wireless communication in the military environment

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Abstract:

Introduction/purpose: This paper seeks to provide a review of the applications of the fifth (5G) and the next, the sixth (6G), generation of mobile wireless communications in the military environment.

Methods: Analyzes and syntheses were used to consider various aspects, challenges, developments, and implementations of the fifth (5G) generation as well as the sixth (6G) generation mobile wireless communications for military purposes.

Results: The background and the state of the art of 5G and 6G mobile wireless communications are presented. Next, 5G military impact and initiatives are described. The paper also presents future prospectives of 6G for its usage in the military. Finally, possible 6G military applications are presented.

Conclusion: 5G had achieved the first deployment by 2020 and completed the first phase of its evolution in 2022. The 5G Advanced starts as a version towards the sixth generation in a way to find different solutions for implementation not only for commercial, but also for military purposes. With the platform approach to connectivity, 5G military networks contain different requirements, range of implementation options with spectral efficiency, latency, and reliability as primary performance metrics. Toward 6G, machine learning (ML) and artificial intelligence (AI) methods have proposed new approaches to modeling, design, optimization, and implementation in military systems.

Key words: the fifth generation (5G) technology, 5G military initiatives, the sixth generation (6G) technology, 6G military applications.

Introduction

Wireless communication systems belong to one of the most important mediums for information exchange and core communication for military relations, especially since 2020 when the fifth generation (5G) networks began with advancement changes worldwide. Today, it is a large evolving field with growing military applications in connection with the physical layer of radio links. The main idea is shifting towards system and application level optimization in order to obtain an improved performance for different, especially military, applications, taking into account that every object will have in built sensors to make decisions with the ability to communicate to every other object without human intervention. In this case, 5G networks represent a kind of infrastructure used to make all this a reality (Forbes, 2018) at ultra-low latency in an extremely dense environment (for example, 1000x more connected compared to a 4G network).

High reliability is also one important characteristic. To pave the way to superior capacity, spatial efficiency, and flexible operation to the next generation military operation wireless systems, new services are introduced. This is achieved by extending the next generation bandwidth and pushing up the transmission rate by coordinating resources across adjustment cells for reduced interference intense reuse of cellular networks and with mesh networking components as well as smart antennas technology for spatial multiple – based transmission (Rao et al, 2014). 5G will work on mm Wave band with directional antenna and beam forming techniques, shared spectrum access and provide super high speed full – duplex communications. These are some of the technologies common among commercial and military communications. It will become a key stone of future military technology. 5G communication will make the machine – to – machine (M2M) communication possible without requiring solutions or communication relay wire crafts. A significant research period in the academic community and industry contributed to the appearance of the next generation of wireless systems – 6G. Some parts of these 6G systems show that machine learning (MC) and artificial intelligence (AI) methods are significant for the protocols and the network architecture.

Background and state of the art

In every decade since 1980, there has been global standardization 3GPP for mobile communication, together with new generations of mobile standards. 1G was the first mobile generation, voice centric, with limited date capabilities in the 1980s. 2G was the first digital mobile communication voice-centric network with limited data capabilities in early

1990s. In 2003, 3G was the first wireless mobile data communication technology that enabled data streaming and mobile Internet access. The first all IP wireless data communication technology launched in 2008 was 4G. Packet switching and adaptation of IP protocols in 3G and 4G networks have led to the applications such as streaming, e-commerce, social networks games, etc. on mobile devices. Also, 5G enables massive Machine – Type communication (MTC) like D2D, Vehicle to Vehicle (V2V) or Vehicle to Infrastructure (V2I) Communications that will minimize the boundary between the digital and physical world (Rodrigez, 2015). Some advanced goals of 5G systems are presented in (Geller & Nair, 2018). They are ranging from 1 Gbps up to 20 Gbps, latency better than 1ms, massive connectivity at super high speed, 1000s of interconnected devices and 1000 x BW per limit are 100% coverage with 99.999% availability, high energy efficiency – 90% reduction in energy and up to 10-year battery life for machine type communications. Various applications can be classified into three domains such as: enhanced mobile broadband (eMBB), Massive Machine – Type Communications (MTC), and Ultra – Reliable Low Latency Connections (uRLLC). The target speed for eMBB platforms is with downloads better than 200 Mbps. Interconnected smart devices, vehicles, and IoT reduction in industrial equipment necessitate the development of metric MTC. The third application, uRLLC, serves for real-time data collection necessary for quick decision making.

To meet the above goals, there are some new technologies applied to 5G systems. For example, Heterogeneous Networks (Het Nets) serve by overlaying a cellular system with small cells of some technology, i.e. micro, pico or femto cells. Het Nets achieve a significantly better area spectral efficiency compared with previous networks. Massive Multi – Input Multi – Output (MIMO) technology is applied for multiple co-located antennas, up to a few hundred, to simultaneous serve/spatially multiple a number of users in the corresponding frequency resource. In the mm Wave, ultra-broadband wireless tapes can be provided due to the availability of spectrum. It should be noted that the smart antenna sizes ($\lambda/2$) and their small separations (around $\lambda/2$) will enable packing tens of antenna elements in one square centimeter. In twin, this will allow achieving very high beam forming gains in relatively small areas. Also, this can be implemented at the Base Stations (BS) and the User Equipment (UE) and improve the system capacity mm Wave, 1s being perceived as the most promising spectrum for further network due to support for massive MIMO and the availability of abundant spectrum in the corresponding frequency band (Bhardway, 2020).

Device – to – Device (D2D) communications enable efficient spectrum usage in 5G and efficiently upload traffic from BSs. The first challenge is in number of devices that need to be connected in large numbers (50 billion devices). The other challenge is for real time and remote control of mobile devices (such as vehicles) through the network and it requires extremely low latency of less than a millisecond. Tactile Internet that is targeting a 20 x latency improvement for 4G to 5G, could be a possible solution. Software – defined network (SDN) can provide logically centralized intelligence, programmability and abstraction so that scalability and flexibility of the network can be with a huge improvement, while cost can be significantly reduced (Agiwal et al, 2016).

Network Function Virtualization (NFV) allows the provisioning of virtual network functions in the network edge, sharing aspects of the Network as a service. These technologies in that way allow the implementation of network functions in software able to run independently of underlying server hardware (Fang el al, 2017).

Actual notation operation articles can be virtualized in a multi – version way, allowing services and functions to be reliably scaled as required. As a result, barriers associated with proprietary hardware are overcome, simplifying the deployment of novel network services. As for network slicing, it is the ability of the network to configure and run multiple logical networks as virtually independent business operations on a common physical infrastructure. Network slicing is a fundamental architecture component of the 5G network.

It is important to emphasize that 5G+ (advanced 5G) is expected to enter the market already during 2024.

Together with development, improvements and implementations of 5G technology, nowadays research community is developing 6G cutting edge technology which is expected to be even more revolutionary not only from the economic and commercial point of view, but also for military applications.

Many of the technologic and user case aspects of 5G are essential for building 6G and lead to applicable optimization and cost reduction.

The implemenatation of 6G has been originally planned to be ready by 2030, but the first applications for mobile telephony will be ready in 2026 (Telefonica, 2022).

6G smart architecture consist of autonomous networks that integrate networks from space through the air to the ground and underwater in order to provide continuous and unlimited wireless connectivity and services.

6G is expected to be able:

- to connect the world with virtual, augmented and mixed realities;

- to transmit holography applications in real time, in high definition and with virtually no latency;
- to have potential bitrate at 1 terabyte per second together with promising latency of only 0.1ms;
- to offer efficient and effective, but also secure communications between different type of devices;
- to work in conjunction with artificial intelligence (AI);
- to use higher frequencies and ranges than 5G networks, for example, to utilize the terahertz band of frequency and provide substantially higher capacity and much lower latency (to support one microsecond-latency communication);
- to connect digital, physical and human worlds;
- to provide greater security and privacy;
- to increase the number of simultaneous device connections;
- to substantially reduce energy consumption;
- to be used in the terahertz space communication segment; and
- to use innovative infrastructure and enhanced integration of "space-air-ground-sea communication technologies".

Important expectations from 6G will be a vastly superior bandwidth, extremely low latency, and high connectivity properties.

6G is expected to be suitable for a wide range of issues, such as advanced functions in portable devices compatible with XR (VR, AR, MR) devices, high definition images and holograms exceeding up to 8K and beyond, as well as sense communications involving tactile sense. Next, communications between human beings and between human and different things will be ultra-real and will introduce real-time holograms, as well as flying taxis and Internet-connected human's bodies and brains.

In order to provide services for many different types of equipment, 6G would be extending the coverage areas for drones, flying cars, ships, and space stations.

Technologies likely to be used in 6G are terahertz and space-air-ground integrated networks (SAGIN).

Finally, the terahertz (0.3 THz to 30 THz) radio frequency band has a real potential to be the next player in wireless communication in 6G as well.

5G military impact and initiatives

5G technologies will have a huge impact on military applications for autonomous vehicles, logistics, maintenance, training, AI (artificial

intelligence), augmented and virtual reality, and Intelligence, Surveillance, and Reconnaissance (ISR) systems capabilities for decision making in command and control (*C2*) as shown in Figure 1.

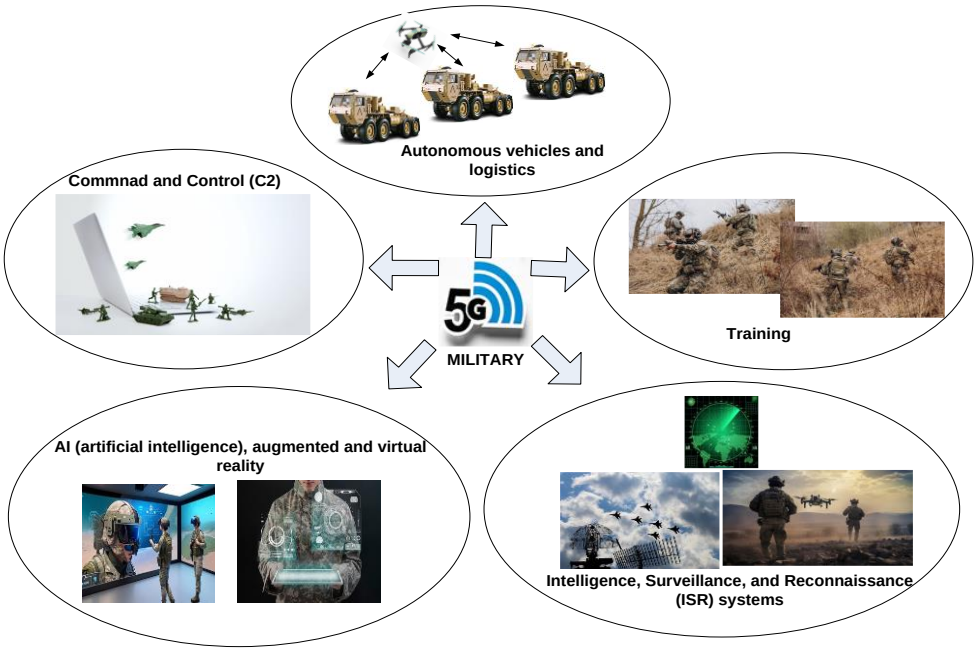

Figure 1 – 5G military applications

The key technology characteristics and improvements in 5G enable it to be more suitable for enhanced sharing of different services (data, video, locations, etc.) between and within military units or combat platforms, as well as command posts on battlefields without the threat of detection, jamming, eavesdropping, etc.

Secondly, interconnected with drone platforms, 5G will have a serious impact on military logistic schemes in order to provide precise delivery all necessary supplies for combat units in order to be sustainable on appropriate locations.

Next, close-range D2D communications supported by 5G will provide fast information sharing without necessity to use military relay stations.

Also, 5G supports interconnectivity of various platforms (sensors, drones, robots, vehicles, etc.) to reduce the response time in military operations, especially in emergency situations.

Next, the concept of smart bases will be possible because 5G will improve access control solutions and provide optimal deployment available resources in the base, as well as support sensors which provide perimeter security without the threat of enemies detecting its communications.

Finally, 5G will be an appropriate platform for telemedicine applications including remote surgery and healthcare in war operation zones (Bhardway, 2020).

In hypersonic weapons usage scenarios, 5G can be able to provide real-time connectivity to these weapons from ground stations as well as to detect them with air defense systems.

Standard 5G technologies are enhanced to connect many platforms and networks operated by various branches of armed services. This is the 5G military initiative (MIL). It has two complementary elements. The first element uses an open scenario: quick, ad hoc establishment of secure, local-based 5G technology. The final goal is to allow forces to take sensors data from any platform and to make it accessible to any shooter. There is no matter how the platform and the shooter are connected to the network (Walker et al, 2021).

Inside a hybrid base station, there is a series of systems, so-called tactical gateways. This will enable a base station to work using different communication protocols. Gateways consist of hardware and software based on military-presented open-architecture standards. These standards are characterised by the fact that they can enable a platform, e.g. a fighter jet, made by one contractor to communicate with a battery made by another supplier.

The second element of the 5G MIL involves connecting local mash networks to the global Internet. A connection between a local network and the wider Internet is known in practice as a backhaul. The connection might be on the ground or in space, i.e., between civilian and military counterparts. In that way, a software-defined virtual globe defense network is achieved.

It is of importance to note that software-defined treatment will allow networks to be reconfigured automatically while operating. It can be a huge challenge, since the network is formed virtually in order to provide the flexibility needed to deal with the exigency of the war. Automatically reconfigurable SDNs will make the need for an enormous video bandwidth in a certain area; different streams of data might need different levels of encryption as well as conveying targeting data in a great number of software programs running on the network.

A key element of 21st century strategy is to collaborate with innovative commercial companies to leverage their technologies for military applications. Technologies such as 5G AI, distributed cloud computing, and anatomy are highly applied. When the military goes to war, it brings its communications infrastructure with it.

One of the most important challenges in 5G is a key large number of interconnected devices with infrastructure with symmetric resources (size computational resources, power requirements, BW, etc.) to be used in a completely new paradigm of the IoT. To ascertain desired functionality, there are a lot of security challenges. For example, security of radio interfaces, security of networks, protecting against Denial of Service (DoS) attacks on the infrastructure, distributed control systems requiring coordination to prevent signaling storms, preventing DoS attacks on end-user devices, etc.

These challenges are highlighted by Next Generation Mobile Networks (NGMN) as well. Massive connectivity will increase the attack surface for the 5G network. Also, the impact of attacks will be seen more deeply. The main raisons are challenges in the containment of a successful attack, due to transit boundaries inter and intra-network arising out of logical separation using NFV as well as SDN of the underlying networking and processing infrastructure, rather than physical separation. Security has been always a major concern for wireless communications and with IP becoming the backbone of cellular communication all threats to an IP network become inherent to cellular networks.

A number of security threats and solutions have been presented by various authors, classified in terms of generic security requirements and applications of technology in perspective (Huawei, 2021; Abd-Elrahman et al, 2015).

Security threats and solutions have been classified broadly in categories such as: threats due to the wireless nature of the network, threats due to vast deployment of end-devices of diverse nature, and threats on information components such as base stations, servers, etc. 5G technology has the potential to make the concept of smart bases a reality. With the maturing of biometric technology, it can be deployed for automated and robust control.

6G military of the future

The terms 6G and 5G refer to the sixth and fifth-generation mobile wireless networks. It is well known that 5G networks have data transmission speeds greater than 4G invoked in 2009; 6G will have a

speed 10 times greater when compared to 5G. It means that 6G has a distinct technological and rich potential for military applications. The gradual application of military 6G might be one of the main focuses for the armed forces to adapt to future military changes. Thus, 6G has a rich potential for military applications (Center for Joint Warfare Studies, 2020).

Beyond data transmission speed, some other potential 6G benefits are better Internet access, high transmission rates, low delay and broad bandwidth delivering military advances: gathering intelligence, visualizing combat operations and precisely delivering logistical support. On the other hand, the commander could make right decisions quickly after the control-and-command network named, learned, and analyzed data from the battlefield.

Some countries published statements expressing their interest in using 6G networks to modernize their armed forces; however, 6G is still a theory. Many countries see 6G as an opportunity to transform their military operations at every level from equipment and war formations to battlefield communications.

6G is bringing the Internet of Military Things which refers to all the smart devices not frequently used in military areas. It should be noted that it ranges from sensing and actuating devices to devices that capture and can carry data. Of course, they are operational with 4G, while some of them need 5G. As for others, they will have to limit 6G to be developed and put into service. It is believed that the military will include smart city monitoring, logistics support, and other functions with the aim to make management as easy as possible.

6G can be the core technology for military strategic networks which consist of a large number of different platforms which could be floating in the space/near space, flying in the air, on the surface and in deep-diving-autonomous underwater vessels (Sakhuja, 2021), in order to conduct large scale surveillance, reconnaissance, and exploration.

6G can be a core architecture in a mix of manned and unmanned forces for better battle efficiency and efficient operational and logistics management.

Today, there is communications blackout at hypersonic speeds, so 6G can be a key technology to solve problems in hypersonic weapons programs.

Potential 6G military applications

In the open literature, there are the following most important fields for possible 6G military applications: battlefield communications, improved location services, and equipment development. The data speeds together

with coverage make a useful communication tool in high stakes environments. Higher communication rates lead to more effective operations, to shorter conflicts, and fewer lives lost.

One of 6G potential capabilities is to improve location detection to be accurate within centimeters, making at the same time technology such as autonomous vehicles practical. The other applications including drones or unmanned vehicles may be sent into dangerous environments. Also, some research notes that high-accuracy localization will improve radar technology as it relates to mobile devices.

The Internet of Things will allow the development of more intelligent autonomous military devices. Battlefields of the future will be populated by different things.

Keeping pace with rivals is one of the ways to ensure national security. Machines instead of humans, i.e. enabling more précise war operations, will affect the way wars are waged. In that way, it will be possible to reduce or eliminate accidents. Each of the noted applications has a potential to be used in waging wars as well as to be used in everyday life. People track research studies and developments even 5G is going to roll out (Bhardwaj, 2022). The 6G possible military use cases are shown in Figure 2.

6G will play a key role in the informatized environment for the military because:

- it would help develop state-of-the-art AI systems that can process vast amounts of data, which military devices receive from a multitude of sensors and sources necessary for their combat operations (Sakhuja, 2021),
- it will support real-time analytics in order to provide command personnel with solutions or courses of action based on the data receieved from military devices, cut latency, and extract the most appropriate data to enable an efficient response.

6G benefits would deliver military advances, such as gathering intelligence, visualizing combat operations, and delivering precise logistical support.

The military expects from 6G to provide fast, reliable and secure transfer of much larger amounts of data between rapidly moving military platforms, as well as high data transmission rates in the outer space for ballistic-missile early warning (Lee et al, 2022).

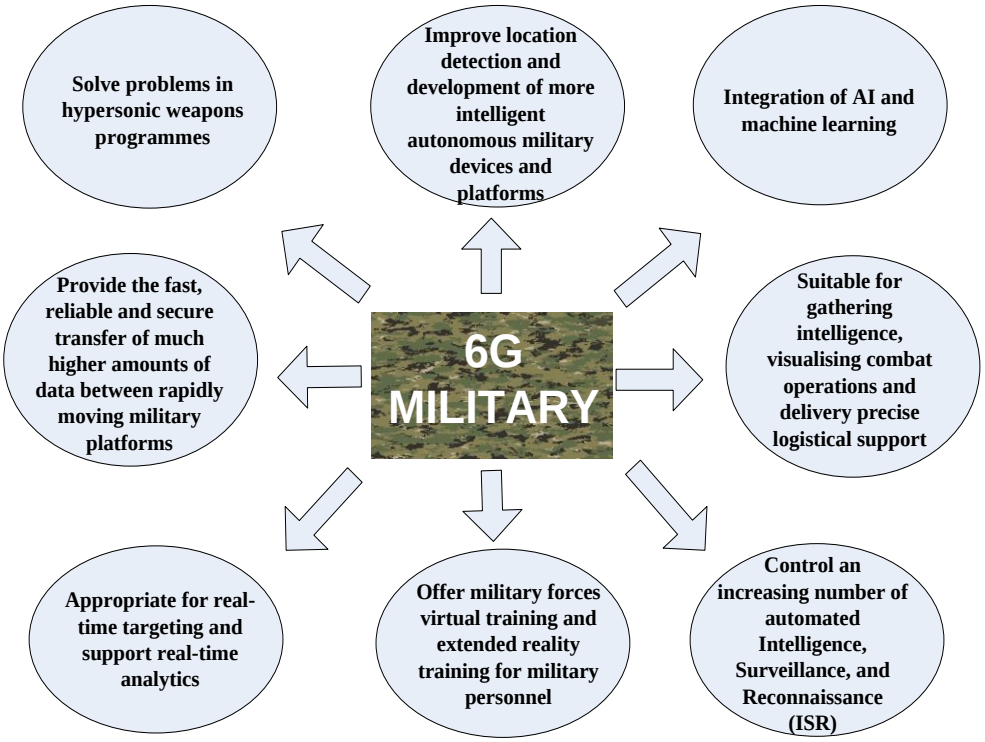

Figure 2 – 6G possible military use cases

On the other hand, at the tactical level, 6G would be appropriate for real-time targeting, AI-enabled decisions by the tactical level of command, and swift data exchange between sensors and combat shooters.

In addition to its possible use in weapons programs, the army is in a position to use big data to enhance command and control, defense mobilization, and finally decision making using integration of AI and machine learning across 6G applications.

In order to control an increasing number of automated Intelligence, Surveillance, and Reconnaissance (ISR) assets, 6G will be appropriate as technology for military's growing requirements to gather, analyse, and share information rapidly, as well as to effectively command geographically dispersed mobile forces (Uppal, 2023).

It should be added that 6G might offer military forces virtual training and extended reality training for military personnel; for example, it could significantly improve fighter pilot training, providing more realistic and

unpredictable scenarios that accurately reflect real combat situations (Hornada, 2022).

Conclusion

The fifth generation (5G) of mobile wireless networks had started with their first deployment by 2020 and completed their first phase of evolution in 2022. The platform in which there is a single standard that can adapt to the heterogeneous connectivity requirements of use cases is one of the most important characteristics of 5G networks. The following dimensions are characterized: faster and better mobile Internet access, low latency with high reliability, and a massive number of Internet of Things (IoT) devices. In validating its effectiveness in the military domain, the main difficulty is the fact that experiments and corresponding data are not completely available.

When applied to military communications, 5G is in a position to improve intelligence, surveillance and reconnaissance systems and processing, enabling new networks of command and control. Also, it is of great importance to provide security mechanisms at each layer in order to prevent attacks.

Today, there is a huge research interest in the academia and industry towards the next generation 6G (sixth generation) wireless systems. Some of the most important characteristics of 6G are machine learning (ML) and artificial intelligence (AI). A large number of connected devices and the network virtualization techniques will increase the potential attack surface. Machine learning forms part of AI. It enables a device to perform tasks without giving any special instructions.

ML and AI methods will play very important roles when analyzing the protocols and architecture of 6G. On the other hand, one of the most important characteristics of 5G is that it will support heterogeneous networks to serve voice, video and data, in addition to new intelligent services.

These services will be embedded by network device to Device (D2D) communications. 6G will give operators greater control over unmanned military machines that would play a leading role in future wars.

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Revisión de aplicaciones 5G y 6G para comunicaciones inalámbricas móviles en el entorno militar

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CAMPO: telecomunicaciones
TIPO DE ARTÍCULO: artículo de revisión

Resumen:

Introducción/objetivo: Este artículo busca proporcionar una revisión de las aplicaciones de la quinta (5G) y la próxima, sexta (6G), generación de comunicaciones inalámbricas móviles en el entorno militar.

Métodos: Se utilizaron análisis y síntesis para considerar diversos aspectos, desafíos, desarrollos e implementaciones de las comunicaciones inalámbricas móviles de quinta (5G) y sexta generación (6G) con fines militares.

Resultados: Se presentan los antecedentes y lom as avanzado de las comunicaciones inalámbricas móviles 5G y 6G. A continuación, se describen el impacto y las iniciativas militares del 5G. El documento también presenta las perspectivas futuras de 6G para su uso en el ejército. Finalmente, se presentan posibles aplicaciones militares del 6G.

Conclusión: 5G logó el primer despliegue en 2020 y completó la primera fase de su evolución en 2022. El 5G Advanced comienza como una versión hacia la sexta generación de manera de encontrar diferentes soluciones de implementación no solo para uso comercial, sino también para propósitos militares. Con el enfoque de plataforma para la conectividad, las redes militares 5G contienen diferentes requisitos, una variedad de opciones de implementación con eficiencia espectral, latencia y confiabilidad como principales métricas de rendimiento. Hacia el 6G, los métodos de aprendizaje automático (ML) y de inteligencia artificial (IA) han propuesto nuevos enfoques para el modelado, el diseño, la optimización y la implementación en sistemas militares.

Palabras claves: la tecnología de quinta generación (5G), iniciativas militares 5G, la tecnología de sexta generación (6G), aplicaciones militares 6G.

Обзор применения 5*G* и 6*G* в мобильной беспроводной связи в военной среде

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РУБРИКА ГРНТИ: 49.33.29 Сети связи
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: В данной статье представлен обзор применения мобильной беспроводной связи пятого (5G) и следующего шестого (6G) поколений в военной среде.

Методы: Анализы и синтезы использовались при рассмотрении различных аспектов, проблем, разработок и внедрения пятого (5G), а также шестого (6G) поколения мобильной беспроводной связи для военных целей.

Результаты: Сначала были представлены история и современное состояние мобильной беспроводной связи поколений 5G и 6G. Затем описаны военное влияние и возможности 5G. Также в статье

представлены будущие перспективы использования 6G в армии. И, наконец, представлены возможности 6G в военном применении.

Выводы: Первое развертывание сети 5G произошло в 2020 году, а его первая фаза эволюции была завершена в 2022 году. Продвинутая система сети 5G стартовала как версия шестого поколения для нахождения различных решений внедрения не только в коммерческих, но и в военных целях. С учетом платформенного подхода к подключению военные сети 5G отличаются различными требованиями и рядом вариантов применения. Причем спектральная эффективность, задержка и надежность являются основными показателями производительности сети. Возможности 6G, машинного обучения (МО) и искусственного интеллекта (ИИ) предлагают новые подходы к моделированию, проектированию, оптимизации и внедрению в военные системы.

Ключевые слова: технология пятого поколения (5G), военное применение 5G, технология шестого поколения (6G), военные приложения 6G.

Преглед примене 5Г и 6Г за мобилну бежичну комуникацију у војном окружењу

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ОБЛАСТ: телекомуникације
ВРСТА ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: У раду је приказна примена пете (5Г) и напредне шесте генерације (6Г) код мобилних бежичних комуникација у војном окружењу.

Методе: Анализе и синтезе су коришћене за разматрање различитих аспеката, изазова, развоја и примене пете генерације (5Г), као и шесте генерације (6Г) мобилних бежичних комуникација у војне сврхе.

Резултати: Представљена је позадина и стање мобилних бежичних комуникација 5Г и 6Г. Затим, описан је војни утицај и иницијативе код 5Г. Такође, у раду су представљене будуће перспективе 6Г за употребу у војсци, као и могућа примена 6Г.

Закључак: Пета генерација постигла је прву примену до 2020. године и завршила прву фазу еволуције 2022. године. Она покреће напредну верзију ка шестој генерацији на начин да пронађе

различита решења за примену не само у комерцијалне, већ и у војне сврхе. Са платформским приступом повезивању, 5Г војне мреже садрже различите захтеве, низ опција примене са спектралном ефикасношћу, кашњењем и поузданошћу као примарним показатељима перформанси. У правцу 6Г, методе машинског учења (МУ) и вештачке интелигенције (ВИ) предложиле су нове приступе моделовању, пројектовању, оптимизацији и примени у војним система.

Кључне речи: технологија пете генерације (5Г), војне иницијативе пете генерације (5Г), технологија шесте генерације (6Г), војне примене 6Г.

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Interaction between humans and computers: key aspects and evolution

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FIELD: information technology
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Abstract:

Introduction/purpose: The research aimed to analyze the key aspects of human-computer interaction, studying the evolution of this field from its beginnings to contemporary trends. Focusing on different aspects of this interaction, it studied how methods, technologies and principles have evolved over time and shaped our experiences in the digital environment.

Methods: The research methodology was based on the analysis of relevant literature and research papers devoted to human-computer interaction. Systematic review and evaluation of sources identified the key information on the evolution of user interaction with computers. Through evaluation of available studies, changes in interface design methods, interaction technologies and understanding of user needs over time were identified.

Results: Based on data synthesis, the key aspects of human-computer interaction were identified. An analysis of the literature revealed changes in interface design methods, interaction technologies, and understanding of user needs over time. Specific results included information on the evolution of interaction aspects, including improvements in efficiency, intuitiveness and personalization of experiences.

Conclusion: The key conclusion of the research is that innovations and evolution of technology have significantly influenced the way users interact with computer systems. Improvements in interface design, recognition technologies, and personalization of experiences are key factors in creating better user experiences and optimizing human-computer interaction. The research points to the continuous development and changes in the field of

human-computer interaction, emphasizing the need for further research and innovation in this area.

Key words: human-computer interaction (HCI), graphical user interfaces (GUI), user experience (UX), internet revolution, mobile revolution.

Introduction

The interaction between humans and computers is becoming ubiquitous in today's society, defining the way we communicate, work, and entertain ourselves. This paper explores the key aspects of this interaction and examines how it has evolved over time.

The development of human-computer interaction represents an impressive journey through time, shaped by key technological milestones and societal changes. The pioneering period in the history of computers, spanning from 1940 to 1950, marks the onset of the computer era and the development of the first digital computers. This period is characterized by experiments, pioneering work, and radical innovations in the field of computer technologies (Rojas, 2002).

The transition to programming (1950-1960) signifies the second phase in the history of computers, bringing significant changes in the approach to programming and computer usage. During this period, computers became prevalent in scientific and business communities, and programming evolved from low-level machine language to the use of high-level programming languages (Campbell-Kelly, 2007).

Starting from the early computers, interaction took place through command lines, leading to the development of graphical user interfaces (GUI) that facilitated interaction. The evolution also includes the development of mobile devices, virtual reality, and other interfaces.

The era of graphical user interfaces from 1980 to 1990 marks a period in which computers shifted from textual interfaces to visually richer user interfaces, significantly changing how people interacted with computers (Engelbart, 1962).

The Internet revolution (1990-2000) signifies a period of rapid growth, development, and commercialization of the Internet. During this decade-long period, the Internet transformed from an academic and military network into a global phenomenon that changed the way people communicate, work, and access information (Berners-Lee, 1989).

The mobile revolution (2000-2010) represents a period of significant development in mobile technology, bringing numerous innovations such as smartphones, mobile applications, broadband Internet access, and changing the way people communicate and use mobile devices (Jobs, 2007).

The era of artificial intelligence (AI) and virtual reality (VR) from 2010 to the present day is marked by accelerated progress in the field of artificial intelligence, machine learning, deep learning, as well as the development of VR and augmented reality (AR) technologies (Goodfellow et al, 2016).

Historical context of human-computer interaction

The evolution of human-computer interaction represents an impressive journey marked by constant technological innovation. This chapter highlights the key moments in the history of this relationship and provides insight into how technological breakthroughs shaped our ability to communicate with computers.

Early computer systems (1940-1950)

In the early decades of the computer era, interaction with computers was limited to physical connections and programming via punched cards. ENIAC, constructed at the University of Pennsylvania, was the first general-purpose digital computer.

ENIAC was one of the earliest large-scale computers, where communication with the machine was rudimentary and required direct manipulation (Rojas, 2002). Physically, ENIAC was immense by contemporary computer standards, aimed at performing mathematical operations faster than humans.

It comprised 17,468 vacuum tubes, 7,200 crystal diodes, 1,500 relays, 70,000 resistors, 10,000 capacitors, and around 5 million hand-soldered joints. It weighed about 27 tons, measured 2.4 m by 0.9 m by 30 m, occupying 167 m2 and consuming 150 kW of power. It was capable of conducting a wide range of numerical computations. Interaction with ENIAC during this period was quite limited. Programming involved physical connections and system configuration using switches and cables. Each program was literally constructed manually, often requiring significant effort.

Mark I, built at Harvard University, was one of the first electromechanical computers. It resulted from the collaboration between Harvard University, IBM, and the U.S. Navy. It used electromechanical components, including electric motors, switches, and electromagnetic circuits. It was designed to solve mathematical problems and generate ballistic tables. Interaction with Mark I was similar to ENIAC, where operators had to set up and configure physical components for each computed operation.

During the pioneering period, programming occurred at a low level, directly manipulating machine language. Programmers needed a deep understanding of hardware specifics. Programs were often written on paper and then manually translated into machine code. This phase demanded precision and patience from programmers. The pioneering period laid the groundwork for computer technology. ENIAC and Mark I represented the initial steps toward the digital age, opening doors to unprecedented computing capabilities. Experiences during this period served as the foundation for the development of subsequent generations of computers, gradually improving performance, size, and accessibility.

The pioneering period marked pioneering efforts in the field of computing, laying the groundwork for later developments that would define modern information technologies. Interaction with computers during this period was raw and physically demanding but set the stage for the technological revolution that would follow.

Development of programming languages (1950-1960)

The introduction of programming languages like Fortran and COBOL marked a key phase of abstraction. Programmers could now communicate with computers in a language more akin to human language, laying the foundation for the development of modern programming methods (Campbell-Kelly, 2007). Here is a more detailed overview of this period:

1) Development of programming languages: In the earlier pioneering period, programming relied on machine language, direct hardware control. Assembler was the first step toward abstraction, enabling programmers to use mnemonic labels instead of binary instructions. In the mid-1950s, the first high-level programming languages were developed. Fortran (Formula Translation) was aimed at scientific computations, while COBOL (Common Business-Oriented Language) was designed for business applications. These languages allowed programmers to write code at a higher level of abstraction.
2) Commercial use of computers: During this era, IBM introduced the System/360, the first family of compatible computers of varying capacities. This allowed companies to scale their computing resources more easily. The development of input and output peripheral devices was significant during this period. Computers acquired keyboards, screens, and other devices that facilitated user-machine communication.
3) Operating systems: Early versions of operating systems dealt with batch processing, where tasks were predefined and executed in groups. This improved data processing efficiency. The first operating

systems like IBM's OS/360 introduced concepts such as multitasking, virtual memory, and resource management, enhancing computer usage efficiency.

4) University influence: Universities became key players in computer science development. Educators and students contributed to the development of new technologies, and research became a fundamental component of the academic world. This period also saw the development of theoretical foundations of computer science, including work on algorithms, complexity theory, and formal languages.
5) Increased accessibility: The development of miniaturized computers during this period allowed smaller organizations and institutions to access computer technology. Commercial use and increased availability of computers contributed to the development of the computer products and services market.
6) Transition to programming: The development of high-level programming languages and operating systems made programming more efficient, allowing programmers to focus on application logic rather than hardware details. The development of academic computer science during this period laid the groundwork for further research and innovation in the field of computing. The transition to programming meant the expansion of computer technology into various societal sectors, from business to the academic community.

The transition to programming from 1950 to 1960 was pivotal in shaping modern computing, introducing high-level programming languages, operating systems, and expanding the use of computers into various fields. These changes laid the groundwork for further developments in information technology.

Appearance of graphical user interfaces (1980-1990)

Entering the eighties, the development of Graphical User Interfaces (GUIs) brought a revolution in human-computer interaction. Xerox PARC pioneered in this field, while Apple, with its Macintosh computer, introduced GUIs to the broader audience, making interaction visually rich and intuitive (Engelbart, 1962). Here is a detailed overview of this era:

1) Development of graphical user interfaces: The development of GUIs began at Xerox Palo Alto Research Center (PARC) in the 1970s. Concepts like the mouse, icons, and windows were developed in this environment. Apple commercialized GUIs for the first time with the Apple Lisa computer in 1983, followed by the more popular Macintosh

computer in 1984. These computers featured user interfaces with icons, a mouse, and drag-and-drop functionalities.

2) Operating systems with graphical interfaces: Microsoft started developing the Windows operating system, with its first release (Windows 1.0) in 1985. The evolution of Windows led to broader acceptance of graphical interfaces on personal computers. Apple's Macintosh System Software continued to evolve, enhancing its user interfaces and introducing new features.
3) Graphic design and user experience: This era witnessed the development of Desktop Publishing software, enabling users to create professional documents, brochures, and other graphic-rich materials. Launched in 1988, Adobe Photoshop became the standard in image processing and graphic design, setting the foundation for digital image manipulation.
4) Internet and WWW: The development of graphical web browsers like Mosaic (1993) and Netscape Navigator (1994) significantly facilitated users' access to the World Wide Web. Incorporating images, graphics, and other graphical elements into web pages added a visual dimension to the online experience.
5) Multimedia and video games: Computers became increasingly capable of reproducing sound, video content, and interactive multimedia applications. GUIs became crucial for the development of video games, and the popularity of gaming grew with computers' advanced graphic capabilities.
6) Significance for user experience: Graphical User Interfaces made computer usage more accessible to a wider audience, enabling quicker and easier interactions. Visual elements like icons and windows allowed users to interact with software more efficiently.

Features like drag-and-drop functionality, contextual menus, and other innovations changed the way users interacted with software. The era of Graphical User Interfaces marked the transition from text-based to visually oriented interfaces, allowing for a more intuitive and accessible interaction with computers. This period had long-term effects on how we use and perceive computers today.

Development of personal computers and the Internet (1990-2000)

The widespread adoption of personal computers and the expansion of the Internet transformed how people communicate and work. Web browsers, email, and other online platforms became an integral part of

everyday life (Berners-Lee, 1989). A detailed overview of the Internet Revolution from 1990 to 2000 is provided further below:

1) Development of the World Wide Web (WWW): Tim Berners-Lee, working at CERN, introduced the concept of the World Wide Web in 1990, using HTTP (Hypertext Transfer Protocol) and HTML (Hypertext Markup Language) to create interconnected pages on the Internet. The development of the first web browsers like Mosaic (1993) and Netscape Navigator (1994) enabled easier access and browsing of web pages.
2) Commercialization of the Internet: Advancements in secure online transactions and the creation of SSL (Secure Sockets Layer) facilitated the emergence of e-commerce. Amazon was founded in 1994, and eBay in 1995. The Dot-com boom, the expansion of Internet companies in the late 1990s, led to significant investments in Internet startups, often without actual profits.
3) Global expansion of the Internet: The development of commercial Internet Service Providers (ISPs) allowed widespread access to the Internet for individuals and businesses. The Internet became a global network, and technologies like email, chat, and video conferencing enhanced communication among people worldwide.
4) Development of technologies and standards: Internet Protocols (IP) became the standard, and IPv6 (Internet Protocol version 6) began to be introduced to overcome the IP address shortage. The proliferation of high-speed Internet access through broadband connections improved the speed and quality of Internet connections.
5) Multimedia development and web applications: The development of streaming technologies allowed users to consume audio and video content directly over the Internet. The development of web applications, along with JavaScript and other technologies, enabled dynamic and interactive functionalities on web pages.
6) Cultural influence: The first social networking sites like Six Degrees (1997) and Friendster (2002) emerged, enhancing online social interaction. The Internet became a key platform for sharing information, arts, and cultural content, leading to the formation of digital culture.
7) Challenges and issues: The expansion of Internet companies culminated in the Dot-com bust in 2000, leading to the collapse of many dot-com businesses. Increased online activity resulted in heightened security challenges, including cyber-attacks, identity theft, and other threats.

The Internet revolution from 1990 to 2000 transformed the way we live and work, opening doors to global communication, a digital economy, and new forms of cultural interaction. This period marked the transition of the Internet from an academic and military network to a universally accepted and indispensable part of everyday life.

Mobile revolution (2000-2010)

Entering the 21st century, smartphones and tablets became indispensable. Touchscreens, sensors, and mobile applications became crucial for everyday interaction, enabling people to communicate with computers anywhere, anytime (Jobs, 2007). Here is a detailed overview of this period:

1) Emergence of smartphones: Apple launched the iPhone in 2007, introducing the concept of a smartphone with an intuitive graphical user interface. The iOS operating system allowed third-party applications. Google responded by launching the Android platform, an open operating system for smartphones, leading to device and application diversity.
2) Rise of mobile applications: The Apple App Store was launched in 2008, followed soon after by Google Play (then Android Market). These platforms facilitated the proliferation of mobile applications. Mobile devices became pivotal for accessing social networks, with Facebook, Twitter, and others adapting to the mobile environment.
3) Development of mobile networks: The introduction of 3G (third generation) and later 4G (fourth generation) mobile networks improved data transmission speed and enabled high-quality multimedia content. The expansion of Wi-Fi and Bluetooth technologies allowed faster and more flexible connections of mobile devices to the Internet and other devices.
4) Mobile multimedia: Smartphones became equipped with increasingly better cameras, changing how people capture moments and share photos. The development of music and video streaming services allowed users to access rich content directly from their mobile devices.
5) Navigation and location: Built-in GPS sensors in smartphones enabled precise navigation and the creation of location-based services like Google Maps. Location-based apps became crucial, including services like geocaching, local guides, and social networks.
6) Social and business mobility: Mobile applications enabled remote work and access to business tools such as email and video conferencing. Social interactions shifted to mobile platforms, allowing constant connectivity and real-time sharing of moments.

7) Sustainable growth in the mobile device market: Increased sales of mobile devices: Mobile devices became ubiquitous, and sales rapidly grew worldwide.
8) Innovations in design: Mobile device design became the focus of innovation, including touch-sensitive screens, thinner profiles, and advanced features.
9) The mobile revolution from 2000 to 2010 transformed the way people communicate, work, entertain, and use technology.

This period marks key milestones in mobile technology that laid the groundwork for further smart device development.

The era of artificial intelligence and virtual reality (2010-present)

In the past decade, the focus shifted towards interacting with artificial intelligence. Voice commands, facial recognition, and gestures have become ubiquitous, while the development of virtual reality opens new dimensions of interaction (Goodfellow et al, 2016). Here is a detailed overview of this period:

1) Advances in artificial intelligence: The development of deep learning became a key component of AI, enabling systems to learn complex patterns from large datasets. The application of machine learning expanded across various industries, including healthcare, finance, manufacturing, and marketing. The development of cloud computing provided access to powerful computing resources needed for training and implementing AI models.
2) Development of virtual reality and augmented reality: The development of consumer VR and AR devices, like Oculus Rift, HTC Vive, Microsoft HoloLens, among others, allowed a wider audience to experience these technologies. VR and AR were used in education, medicine, engineering, as well as in business scenarios like virtual meetings and employee training. The development of virtual worlds allowed users to fully immerse themselves in digital environments, contributing to the gaming industry and simulations.
3) Autonomous vehicles and AI in traffic: AI and machine learning play a crucial role in the development of autonomous vehicles, representing a revolution in transportation. Integrating artificial intelligence into infrastructure systems contributes to the development of smart cities with improved efficiency and safety.
4) Growth of ethical issues and regulations: The increased use of AI has raised important ethical issues, including privacy, discrimination, and

responsibility. The development of regulatory frameworks and guidelines attempts to regulate the use of artificial intelligence in various sectors.

5) AI in healthcare: The development of AI enabled personalized medicine with tailored therapies and diagnoses. AI is used to analyze large datasets in the healthcare sector, identify patterns, and enhance diagnostic procedures.
6) Development of quantum computing: Although still in the experimental phase, the development of quantum computing promises a revolution in computing capacity and speed.
7) Artificial intelligence in networking and security: AI is used for detecting and preventing cyber-attacks, providing an additional layer of security. Artificial intelligence helps optimize network performance and resource management.

The era of artificial intelligence and virtual reality from 2010 until now has been marked by rapid technological advancements, creating new possibilities and challenges for society. This period continues to shape the way we use technology and interact with the digital world.

The path to intuitive interaction

The history of human-computer interaction testifies to a continual quest for more intuitive modes of communication and more efficient methods of using technology, aimed at enhancing user experience and facilitating interaction between humans and machines.

This detailed retrospective demonstrates how the steps in human-computer interaction have been marked by technological innovations often intertwined with societal changes. Each phase has brought new challenges and possibilities, shaping the modern paradigm of interaction that we know today.

Intuitive interaction refers to the mode of communication between users and technological systems that is natural, easy to understand, and requires minimal effort. This is often achieved through user interface design and technology that mimics natural human abilities and behavioral patterns.

Below, several key aspects of intuitive interaction will be presented:

1) Ease of use: Intuitive interaction demands minimal learning and training for users to effectively utilize the system. It is designed to provide users with quick access to functions and tools. It employs recognizable symbols, icons, and behavioral patterns familiar to users

from everyday life, thereby reducing the need for additional explanations. The work of Norman (2002) discusses how the design of objects around us impacts our daily experience, focusing on design concepts that facilitate or hinder the use of objects and technology in everyday life. In the book by Preece, Rogers, and Sharp (Preece et al, 2015), the design of interactions between humans and computer systems is explored, covering a wide range of interface design topics, including principles, techniques, and processes for creating efficient interactive systems.

2) Response to user actions: Intuitive systems respond quickly and consistently to user actions, providing a sense of immediacy and control. They offer clear feedback to users about what is happening in the system after their actions. This can include visual indicators, sound signals, or other forms of notification. The book by Shneiderman et al. (2016) provides strategies for effectively designing interfaces between people and computer systems, covering the basics of user interface design and focusing on strategies to enhance interaction. Furthermore, the book by Cooper et al. (2007) is a guide to essential principles of interaction design, highlighting key concepts of interaction between people and technology to achieve a better user experience.
3) Natural interactions: Implementation of voice recognition technology allows users to communicate with the system through verbal commands. Touch-sensitive screens and technologies like gestures enable users to interact with the device in a manner similar to real-world communication. The book by Dix et al. (2004) provides a broad overview of interaction between humans and computer systems, covering topics such as interface design, evaluation of user experience, and theories underlying human-computer interaction.
4) Personalization and contextual awareness: Intuitive systems can adapt to user preferences and behavior, offering a personalized experience. Through context analysis, systems can better understand user needs and provide relevant information or functionalities at a given moment (Norman, 2002; Cooper et al, 2007).
5) Use of visual metaphors: Employing visual metaphors helps users understand system functionalities more quickly. Examples include icons representing real objects or operations. Intuitive interaction often involves elements that resemble real objects or processes to facilitate understanding (Shneiderman et al, 2016).

Intuitive interaction plays a crucial role in enhancing user experience, especially in an era where technology is becoming ubiquitous. This

approach not only facilitates system usage but also increases the adoption of new technologies among different users.

Principles of user experience design

User Experience (UX) design has become crucial for the success of human-computer interaction and is a key factor in creating innovative and efficient digital products.

This section of the work will analyze the fundamental principles of user experience design, emphasizing their importance in creating positive interactions between users and technology. Principles such as ease of use, consistency, and intuitiveness play a crucial role in creating a positive user experience.

1) Clarity and simplicity principle
   The central principle of UX design is clarity and simplicity. Designers should create interfaces that are intuitive, easily understandable, and unburdened by unnecessary information. This principle helps users quickly understand how to use a product without unnecessary difficulties. One of the fundamental principles of UX design is clarity and simplicity, as evident in Krug's book "Don't Make Me Think" (Krug, 2014). Krug argues that interfaces should be intuitive and reduce the user's mental effort, making them clear and simple.
2) Consistency principle
   Don Norman, in his work "The Design of Everyday Things" (Norman, 2002), emphasizes the importance of consistency in design, arguing that users should recognize patterns and expect consistency in interfaces for better understanding. Consistency is crucial for maintaining user trust. Elements such as icons, colors, and layout should be consistent throughout the product. Consistency aids users in recognition and expectation, creating a unified experience.
3) User contribution
   Principle Good UX design should ensure that the product contributes to users, helping them achieve their goals. A user-centered approach involves understanding user needs and adapting the design to meet these needs. Jeff Gothelf and Josh Seiden in the book "Lean UX" (Gothelf & Seiden, 2013) advocate an approach oriented towards users and creating value for them. This principle connects design with real user needs, creating products that contribute to their goals.
4) Trust and security principle
   Kim Goodwin, in the book "Designing for the Digital Age" (Goodwin, 2009), explores aspects of trust and security in UX design. Goodwin

highlights the importance of creating designs that instill user confidence in the digital environment. Security is a critical component of UX design, especially in a digital environment where user data is frequently processed. Designers must ensure that users have confidence in the product and a clear understanding of security measures.

5) User-centric principle
This principle emphasizes the importance of placing users at the center of design. Designers should conduct user research to gain a deep understanding of their needs, behaviors, and goals. This allows for the creation of personalized and relevant experiences. Jakob Nielsen, in the book "Usability Engineering" (Nielsen, 1993), lays out the basic guidelines for user research and an approach focused on their needs to create a usable product.
6) Accessibility principle
Good UX design should be accessible to everyone, including individuals with different abilities. Designers should consider proper contrast, font size, navigation, and other aspects to enable access to the product for all users. "Inclusive Design Patterns" (Pickering, 2016) by Heydon Pickering provides guidelines on creating accessible digital products that offer equal accessibility to users with different abilities.
7) Innovation and adaptability principle
While consistency and clarity are important, UX design also requires innovation and adaptability. Designers should explore new technologies, trends, and interaction methods to improve the user experience and remain relevant. Tom and David Kelley in the book "Creative Confidence" (Kelley & Kelley, 2013) present innovation and adaptability as a key principle for maintaining relevance in UX design.

The combination of these principles forms the basis for creating UX design that not only meets but exceeds user expectations. Proper implementation of these principles creates lasting relationships between users and products, enabling them to have a positive experience and achieve design goals.

Types of interaction

There are several different types of interaction, each with its own specifics and applications in various contexts. Here is a detailed overview of some classical types of interaction:

1) Physical interaction

Physical interaction refers to the direct physical manipulation of objects or systems. The study by Wensveen, Djajadiningrat & Overbeeke (Wensveen et al, 2004) explores the ways physical interactions can be linked to functionalities through feedback. It focuses on developing frameworks that allow aligning user actions with functions through feedback and previous information. Examples of physical interaction include touching the screen on a smartphone or tablet, using a keyboard, mouse, or other devices on a computer, or manipulating physical objects in a virtual space using VR controllers.

2) Visual interaction
   Visual interaction focuses on the perception and reaction to visual elements. This encompasses elements such as icons, colors, graphics, and visual information. Ware's book (Ware, 2012) deals with perception in information design. It analyzes how people perceive visual information and how that understanding can be applied to the design of interactive systems. Examples of visual interaction include clicking on desktop icons, browsing and clicking elements on web pages, or using visual elements for navigation in a VR environment.
3) Voice interaction
   The development of voice assistants and speech recognition technologies has enabled verbal communication (Young et al, 2006). Voice interaction uses verbal communication between users and systems. The system can interpret and respond to voice commands. Examples of voice interaction include using virtual assistants like Siri, Google Assistant, or Amazon Alexa, voice commands in smart devices such as smart TVs or smart bulbs.
4) Gesture interaction
   Gesture interaction uses movements and gestures as a means of communicating with the system. This can involve hand, body movements, or other body parts (O'Conaill et al, 1993). Examples include using gestures on smartphones for zooming, rotating images, or opening applications or controlling video games through body movements, such as Kinect sensors.
5) Cognitive interaction
   Cognitive interaction relates to communication between users and systems through cognitive abilities, such as recognizing emotions, understanding intentions, or interpreting brain signals. Norman explores the design of everyday objects and how that design impacts our interactions (Norman, 2002). It focuses on design principles that facilitate or hinder the use of objects and technology. Examples of cognitive interaction include using devices that interpret brain signals

to control computers or devices, as well as systems that analyze user emotions for personalized user experiences.

6) Haptic interaction
   Haptic interaction uses tactile feedback to enhance interaction by giving users a sense of touch or pressure. This may involve vibrations, pressure, or other tactile feedback (Sears & Shneiderman, 1991). Examples include smartphone vibration as feedback for touching the screen, using vibrations in gaming controllers to simulate touch or impact.
7) Immersive interaction
   In a contemporary context, the term "immersive" describes an experience that fully engages the senses, creating a sense of complete immersion in a particular environment, situation, or activity. Immersive experiences typically involve intense user engagement, often through advanced technologies, to achieve a sense of reality or presence in a digital or real space. Bowman et al.'s book (2005) explores the theory and practice of interfaces in 3D space, focusing on the development and application of interactive systems using three-dimensional interfaces.

Applications of immersion can be seen in various contexts, including:

1) Virtual Reality (VR): VR technology provides an immersive experience by creating a digital world that users perceive as real. Users typically use VR headsets and headphones to fully immerse themselves in a virtual environment. Sherman & Craig's book (Sherman & Craig, 2002) deals with concepts and applications of virtual reality, exploring interfaces, applications, and design related to virtual reality.
2) Augmented Reality (AR): AR integrates digital elements into the real world, providing users with an immersive experience by combining real and virtual elements. Examples include smart glasses that project real-time information onto the real world.
3) Gaming: Immersive video games provide players with an intense experience through high-quality graphics, realistic sound, and technologies such as 3D effects.
4) Education: Immersive technologies are used in education to provide students with a realistic experience, such as virtual tours, simulations, and interactive lessons.
5) Film and television: The use of advanced technologies in movie and series production can create an immersive experience for viewers, including 3D effects, high-quality sound, and more.

6) Training and simulations: Immersion is often used in professional training and simulations, creating realistic environments to practice specific skills or situations.

Immersive experience creates an intense sense of presence and engagement, often enhancing the emotional and cognitive response of users. This concept often finds wide application in various industries and fields, especially where creating an authentic and profound experience is desired.

Immersive interaction refers to the user's interaction with digital environments or content in a way that provides an intense and immersed experience. This type of interaction is often associated with augmented reality, virtual reality, and other advanced technologies that enable users to experience the digital world in a deep and exciting way.

The key elements of immersive interaction include:

1) Virtual Reality: VR technology uses devices like VR headsets and headphones to provide users with a completely immersed experience in a digital world. Examples: Playing VR games, virtual tours through digitally reconstructed spaces, or educational simulations and training in a virtual environment.
2) Augmented Reality: AR integrates digital elements into the real world, providing users with a combined experience of the real and virtual. Examples: Using smart glasses that project real-time information onto the real world, applications that add digital layers of information to real objects or scenes.
3) Haptic feedback: Haptic feedback involves tactile feedback that allows users to feel touch, pressure, or vibrations during an immersive experience. Examples: Vibrations in controllers during VR gaming and haptic feedback when touching virtual objects in a VR environment.
4) Interaction with 3D content: Immersive interaction allows users to interact with three-dimensional objects and scenes, providing a deeper level of involvement. Examples: Rotating, moving, and manipulating 3D objects in a VR space or interacting with digital elements appearing in the real world via AR applications.
5) Contextual adaptation: Immersive interaction often involves adapting the user experience based on context, such as movement, location, or focus of vision. Examples: Changes in a virtual environment in response to user movements or information that automatically appears in the real world via AR based on the user's location.
6) Real-time and quick response: Immersive interaction requires real-time and fast responses to maintain a sense of reality during the user's

experience. Examples: Quick responses to head or body movements in a VR space or immediate changes in the real world recognizable through AR applications.

7) Combination of technologies: Immersive interaction often combines multiple technologies to achieve the most efficient and exciting experience. Examples: Using AR and VR in combination to explore real and virtual elements or integrating gestures, speech, and haptic feedback into a unified immersive experience.

Each of these types of interactions has its advantages and limitations, often used in combination to provide a richer and more efficient user experience. The diversity of these approaches allows users to choose the most suitable way of interaction depending on the context and preferences.

The impact of technology on society

The impact of technology on society has profound and complex consequences across various levels, including the economy, education, culture, social relationships, and other aspects of social life. Here is a more detailed overview:

1) Economic impact: Technology, including automation and artificial intelligence, can enhance efficiency and productivity but also raises questions regarding job losses (Brynjolfsson & McAfee, 2014). The development of online commerce and digital platforms is transforming how people buy and sell products (Laudon & Traver, 2019).
2) Educational changes: Digital technologies enable access to education via the Internet, bringing changes to teaching and learning methods. The COVID-19 pandemic further highlighted the role of technology in supporting remote learning (Hodges et al, 2020).
3) Social changes: The impact of social networks on communication, communities, and shaping public opinion (Boyd & Ellison, 2007). The emergence of digital divides between those with access to technology and those without can deepen social inequalities (Warschauer, 2003).
4) Cultural dynamics: Technological advancements support the development of digital art, introducing new forms of expression and distribution (Greene, 2004). The integration of technology into literary creativity, including interactive stories and e-books (Hayles, 2008).
5) Privacy and security: Growing concerns about data privacy protection in the digital environment (Solove, 2006). Challenges and threats of

cybersecurity in an increasingly connected digital world (Clarke & Knake, 2010).

6) Politics and activism: Technology significantly influences the organization and mobilization of social movements and activism (Earl & Kimport, 2011). The application of technology in political engagement and democratic processes (Coleman, 2012).

This extensive impact of technology on society represents a dynamic process with numerous aspects. Studying these impacts enables a better understanding of how technological advancements shape our society and raises questions that require careful consideration and regulation.

Ethical aspects of human-computer interaction

With the growing integration of technology into people's lives, issues of privacy, data security, and ethical technology use become increasingly important.

Ethical aspects of human-computer interaction play a crucial role in the design, development, and use of technology. These aspects encompass questions of fairness, privacy, transparency, security, and many other dimensions aimed at ensuring a positive impact of technology on society.

Here is a more detailed overview of some key ethical issues related to human-computer interaction:

1) Privacy:
   Questions: How does technology collect, store, and use users' personal data? How is transparency and control over this data ensured?
   Principles: Respect for privacy, implementation of security measures, informing users about data collection.
   Issues of privacy in technology have been explored in many works which discuss the challenges of digital privacy. Principles concerning privacy and data security are highlighted in the work of Craig and Ludloff (2011), which explores the relationship between privacy and big data.
2) Fairness and discrimination:
   Questions: Does technology promote injustice or discrimination, for instance, through algorithmic systems that may exhibit bias?
   Principles: Universal access, respect for diversity, fairness in algorithms.

Fairness issues in algorithms have been explored in works like (O'Neil, 2016), emphasizing how algorithms can contribute to inequality. Principles of universal access to technology are presented in the work of (Noble, 2018), addressing discrimination and search algorithms.

3) Transparency:
   Questions: How informed are users about how technology operates and what data is collected?
   Principles: Providing clear information about system operations, openness in design and decision-making.
   The book edited by Sorin Adam Matei, Martha Russell and Elisa Bertino (Matei et al, 2015) delves into the topic of transparency in social media, particularly examining how technology operates and what data is collected in the context of online interactions. This book explores tools, methods, and algorithms used for mediating online interactions, focusing on transparency in the functioning of social media systems. The authors investigate ways to provide clear information to users about how technology works, what information is collected, and how it is used in an online environment. The book promotes the idea of openness in design and decision-making, emphasizing the importance of transparency for social media users.
4) Security:
   Questions: How is technology protected from misuse and cyber-attacks? How is data and system integrity ensured?
   Principles: Implementation of strong security measures, regular system updates, responding to security threats.
   In the book (Singer & Friedman, 2014), the authors explore topics related to cyber-security and cyber-warfare. Focusing on a broad audience, the book addresses issues related to Internet security, cyber threats, strategies for protection against cyber-attacks, and the implications of cyber warfare on society. Authors examine the role of technology in the global cyber space, providing fundamental knowledge and guidelines on Internet security and cyber threats.
   Author Bruce Schneier, in the book (Schneier, 2016), investigates issues related to data privacy and the use of personal information. Schneier explores how data is collected, stored, and used in today's digital age, highlighting the issues associated with mass data collection by companies and government institutions. The book analyzes the impact of data collection on individual privacy and society, emphasizing dilemmas related to controlling personal information and protecting privacy in the digital world.
5) Accountability and oversight:

Questions: Who is responsible for the harm that may arise from the use of technology? How can adequate oversight and regulation be ensured?
Principles: Establishing responsibility, ethical conduct in technology development, regulations that protect users.
The book (De George, 2003) presents ethical aspects of information technology and business. The author explores moral and ethical dilemmas arising from the use of information technology in the context of business. It focuses on issues such as data privacy, information security, responsibility towards users, ethical dilemmas in managing information systems, and legal aspects of information technology. The book provides a theoretical framework for understanding ethical challenges in these areas.
The author addresses broader ethical and social issues in the information age in his book (Kizza, 2013). Through the analysis of ethical dilemmas in the information era, the author discusses issues such as data privacy, freedom of speech on the Internet, fairness in accessing information, ethical implications of artificial intelligence, and the implications of technological development on society. The book explores questions arising from the use of information technology, providing an analysis of its impact on society and individuals from ethical and social perspectives.

6) Dependency and social impact:
Questions: How does technology impact social relationships, mental health, and the overall well-being of society? Is there excessive dependence on technology?
Principles: Comprehensive approach to technology development, assessment of social impacts, promotion of healthy digital habits.
Adam Alter, in his book (Alter, 2017), explores the impact of technology on our behavior, focusing on how digital technologies have become irresistible and how the industry strives to keep us "hooked" to them. The author investigates psychological mechanisms and strategies that technology companies use to create products that are attractive and addictive. This book analyzes how digital technology shapes our habits, behavior, and society as a whole, providing insights into our interactions with technology.
Nicholas Carr, in his book (Carr, 2010), explores the impact of the Internet on the human brain. He analyzes how constant use of the Internet, searching, and consuming information through digital devices shape our ability to concentrate, think, and process information. Carr explores how technological tools shape our cognitive ability,

highlighting their influence on our thinking and how we absorb and process information.

7) Environmental aspects:
   Questions: How does technology affect the environment? Is technology development guided by sustainable practices?
   Principles: Development of environmentally sustainable technologies, reducing negative environmental impacts.
   In the book (O'Toole, 2013), authors focus on the environmental aspects of technology and web design. They explore how technology, particularly web technologies, affects the environment and which practices in designing web ecosystems can contribute to sustainability. This book analyzes how digital technologies can be developed while reducing negative impacts on the environment. It examines how optimization, resource efficiency, and the development of sustainable technologies can contribute to creating more environmentally friendly web systems. The book explores principles of sustainable design for web ecosystems, providing guidelines for reducing the ecological burden caused by technological development.

These ethical aspects often require reflection and responsible actions from all stakeholders involved in the process of technology development and implementation. An ethical framework helps ensure that technology serves the well-being of people and society, minimizing potential negative consequences.

The future of human-computer interaction

The rapid development of artificial intelligence, augmented reality, the Internet of Things, and other technologies promises an even more intriguing future for human-computer interaction. Here are several key aspects that could shape the future of this interaction:

1) Artificial Intelligence and Machine Learning: AI will enable systems to better understand and adapt to individual user needs, making interactions more intuitive and efficient. The development of smart assistants using deep learning to provide more complex and personalized services.
2) Augmented Reality and Virtual Reality: Integrating digital elements into the real world through AR devices, such as smart glasses, will create richer and contextually enriched interactions. Advancements in VR technology will offer even more realistic and immersive experiences in digital environments.

3) Advanced Interfaces: Technologies allowing precise system control through gestures, enhancing flexibility and natural interaction. The use of haptic feedback technology to provide users with a sense of touch or sensations during interaction.
4) Voice Interaction: Advanced assistants with voice intelligence: Developing voice assistants that use natural language, recognize speech nuances, and better understand context. Integrating voice interfaces into business applications to enhance productivity.
5) Ethical Aspects: Focus on developing and applying ethical guidelines regarding AI to avoid injustices, discrimination, and other negative impacts. Strengthening measures for data privacy protection and security in the face of increasing connectivity and interaction.
6) Quantum Computing: New computing possibilities: The development of quantum computers will enable solving problems currently unachievable for classical computers. Adapting algorithms to leverage the specific characteristics of quantum computers.
7) Social Interaction and Artificial Emotion: Technology development capable of recognizing and simulating emotions to create more emotional and intuitive interactions. Progress in robotics allowing the creation of social robots capable of emotionally based interactions with humans.
8) Education and Training: Development of virtual classrooms and training will enable students and employees to acquire skills and knowledge in realistic digital environments.

These are just some of the potential developments in the future of human-computer interaction. The fast-paced progress of technology promises exciting innovations but also poses challenges in terms of ethics, security, and accessibility. Continuous study and consideration of these aspects are crucial to shape a positive and responsible technological development.

Conclusion

Human-computer interaction is not merely a technical concept but a pivotal element shaping our everyday lives. Understanding its evolution, principles of user experience design, and ethical implications is essential for building a positive and sustainable technological future.

The principles of user experience design form the foundation of successful digital products. Their application allows for the creation of user-friendly, functional, and efficient interfaces, ensuring that technology

serves users in the best possible way. By considering these principles, designers can shape experiences that exceed expectations and build lasting relationships with users.

Human-computer interaction significantly impacts society. From changes in communication to the transformation of work processes, technological progress shapes our everyday lives.

With the growing integration of technology into people's lives, questions of privacy, data security, and ethical technology use become increasingly important.

The rapid development of artificial intelligence, augmented reality, the Internet of Things, and other technologies promises an even more intriguing future for human-computer interaction. This interaction is not just a technical concept but a crucial element shaping our everyday lives. Understanding its development, principles of user experience design, and ethical implications is essential for building a positive and sustainable technological future.

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Interacción entre humanos y computadoras: aspectos clave y evolución

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Resumen:

Introducción/objetivo: La investigación tuvo como objetivo analizar los aspectos clave de la interacción persona-computadora, estudiando la evolución de este campo desde sus inicios hasta las tendencias contemporáneas. Centrándose en diferentes aspectos de esta interacción,

estudió cómo los métodos, tecnologías y principios han evolucionado con el tiempo y han dado forma a nuestras experiencias en el entorno digital.

Métodos: La metodología de investigación se basó en el análisis de bibliografía relevante y artículos de investigación dedicados a la interacción persona-computadora. La revisión y evaluación sistemática de las fuentes identificó la información clave sobre la evolución de la interacción de los usuarios con las computadoras. A través de la evaluación de los estudios disponibles, se identificaron cambios en los métodos de diseño de interfaces, tecnologías de interacción y comprensión de las necesidades de los usuarios a lo largo del tiempo.

Resultados: A partir de la síntesis de datos, se identificaron los aspectos clave de la interacción persona-computadora. Un análisis de la bibliografá reveló cambios en los métodos de diseño de interfaces, tecnologías de interacción y comprensión de las necesidades de los usuarios a lo largo del tiempo. Los resultados específicos incluyeron información sobre la evolución de los aspectos de interacción, incluidas mejoras en la eficiencia, la intuición y la personalización de las experiencias.

Conclusión: La conclusión clave de la investigación es que las innovaciones y la evolución de la tecnología han influido significativamente en la forma en que los usuarios interactúan con los sistemas informáticos. Las mejoras en el diseño de la interfaz, las tecnologías de reconocimiento y la personalización de las experiencias son factores clave para crear mejores experiencias de usuario y optimizar la interacción persona-computadora. La investigación apunta al continuo desarrollo y cambios en el campo de la interacción persona-computadora, enfatizando la necesidad de más investigación e innovación en esta área.

Palabras claves: *interacción persona-computadora (HCI), interfaces gráficas de usuario (GUI), experiencia de usuario (UX), revolución de Internet, revolución móvil.*

Взаимодействие человека и компьютера: ключевые аспекты и эволюция

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РУБРИКА ГРНТИ: 50.41.29 Пользовательский интерфейс программного обеспечения

ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: Цель данной статьи – проанализировать ключевые аспекты взаимодействия человека и компьютера, изучить эволюцию этой области от истоков до современных тенденций. В исследовании внимание сосредоточено на различных аспектах взаимодействия и было изучено, как методы, технологии и принципы развивались с течением времени и формировали наш опыт в цифровой среде.

Методы: Методология исследования была основана на анализе релевантной литературы и исследовательских работ, посвященных взаимодействию человека и компьютера. Систематический обзор и оценка источников выявили ключевую информацию об эволюции взаимодействия пользователя с компьютерами. Благодаря оценке доступных исследований были выявлены изменения в методах разработки интерфейсов, технологиях взаимодействия и понимании потребностей пользователей, с учетом аспекта времени.

Результаты: Синтез данных выявил ключевые аспекты взаимодействия человека и компьютера. А анализ литературы указывает на изменения в методах разработки интерфейсов, технологиях взаимодействия и понимании потребностей пользователей с учетом аспекта времени. На основании конкретных результатов была освещена информация об эволюции аспектов взаимодействия, включая улучшения в эффективности, интуитивности и персонализации опыта.

Выводы: Ключевой вывод исследования заключается в том, что инновации и эволюция технологий существенно повлияли на то, как пользователи взаимодействуют с компьютерными системами. Улучшения в дизайне интерфейсов, технологиях распознавания и персонализации опыта являются ключевыми факторами в создании более удобной пользовательской среды и оптимизации взаимодействия человека с компьютером. Исследование указывает на постоянное развитие и изменения в области взаимодействия человека и компьютера, подчеркивая необходимость дальнейших исследований и инноваций в этой области.

Ключевые слова: взаимодействие человека с компьютером (HCI), графические пользовательские интерфейсы (GUI), пользовательский опыт (UX), интернет революция, мобильная революция.

Интеракција између човека и рачунара: кључни аспекти и еволуција

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ОБЛАСТ: информационе технологије
КАТЕГОРИЈА (ТИП) ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: Циљ истраживања била је анализа кључних аспеката интеракције човека и рачунара; проучавана је еволуција овог поља од почетака до савремених трендова. Фокусирајући се на различите аспекте интеракције, истраживано је како су се методе, технологије и принципи развијали током времена и обликовали наша искуства у дигиталном окружењу.

Методе: Методологија истраживања заснивала се на анализи релевантне литературе и истраживачких радова посвећених интеракцији човека и рачунара. Систематским прегледавањем и евалуацијом извора идентификоване су кључне информације о еволуцији ове интеракције. Кроз вредновање доступних студија идентификоване су промене у методама дизајна интерфејса, технологијама интеракције и разумевању потреба корисника током времена.

Резултати: Синтетизацијом података идентификовани су кључни аспекти интеракције човека и рачунара. Анализом литературе откривене су промене у методама дизајна интерфејса, технологијама интеракције и разумевању потреба корисника током времена. Конкретни резултати обухватили су информације о еволуцији аспеката интеракције, укључујући побољшања у ефикасности, интуитивности и персонализацији искустава.

Закључак: Иновације и еволуција технологије значајно су утицали на начин интеракције корисника с рачунарским системима. Побољшања у дизајну интерфејса, технологијама препознавања и персонализацији искустава представљају кључне факторе у креирању све бољег корисничког доживљаја и оптимизацији интеракције човека и рачунара. Истраживање указује на континуирани развој и промене у домену ове интеракције , наглашавајући потребу за даљим истраживањем и иновацијама у овој области.

Кључне речи: интеракција човек-рачунар (HCI), графички кориснички интерфејси (GUI), корисничко искуство (UX), интернет револуција, мобилна револуција.

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Јапански електромагнетни шински топ средњег калибра[1]

Јапански електромагнетни шински топ средњег калибра, који се дуго развијао, могао би значајно побољшати способности одбране

Јапански стручњаци тврде да су успешно тестирали свој електромагнетни шински топ средњег калибра за поморску употребу путем платформе на отвореном мору. Према информацијама Агенције за технологију набавке и логистику (*ATLA),* то је први пут да је нека земља постигла такав циљ. Тест би представљао важан корак напред и на мору и на копну.

ATLA, као део јапанског Министарства одбране, удружила се с јапанским поморским самоодбрамбеним снагама *(JMSDF*) за овај тест. Међутим, о детаљима тестирања не зна се много.

Тренутне спецификације прототипског шинског топа средњег калибра, које је агенција *ATLA* први пут објавила у мају ове године, наглашавају да је ова оружана платформа способна да испаљује пројектиле 40 мм, масе 320 грама. На основном нивоу, шински топови се ослањају на електромагнете уместо на хемијске пропеланте како би испаљивали пројектиле великим брзинама, чак и у хиперсоничном режиму.

Топ агенције *ATLA* може испаљивати пројектиле брзином од око 2.230 м/с (Max 6,5), и користи пет мегаџула (MJ), односно 5 милиона џула (J) енергетског капацитета. *ATLA* планира да на крају функционише са 20 MJ енергетског капацитета.

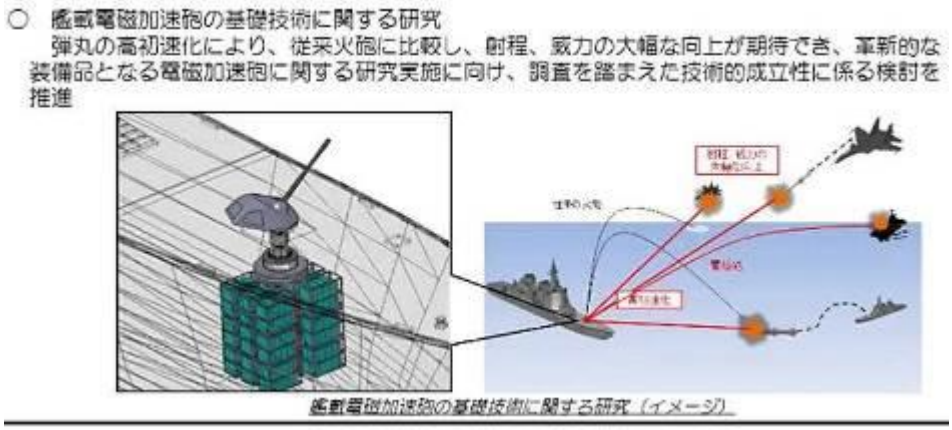
[1] The War Zone, 17th October 2023

Видео-снимак шинског топа у акцији током тестирања, који је објавила ATLA, показује испаљивање пројектила из различитих углова

Тренутно се не зна са сигурношћу на којим пловилима би Јапан могао евентуално инсталирати будуће шинске топове, уколико се заиста покажу оперативним. Међутим, раније је указивано на могућност инсталирања на бар неким разарачима *JMSDF*. На пример, 2015. године, када су се појавили први бродови класе *27DD* или *27DDG*, као подваријанте вођених ракетних разарача класе *Atago*, компанија *Japan Marine United (JMU)* сугерисала је да би ова пловила могла бити опремљена електромагнетним шинским топом због побољшаних способности производње електричне енергије ових бродова.

Осим што су монтирани на разарачима, могуће је да би ова оружја могла завршити на јапанским вишенаменским бродовима за одбрану од балистичких ракета. Јапан је последњих година значајно инвестирао у набавку ратних бродова за одбрану од балистичких ракета, за употребу против све шире палете претњи из ваздушног простора и са мора.

Брзине којима се пројектили могу испаљивати из шинских топова вероватно би их учиниле привлачном опцијом за гађање различитих ваздушних претњи на мору, укључујући надолазеће хиперсоничне крстареће, а можда чак и хиперсоничне балистичке ракете. Такође, речено је да *ATLA* планира постављање неколико шинских топова на копнена возила ради гађања сличних хиперсоничних ракета.



Концептуализација шинског топа инсталираног на броду класе 27DDG, приказана испод, показује како оружје гађа различите ваздушне и морске мете

Средњи калибар овог концепта шинског топа потенцијално би ограничио ове способности на високолокализовану одбрану бродова и значајних копнених мета. Други концепти шинских топова, као што је онај америчке ратне морнарице, који је сада напуштен, базирају се на много већим калибрима који, иако знатно способнији, захтевају сложеније системе и много више енергије и хлађења него јапански тестни топ. Ипак, чак и са калибром од 40 мм, постоје значајне препреке које треба превазићи како би се остварио било какав оперативни морнарички шински топ.

Дуго се очекивало да агенција ATLA тестира функционални пример овог оружја. Године 1990. Центар за истраживање система на копну (*GSRC)* те агенције започео је рад на основном, мањем шинском топу калибра 16 мм. Затим су, 2016. године, уложени напори за развој оружја пројектованог за противваздухопловна и противбродска дејства. Видео-снимак примера овог концепта, који је служио као доказ изводљивости, и приказивао развојни шински топ малог калибра заједно са припадајућом подршком и тестном опремом објавила је агенција ATLA 2018. године.

Касније, у мају 2022. године, *GSRC ATLA* закључила је уговор вредан 47,9 милиона долара (6,5 милијарди јапанских јена) са компанијом *Japan Steel Works* за истраживање и развој прототипског шинског топа, који је, као што је већ напоменуто, представљен у мају 2023. године.

Прототип електромагнетног топа 2018, године

Иако су америчке војне снаге одустале од развоја електромагнетног шинског топа, Јапан се и даље посвећује развоју ове технологије. Америчка истраживања о унапређењу два дизајна електромагнетних шинских топова, једног од компаније *BAE Systems* и другог компаније *General Atomics,* почела су 2005. године. Овај програм је окончан када је обустављено финансирање у оквиру буџета ратне морнарице за буџетску 2022. годину.

Shigenori Mishima, потпредседник и главни технички директор агенције *ATLA*, указао је на могућност да амерички извођачи у будућности могу да се придруже мање амбициозном јапанском програму шинских топова. То би америчким војним снагама могло пружити могућност повратка у развој технологије ових топова.

Друге земље које тренутно раде на развоју шинских топова укључују Кину и Турску. Да Кина развија свој шински топ први пут је примећено још 2018. године, након појаве кинеског поморског шинског топа у напредном стању развоја. Кина тврди да је развила систем који може испаљивати пројектил масе 124 кг брзином од 700 км/ч за мање од 0,05 секунди. Земља планира да ову технологију користи као кључну компоненту својих будућих морнаричких ресурса. Још увек нема доказа о томе шта је овај прототип шинског топа заправо постигао, али, као и у случају америчке ратне морнарице, реч је о великокалибарском оружју.

Пред Јапаном је очигледно још дуг пут до израде оперативног поморског електромагнетног шинског топа. Наиме, мораће се превазићи значајне препреке, као што су корозивна слана вода, константне промене, екстремна врућина и хладноћа, као и други фактори који су неизбежни у морском окружењу. Међутим, недавни тест представља важан корак према том циљу.

Кинески електромагнетни топ

Технологија електромагнетног топа, као и у случају ласерске технологије, представља будућност развоја оружја. Наиме, у овим областима ради се о оруђима која су скупа за производњу, али врло јефтина у експлоатацији. Струја и јефтини пројектил од метала високе густине у случају електромагнетног топа и само струја у случају ласерског оружја представљају огромну разлику у цени када се ова оруђа упоређују са ценама ракетних и противракетних система. Енергетска цена испаљивања једног шинског пројектила, или једног ласерског снопа, мери се у десетинама или стотинама долара, а не више у десетинама или хиљадама долара када су у питању сложени ракетни или антиракетни системи.

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Граната за артиљеријско оруђе са набојномлазним мотором[2]

Граната за артиљеријско оруђе са млазним мотором одлетела је даље него икада раније и могла би више него дупло да повећа домет постојећих и будућих хаубица калибра 155 мм.

Компанија *Boeing* представила је досад најбољи преглед своје гранате за артиљеријско оруђе калибра 155 мм са набојномлазним мотором. Тврди да је недавно тестирање овог дизајна, који развија у сарадњи с норвешком компанијом *Nammo,* оборило постојећи рекорд у домету гранате за артиљеријско оруђе с млазним мотором. Међутим, тачна удаљеност коју је граната прелетела није позната.

[2] The War Zone, 9th October 2023

На саопштењу за медије које је компанија *Boeing* објавила види се слика гранате *Ramjet 155* , заједно са детаљима о историјском тесту и другим будућим плановима за ову муницију. Компанија *Nammo* је први пут представила дизајн гранате калибра 155 мм са набојномлазним мотором 2018. године. Две компаније тренутно развијају ову гранату као део програма америчке војске под називом *Army's Extended Range Artillery Munitions Suite (ERAMS) program.*

Компаније *Boeing* и *Nammo* су прошле године објавиле да су извршиле тестирање гранате *Ramjet 155* која је поставила претходни рекорд у домету за гранату овог типа. Међутим, није обелодањено колико далеко је тада прелетела.

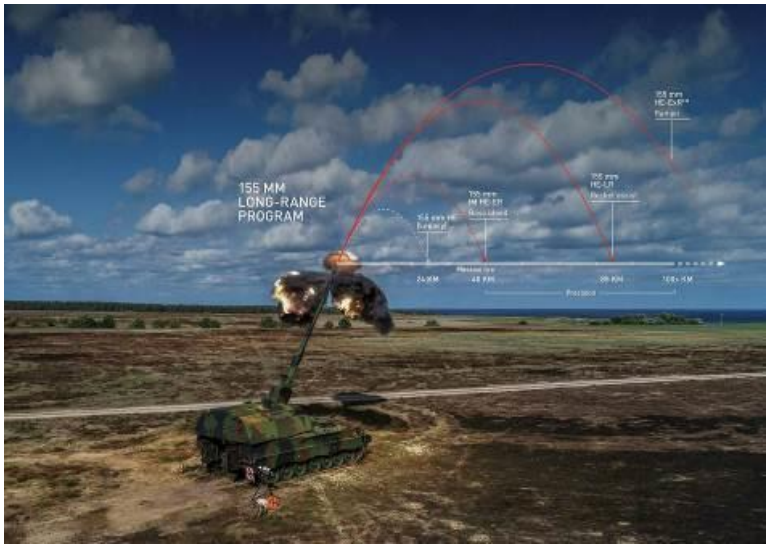
Стручњаци компаније *Boeing* раније су изјавили да је циљ да граната *Ramjet 155* буде у могућности да погоди циљеве удаљене више од 70 километара (око 43,5 миља), док се из компаније *Nammo*чуло да би граната са млазним мотором могла да достигне домет од 150 километара (нешто више од 93 миље), у зависности од оруђа из којег се испаљује.

Типичне гранате за артиљеријско оруђе калибра 155 мм испаљују се користећи одвојене погонске набоје. Постоје и продужени типови који укључују мали ракетни потисник у основу гранате, а тренутно су у употреби широм света.

Граната *Ramjet 155* укључује набојномлазни мотор који усисава ваздух. Детаљи о дизајну су ограничени. Општи концепт, с којим се експериментише широм света већ деценијама, укључује повећање домета путем комбинације одрживог надзвучног лета и чињенице да мотор активно вуче пројектил кроз ваздух.

Пакет за вођење на гранати *Ramjet 155* такође ће укључивати исту компоненту „рачунар за мисију" која се налази на прецизно вођеним бомбама које се користе у ваздухопловству. То указује на методу вођења уз помоћ ГПС-а која је погодна за нападе на статичке циљеве. Постоји могућност да се у будућности интегрише нека врста трагача, или комбинације трагача, како би се омогућило гађање покретних циљева.

Фотографија коју су објавили Boeing и Nammo након тестирања гранате Ramjet 155 2022. године, који је одржан у Andøya тест центру у Норвешкој (Извор: Boeing)



Графикон компаније Nammo приказује максималне домете које нуде различите врсте постојеће и у развоју муниције 155 мм, укључујући напредне ракетнопомогнуте типове и гранату Ramjet 155 (Извор: Nammo)

Компаније *Boeing* и *Nammo* се надају да ће ускоро демонстрирати могућности прецизног вођења гранате *Ramjet 155.*

Чак и ако почетни дизајн може да погађа само специфичне фиксне координате циљева, граната *Ramjet 155* могла би знатно да превазиђе способности постојећих хаубица калибра 155 мм. Граната са набојномлазним мотором има очекивани домет који је историјски више у складу са дометом великокалибарских артиљеријских ракета.

Самоходне хаубице M109A7 155 мм у америчкој војсци тренутно могу да погоде циљеве на удаљености од 22 километра (око 13,6 миља) и 30 километара (око 18,6 миља) користећи постојеће муниције без ракета. Са гранатом *Ramjet 155* домет ових хаубица би се најмање удвостручио, ако не и додатно проширио.

Америчка самоходна хаубица M109A7, калибра 155 мм.

Тај додатни домет даје хаубицама 155 мм драматично већу флексибилност. Са дометом од 30 километара једно од ових оруђа може погодити било шта унутар округлог подручја које покрива око 2.827 квадратних километара (скоро 1.092 квадратне миље). Ако се домет прошири на 70 или 150 километара, простор у којем могу гађати циљеве без потребе за премештањем повећава се на 15.394 квадратна километра (5.944 квадратне миље) и 70.686 квадратних километара (27.292 квадратне миље).

Хаубице већ имају способност да брзо промене фокус са једног циљног подручја унутар свог домета на друго као одговор на нове догађаје на бојишту.

Ипак, питање је да ли ће америчка војска, или било која друга војна сила на свету, коначно набавити гранате *Ramjet 155* компанија *Boeing/Nammo* или неког другог пројекта гранате калибра 155 мм са набојномлазним мотором. Компаније *Boeing* и *Nammo* су само један тим

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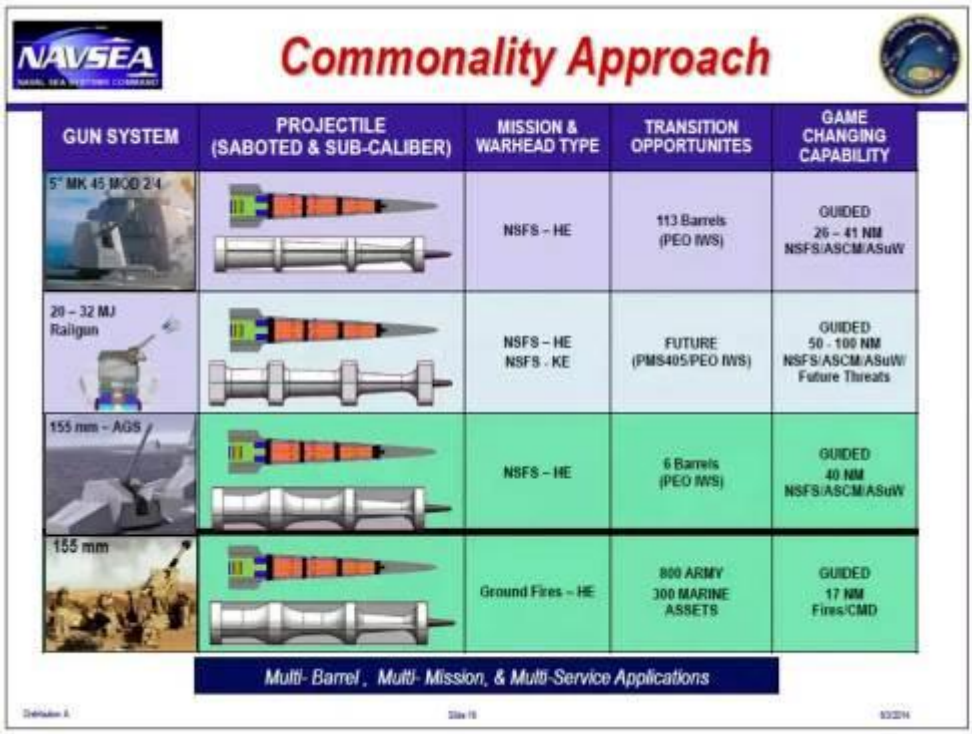
који ради на напредној муницији 155 мм као део програма *ERAMS*. Америчка војска већ је у процесу одлучивања коју од ових граната ће набавити под ознаком XM1155.

Тимови које предводе компаније *Raytheon* и *BAE Systems* такође раде на конкурентским дизајнима. Граната компаније *Raytheon* је такође тип са млазним мотором, а развија је у сарадњи са холандском организацијом за примењена научна истраживања, познатом под холандским акронимом *TNO.*

Граната компаније *BAE Systems* је такозвани поткалибарни концепт који укључује испуштање мањег пројектила након лансирања који затим лети великом брзином. Очекивани максимални домет за овај дизајн је најмање 110 километара (нешто више од 68 миља). Изведен је из муниције коју је компанија развила за пропали пројект електромагнетног шинског топа америчке морнарице. Компанија *BAE Systems* тврди да њена граната XM1155-SC (где SC означава поткалибар) тренутно држи рекорд за најдуже прецизно вођен погођен из хаубице серије M109 америчке војске, који је такође један од производа компаније, користећи било коју врсту муниције.



Стари слајд из презентације програма америчке морнарице о шинском топу приказује друге потенцијалне примене основног пројектила велике брзине (ХВП), укључујући гранату за хаубице калибра 155 мм

Раније објављена слика гранате XM1155-SC компаније BAE Systems током тестирања

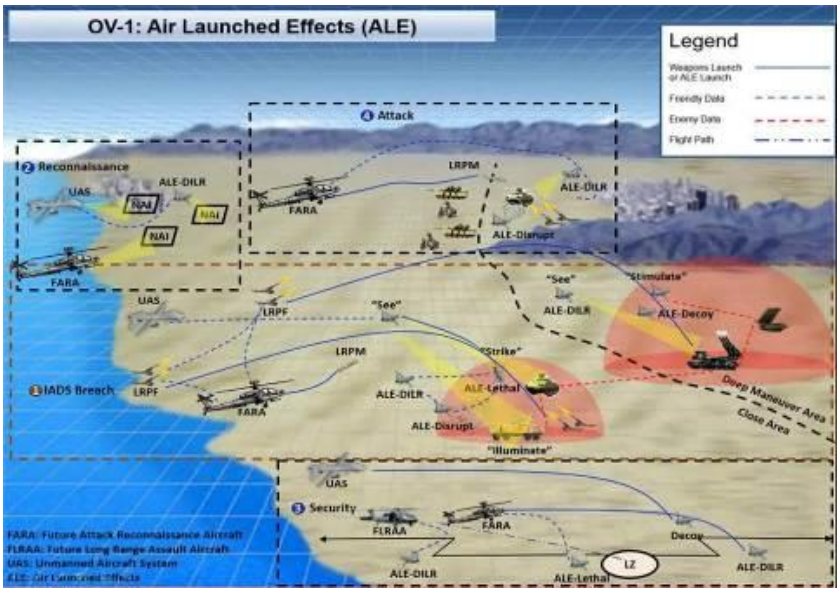
За америчку војску је нова граната калибра 155 мм са набојномлазним мотором, или друга граната са дугим дометом, само део много веће иницијативе за проширење домета њених тактичких и стратешких јединица. То укључује низ других програма који се баве развојем нових крстарећих ракета и балистичких ракета на земљи, беспилотних летелица и других средстава.

У исто време, чини се да је будућа стратегија америчке војске, када је реч о артиљерији, посебно о напредним хаубицама калибра 155 мм и њиховојмуницији, сада у процесу промене. Већ неко време, војска је пратила нову самоходну хаубицу калибра 155 мм под ознаком *XM1299* која је пројектована да максимално искористи *ERAMS* муницију и има унапређења, укључујући аутоматски пуњач.

Међутим, високи званичници војске сада су поставили питање да ли је то најисплативија опција и да ли би друге алтернативе, које су тренутно доступне на отвореном тржишту, могле понудити сличне способности али у краћем периоду.

Проблем је и што тешкооклопљена самоходна хаубица *XM1299* није баш погодна за лако наоружане снаге, попут ваздушнопокретних јединица војске, којима би више одговарао лакши дизајн хаубица. Године 2021. америчка војска је тестирала неколико типова самоходних хаубица калибра 155 мм на точковима, укључујући неколико страних типова, али није одабрано ниједно од понуђених решења.

Самоходна хаубица *Archer,* коју је произвела компанија *BAE Systems Bofors* у Шведској, била је једна од иностраних пројеката самоходних хаубица калибра 155 мм које је америчка војска раније тестирала.



Графикон приказује различите улоге и задатке будућих беспилотних летелица и муниције америчке војске, укључујући сарадњу са артиљеријом великог домета

Слајд презентације приказује различите елементе програма америчке војске за проширење домета артиљерије Extended Range Cannon Artillery (ERCA) artillery иницијативу, укључујући гранату XM1155 ERAMS и самоходну хаубицу XM1299

Дакле, јасно је да америчка војска и даље види проширење домета својих артиљеријских јединица као кључну област. Чини се да ће граната за артиљеријско оруђе са набојномлазним мотором компанија *Boeing* и *Nammo*, или неки други дизајн гранате *ERAMS*, бити кључан део постизања те способности.

Рат у Украјини је показао сву моћ артиљерије која је непревазиђена као краљица рата. Потврђена је и слабост руских класичних артиљеријских оруђа са релативно кратким дометом (до 35 км) у односу на нека западна оруђа домета и до 45 км. Такође, дошло је и до премоћи прецизних артиљеријских оруђа у односу на тактику употребе покривања великих области неселективним артиљеријским нападима која се карактеришу великом потрошњом граната и врло скромним учинком. Дакле, будућност је у даљем повећавању домета артиљеријских граната и у још већој прецизности.

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Нови подаци о бомбардеру B-21[3]

Нови тајни бомбардер америчког ваздухопловства B-21 *Raider* корак је ближе свом првом лету након што су најављена тестирања мотора на земљи. Међутим, треба се подсетити да је та летелица заправо само део – наравно највидљивији – „породичног система".

Начин удара на великим даљинама укључује системе који ће бити интегрисани са авионом, као што су оружје и сензори, и системе који ће га „пратити". Чини се да описи последње категорије, бар делимично, упућују на постојање једног или више додатних врло напредних дизајна авиона, вероватно са технологијама „невидљивости" и без посаде, који су можда већ у употреби на одређеном нивоу.

Бомбардер *B-21* би могао дејствовати заједно са будућим напредним беспилотним летелицама високог степена аутономије које ће бити набављене путем програма *Collaborative Combat Aircraft (CCA*). То је део веће иницијативе за модернизацију ваздухопловних снага следеће генерације у доминацији ваздушним простором (*Next Generation Air Dominance (NGAD*) која је, такође, заснована на породичном систему, *B-21* и екосистему удара на великим даљинама.

Породица система *B-21* укључује унутрашњи корисни терет, али и летелице које би га можда пратиле и подржавале.

Познато је, мада се ретко дискутује о томе, да ће *B-21* бити само један део већег директно интегрисаног екосистема, откако су ваздухопловне снаге почеле да говоре о програмима који ће довести до развоја *B-21*

[3] The War Zone 12th Septembre 2023

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крајем двехиљадитих. Пројектовање *B-21* првобитно је названо програмом бомбардер на великим даљинама (*Long Range Strike-Bomber, LRS-B)*, који је тада описан као део породичног система за удар на великим даљинама.

Бомбардер B-21 Raider

Први серијски B-21 Raider

Још већи напор уложен је за постизање оптималних резултата на великим даљинама у виду крстареће ракете наоружане нуклеарним главама и „невидљивим" технологијама (*Long Range Stand Off, LRSO*), коју ће бомбардери *B-21* и *B-52* моћи да користе. Тренутна ознака ракете је *AGM-181*. Ракете *LRSO* ће заменити постојећу ваздухопловну крстарећу ракету *AGM-86B*. Други системи наоружања, укључујући оружје са усмереном енергијом, такође су помињани у прошлости као део концепта породичног система *LRS.*

Све то се уклапа у идеју „муниције" као дела будуће породичне групе система *B-21*. Оружје са усмереном енергијом, попут ласера, могло би бити

једно од нових технолошких решења међу будућим способностима за одбрану, а које могу укључивати и напредне системе електронског ратовања и мамце, па чак и противракетне пресретаче.

Прилагођено свемирско осматрање и комуникације такође могу бити део овог екосистема.

Raider поседује архитектуру отворених система, што га чини веома прилагодљивим. Дакле, са развојем иновација, овај бомбардер ће моћи да брани САД новим будућим оружјима. Вишенаменска летелица *B-21* може обављати различите функције, од прикупљања обавештајних података до вођења битке.

Такође, B-21 би могао бити платформа за доставу (прецизних бомби), или имати друге улоге, било као сензорска платформа, било у пратњи различитих врста савезничких борбених авиона. Бомбардер ће имати способност да обавља врло јединствене задатке, који се можда не уклапају у традиционално виђење: „Убаци бомбе у бомбашку комору, иди што дубље можеш и испусти бомбе (правило)."

Речено је, међутим, да елементи *P-AEA* и *P-ISR* посебно указују на могуће постојање потпуно одвојених летелица. Истовремено, већ неко време постоје назнаке да се високолетећи шпијунски беспилотни авион са способношћу прикривености, често називан *PQ-180*, приближава увођењу у службу, ако се то већ није догодило, бар на ограниченом нивоу.

На основу онога што се сазнало током година, *PQ-180* би био веома погодан за улогу *P-AEA,* као и за *P-ISR* и друге мисије, и могао би бити идеалан за подршку бомбардера *B-21*. Наредне варијације или деривати *PQ-180* могли би бити боље оптимизовани за било коју од ових функција.

PQ-180

Препознат као још један дизајн компаније *Northrop Grumman* са летећим крилима, *PQ-180* би такође могао имати улогу у напорима за смањење ризика у подршци развоју *B-21*.

Америчко ратно ваздухопловство још увек истражује како би њихова тренутна визија о томе како ће користити *CCA*, претежно у блиској координацији са посадним тактичким борбеним авионима у различитим улогама, могла да се прошири на сарадњу са *B-21*.

Врста сценарија у којој би бомбардер *B-21* „покупио" *CCA*, како се приближава зони дејства док је *CCA*, претходно био навођен испред бомбардера у случају пробоја ваздушног фронта, као додатак *B-21*. Ове беспилотне летелице могу побољшати одбрамбене способности, као и омогућити бољу ситуациону свесност за *B-21*.

Одбрану изван авиона може спровести врста беспилотне летелице типа „*loyal wingman*" или неки нови систем. Агенција за напредна истраживања одбране (*DARPA*) тренутно има програм под називом „*LongShot*" који истражује идеју о беспилотној летелици која се лансира из ваздушног простора и наоружана је ракетама ваздух-ваздух које би ловци и бомбардери могли користити. Компанија *General Atomics* је управо добила уговор за изградњу и тестирање прототипа дизајна „*LongShot*".

Током марта 2023. године најављено је да америчко ратно ваздухопловство планира набавку најмање 1.000 *CCA*, као и 200 борбених авиона са посадом шесте генерације са технологијама „невидљивости" као део одвојеног *NGAD* потпрограма. Број од 1.000 *CCA* заснива се на концепту операција у којима би се сваки од 200 *NGAD* борбених авиона упарио са по две од ових беспилотних летелица, заједно са ловцима бомбардерима *F-35A Joint Strike Fighter*.

Чини се да ће програм *CCA* имати жестоку конкуренцију од многих компанија. Првокласни амерички одбрамбени извођачи као што су *Lockheed Martin*, *Northrop Grumman*, *Boeing* и *Raytheon* већ су поставили визије, експлицитно или имплицитно, како би, у овом погледу, могли да испуне захтеве америчког ратног ваздухопловства.

Беспилотна летелица LongShot, компаније General Atomics, са америчким ловцем F-15C Eagle у позадини

Приказ авиона F-35 Joint Strike Fighter у лету са различитим врстама беспилотних летелица

Приказ беспилотне летелице Fury

Што се тиче *B-21* и његове породичне групе система, више детаља биће познато како програм буде напредовао. Такође, многи подаци о *B-21*тренутно су високо класификовани, што ће тако остати годинама, с обзиром на његову кључну улогу у будућој оперативној визији америчког ратног ваздухопловства, посебно када је реч о одвраћању Кине.

Америчко ратно ваздухопловство верује да ће бомбардери *B-21* почети да улазе у оперативну употребу средином двадесетих година.

Може се закључити да ће *B-21* бити много више од самог авиона, укључујући могућност постојања више нивоа разних беспилотних летелица/сарадника.

Приказ бомбардера B-21 Raider у лету, који је објавило америчко ваздухопловство у 2021. години. УСАФ

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E-7A Wedgetail AEW&C – замена за стари E-3 AWACS[4]

Организација НАТО подржава америчко ратно ваздухопловство у одлуци да се определи за летелицу *E-7A Wedgetail AEW&C* као делимичну замену за свој стари војни систем *E-3 AWACS*.

E-7A Wedgetail AEW&C

[4] The War Zone, 15th november 2023

НАТО је објавио да ће следећа платформа за рано упозоравање и контролу (*AEW&C*) бити *Boeing E-7A Wedgetail*. Ова летелица ће покренути неопходну модернизацију старе флоте НАТО-а *AEW&C*, коју чине авиони *E-3 Sentry Airborne Warning and Control System (AWACS*). Америчко ратно ваздухопловство такође набавља *E-7* делимично као замену за своју флоту *E-3*, а исто чини и Уједињено Краљевство, док Турска већ користи овај тип, због саобразности са снагама НАТО-а.

Агенција *NATO Support and Procurement Agency (NSPA*) – одговорна за мултинационалну набавку, подршку и одржавање за потребе савеза – данас је објавила свој план за „предузимање корака ка набавци" шест *E-7A* летелица. То је почетак иницијативе познате као Иницијатива за будући надзор и контролу савеза (*IAFSC*). НАТО планира да купи Wedgetail. путем канала *U.S. Foreign Military Sales (FMS)*.

На основу прилагођеног авиона *Boeing 737*, главни мисијски сензор *E-7* је радар компаније *Northrop Grumman Multi-role Electronically Scanned Array (MESA)* који се налази на носачу изнад трупа авиона. Радар има режиме претраге ваздушног простора и мора, док је летелица опремљена обимним могућностима комуникације и дељења података што јој омогућава поделу релевантних информација са другим савезничким средствима у ваздушном простору, као и на мору и на земљи.

Уопштено говорећи, платформа *AEW&C,* попут *E-7,* кључна је подршка модерним операцијама ратовања у ваздушном простору. Летелице попут ових могу открити и пратити више претњи, као и одређена подручја ваздушног бојишта. Такође, могу пратити циљеве на мору. Осим тога, оне служе као кључне платформе за управљање командама и борбеним операцијама, обезбеђујући проток података другим средствима у ваздушном простору и на земљи.

Одлуку о набавци *E-7A* донела је *NSPA* заједно са партнерима за подршку алијансе: Белгијом, Немачком, Луксембургом, Холандијом, Норвешком, Румунијом и Сједињеним Америчким Државама. Као део „ригорозног процеса процене", анализирани су захтеви за информацијама (RFI), као и цене и доступности (P&A), а спроведене су и студије претходних програма набавке *E-7*, посебно у Аустралији, Јужној Кореји, Турској, Уједињеном Краљевству и Сједињеним Америчким Државама.

Летелица Е-7 је већ у оперативној употреби у Аустралији, Јужној Кореји и Турској. Такође, поручили су је Уједињено Краљевство и Сједињене Америчке Државе, иако је британски програм набавке каснио, а дошло је и до прекорачења трошкова.

NSPA и партнери за подршку алијансе закључили су да је *E-7A* „једини познати систем тренутно способан да испуни основне оперативне захтеве и кључне параметре перформанси стратешких команди и доступан за испоруку у потребном временском оквиру".

Тај временски оквир заснован је на плану да се садашња флота НАТО-а *E-3* избаци из употребеоко 2035. године и аспирацијама да *E-7A* постигне почетну оперативну способност (*IOC*) до 2031. године.

Аустралијски E-7A Wedgetail у пратњи ловаца F-22

E-3

Према *NSPA*, међу разлозима због којих је Wedgetail оцењен као најбољи кандидат су „погодности економије обима, компатибилност и интероперабилности произашле из мултинационалне набавке војних платформи off-the-shelf platforms ”. Ова мера компатибилности и изгледи за интероперабилност с другим флотама *E-7* јасно су дали предност Боинговом производу у односу на јединог другог реалног кандидата *Saab GlobalEye*, који се заснива на летелици *Bombardier Global 6000/6500*.

До сада су конкурентски *GlobalEye* набавили Уједињени Арапски Емирати и Шведска, мада она још увек није формално приступила НАТО-у.

Saab GlobalEye, који се заснива на летелици Bombardier Global 6000/6500

Занимљиво је да се *IAFSC* иницијатива описује као пружање „почетног елемента за ублажавање ризика празнине у способности надзора и контроле ваздушног простора", али Wedgetail ће бити само „један допринoсећи елемент укупном систему способности надзора и контроле савеза (AFSC)".

С обзиром на то да ће НАТО наручити само шест летелица *E-7A* у оквиру IAFSC иницијативе, чини се да постоји велика вероватноћа да ће бити постављене даље наруџбине за летелицу Wedgetail, као део шире иницијативе *AFSC*. Пошто је НАТО *Airborne Early Warning & Control Force (NAEW&CF*) смештена у бази немачког ратног ваздухопловства Geilenkirchen у Немачкој, она тренутно оперише са 16 *E-3A* летелица.

IAFSC или E-7A приказан је као један део вишеслојног *AFSC* система који ће, такође, укључивати беспилотне летелице за надзор у ваздушном простору, као што су *RQ-4D Phoenix* беспилотне летелице (оперишу на великим висинама и имају дуги долет), свемирски *ISR* (обавештајни, надзорни и извиђачки), морски *ISR,* радар на земљи и *MILSATCOM*. Такође, приказани су дигитални ослонац и борбени облак, док је последњи сегмент празан, што указује на могућност додавања других платформи или способности у каснијем периоду.

Ова визија будућности AEW&C има неке сличности с оним што разматра америчко ратно ваздухопловство. Наиме, оно види *E-7* као решење за премошћавање јаза између „пензионисања" *E-3* и будућих способности свемирског радара и других класификованих система.

Иако чак и свемирски ресурси више нису непробојни, важно је напоменути да се америчка војска све више бави могућностима будућих дистрибуираних свемирских мрежа које су отпорније и мање рањиве, као и

начинима брзе замене уништених или на други начин онеспособљених сателита.

Попут америчког ратног ваздухопловства, нејасно је колико је НАТО напредовао у развоју сателита са радаром који би могао пружити способности сличне авионима *E-3* і *E-7*. Али, изван тајних програма, остаје чињеница да већ постоје многе земље, као и приватне компаније, које јавно користе разне свемирске радаре, иако су они, углавном, намењени снимању у оквиру различитих програма.

Интересантно је да се НАТО до сада није оглашавао поводом куповине ових летелица након набављених првих шест *E-7A*, а камоли набавке других типова авиона. Да ли у том смислу и даље постоји нада за компанију *Saab* у контексту европског AEW&C.

На сајму авијације у Дубаијуоткривено је да Данска, Финска и Шведска разговарају са компанијом Saab о потенцијалном заједничком коришћењу авиона GlobalEye. За почетак, таква иницијатива вероватно би укључивала два GlobalEye-а које је Шведска поручила, а испоруке су предвиђене за 2027. годину. Поред тога, Шведска има опцију за још два таква авиона.

Два GlobalEye-а комапније Saab

Осим летелице GlobalEye, компанија Saab већ има своје летелице у *AEW&C* домену код оператера НАТО-а у Европи. Грчка користи ранији систем *Erieye,* монтиран на регионалним млазњацима *EMB-145H*, док је Пољска недавно примила први од својих авиона *Saab 340* опремљених *Erieye* системом. Шведска, тренутно у очекивању чланства у НАТО-у, такође користи ***авионе Saab 340 с Erieye*** системом, под локалним називом *S 100B Argus.*

Saab 340 са Erieye системом, под локалним називом S 100B Argus

У Европи је интерес за *AEW&C* подстакнут поновним појављивањем претње услед рата у Украјини, као и других оперативних контингената који захтевају надзор широке области и контролу ваздушног простора. Већ сада *E-7* има важну улогу у тим мисијама, не само с Турском, већ и с авионима које је Аустралија распоредила у Европи. Краљевско ратно аздухопловство Аустралије (RAAF) користило је свој Wedgetail како би надгледало војне и хуманитарне испоруке које улазе у Украјину, а перформансе авиона у овој области такође би могле утицати на одлуку НАТО-а да набави *E-7A*.

Свеукупно, специфични захтеви европског подручја операција чине *AEW&C* платформу, попут летелице *Wedgetail,* посебно вредном, имајући у виду близину НАТО-а са Русијом и потребу да се прате покрети руских војних авиона, као и беспилотних летелица и ракета. Иако је то постало већи проблем у последњим годинама, свакодневни надзор ваздушног простора у Европи постоји још од хладног рата.

Са тежњом компаније *Saab* да би *GlobalEye* још увек могао пронаћи нове купце у Европи и с НАТО-ом који се придружио америчком ратном ваздухопловству у објављивању планова за набавку *E-7A*, може се рећи да *AEW&C* доживљава неку врсту ренесансе унутар НАТО-а.

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ПОЗИВ И УПУТСТВО АУТОРИМА
ПРИГЛАШЕНИЕ И ИНСТРУКЦИЯ ДЛЯ АВТОРОВ РАБОТ
CALL FOR PAPERS AND INSTRUCTIONS FOR AUTHORS

ПОЗИВ И УПУТСТВО АУТОРИМА О НАЧИНУ ПРИПРЕМЕ ЧЛАНКА

Упутство ауторима о начину припреме чланка за објављивање у *Војнотехничком гласнику* урађено је на основу Правилника о категоризацији и рангирању научних часописа Министарства просвете, науке и технолошког развоја Републике Србије ("Службени гласник РС", број 159/20). Примена овог Правилника првенствено служи унапређењу квалитета домаћих часописа и њиховог потпунијег укључивања у међународни систем размене научних информација.

Војнотехнички гласник / Vojnotehnički glasnik / Military Technical Courier (втг.мо.упр.срб, www.vtg.mod.gov.rs, ISSN 0042-8469 – штампано издање, e-ISSN 2217-4753 – online, UDC 623+355/359, DOI: 10.5937/VojnotehnickiGlasnik; https://doi.org/10.5937/VojnotehnickiGlasnik), јесте рецензирани научни часопис.

Власници часописа су Министарство одбране Републике Србије и Војска Србије. Издавач и финансијер часописа је Универзитет одбране у Београду (Војна академија).

Програмска оријентација часописа заснива се на годишњој категоризацији часописа, коју врши надлежно државно министарство у одређеним областима, као и на његовом индексирању у међународним индексним базама.

Часопис обухвата научне, односно стручне области у оквиру образовно-научног поља **природно-математичких наука**, као и у оквиру образовно-научног поља **техничко-технолошких наука**, а нарочито области **одбрамбених наука и технологија**. Објављује теоријска и практична достигнућа која доприносе усавршавању свих припадника српске, регионалне и међународне академске заједнице, а посебно припадника војски и министарстава одбране. Публикује радове са уравнотеженим извештавањем о аналитичким, експерименталним и примењеним истраживањима, као и нумеричким симулацијама, обухватајући различите дисциплине. Објављени материјали су високог квалитета и релевантности, написани на начин који их чини доступним широкој читалачкој публици. Сви радови који извештавају о оригиналним теоријским и/или практично оријентисаним истраживањима или проширеним верзијама већ објављених радова са конференција су добродошли. Радови за објављивање одабиру се двоструко слепим поступком рецензије како би се осигурала оригиналност, релевантност и читљивост. Притом циљ није само да се квалитет објављених радова одржи високим већ и да се обезбеди правовремени, темељни и уравнотежени поступак рецензије.

Уређивачка политика *Војнотехничког гласника* заснива се на препорукама Одбора за етичност у издаваштву (COPE Core Practices) и заједничким принципима транспарентности и најбоље праксе у издаваштву COPE, DOAJ, OASPA и WAME, као и на најбољим прихваћеним праксама у научном издаваштву. *Војнотехнички гласник* је члан COPE (Committee on Publication Ethics) од 2. маја 2018. године и члан OASPA (Open Access Scholarly Publishers Association) од од 27. новембра 2015. године.

Министарство просвете, науке и технолошког развоја Републике Србије утврдило је дана 27. 12. 2023. године категоризацију *Војнотехничког гласника*, за 2023. годину:

– **на листи часописа за рачунарске науке:**
категорија врхунски часопис националног значаја **(М51)**,

– **на листи часописа за електронику, телекомуникације и информационе технологије:**
категорија врхунски часопис националног значаја **(М51)**,

– **на листи часописа за машинство:**
категорија национални часопис међународног значаја **(М24)**,

– **на листи часописа за материјале и хемијске технологије:**
категорија национални часопис међународног значаја **(М24)**.

Усвојене листе домаћих часописа за 2023. годину могу се видети на сајту *Војнотехничког гласника*, страница *Категоризација часописа*.

Детаљније информације могу се пронаћи и на сајту Министарства просвете, науке и технолошког развоја Републике Србије.

Подаци о категоризацији могу се пратити и на сајту КОБСОН-а (Конзорцијум библиотека Србије за обједињену набавку).

Категоризација часописа извршена је према Правилнику о категоризацији и рангирању научних часописа Министарства просвете, науке и технолошког развоја Републике Србије ("Службени гласник РС", број 159/20).

Часопис се прати у контексту Српског цитатног индекса – СЦиндекс (база података домаћих научних часописа), Научно-информационог система Redalyc и Руског индекса научног цитирања (РИНЦ). Подвргнут је сталном вредновању (мониторингу) у зависности од утицајности (импакта) у самим базама. Детаљи о индексирању могу се видети на сајту *Војнотехничког гласника*, страница *Индексирање часописа*.

Војнотехнички гласник, у погледу свог садржаја, пружа могућност отвореног приступа (DIAMOND OPEN ACCESS) и примењује Creative Commons (CC BY) одредбе о ауторским правима. Детаљи о ауторским правима могу се видети на сајту часописа, страница *Ауторска права и политика самоархивирања*.

Радови се предају путем онлајн система за електронско уређивање АСИСТЕНТ, који је развио Центар за евалуацију у образовању и науци (ЦЕОН).

Приступ и регистрација за сервис врше се на сајту www.vtg.mod.gov.rs, преко странице *АСИСТЕНТ* или *СЦИНДЕКС*, односно директно на линку aseestant.ceon.rs/index.php/vtg.

Детаљно упутство о регистрацији и пријави за сервис налази се на сајту www.vtg.mod.gov.rs, страница *Упутство за АСИСТЕНТ*.

Потребно је да се сви аутори који подносе рукопис за објављивање у *Војнотехничком гласнику* региструју у регистар ORCID (Open Researcher and Contributor ID), према упутству на страници сајта *Регистрација за добијање ORCID идентификационе шифре*.

Војнотехнички гласник објављује чланке на енглеском језику (arial, величина слова 11 pt, проред Single).

Поступак припреме, писања и уређивања чланка треба да буде у сагласности са *Изјавом о етичком поступању* (http://www.vtg.mod.gov.rs/izjava-o-etickom-postupanju.html).

Чланак треба да садржи сажетак са кључним речима, увод (мотивацију за рад), разраду (адекватан преглед репрезентативности рада у његовој области, јасну изјаву о новини у представљеном истраживању, одговарајућу теоријску

позадину, један или више примера за демонстрирање и дискусију о представљеним идејама), закључак и литературу (без нумерације наслова и поднаслова). Обим чланка треба да буде до једног ауторског табака (16 страница формата А4 са проредом Single), а највише 24 странице.

Чланак треба да буде написан на обрасцу за писање чланка, који се у електронској форми може преузети са сајта на страници *Образац за писање чланка*.

Наслов

Наслов треба да одражава тему чланка. У интересу је часописа и аутора да се користе речи прикладне за индексирање и претраживање. Ако таквих речи нема у наслову, пожељно је да се придода и поднаслов.

Текући наслов

Текући наслов се исписује са стране сваке странице чланка ради лакше идентификације, посебно копија чланака у електронском облику. Садржи презиме и иницијал имена аутора (ако аутора има више, преостали се означавају са „et al.“ или „и др.“), наслове рада и часописа и колацију (година, волумен, свеска, почетна и завршна страница). Наслови часописа и чланка могу се дати у скраћеном облику.

Име аутора

Наводи се пуно име и презиме (свих) аутора. Веома је пожељно да се наведу и средња слова аутора. Имена и презимена домаћих аутора увек се исписују у оригиналном облику (са српским дијакритичким знаковима), независно од језика на којем је написан рад.

Назив установе аутора (афилијација)

Наводи се пун (званични) назив и седиште установе у којој је аутор запослен, а евентуално и назив установе у којој је аутор обавио истраживање. У сложеним организацијама наводи се укупна хијерархија (нпр. Универзитет одбране у Београду, Војна академија, Катедра природно-математичких наука). Бар једна организација у хијерархији мора бити правно лице. Ако аутора има више, а неки потичу из исте установе, мора се, посебним ознакама или на други начин, назначити из које од наведених установа потиче сваки од наведених аутора. Афилијација се исписује непосредно након имена аутора. Функција и звање аутора се не наводе.

Контакт подаци

Адреса или е-адреса свих аутора даје се поред имена и презимена аутора.

Категорија (тип) чланка

Категоризација чланака обавеза је уредништва и од посебне је важности. Категорију чланка могу предлагати рецензенти и чланови уредништва, односно уредници рубрика, али одговорност за категоризацију сноси искључиво главни уредник. Чланци у *Војнотехничком гласнику* класификују се на научне и стручне чланке.

Научни чланак је:

– оригиналан научни рад (рад у којем се износе претходно необјављени резултати сопствених истраживања научним методом);

– прегледни рад (рад који садржи оригиналан, детаљан и критички приказ истраживачког проблема или подручја у којем је аутор остварио одређени допринос, видљив на основу аутоцитата);

– кратко или претходно саопштење (оригинални научни рад пуног формата, али мањег обима или прелиминарног карактера);

– научна критика, односно полемика (расправа на одређену научну тему, заснована искључиво на научној аргументацији) и осврти.

Изузетно, у неким областима, научни рад у часопису може имати облик монографске студије, као и критичког издања научне грађе (историјско-архивске, лексикографске, библиографске, прегледа података и сл.), дотад непознате или недовољно приступачне за научна истраживања.

Радови класификовани као научни морају имати бар две позитивне рецензије.

Ако се у часопису објављују и прилози ваннаучног карактера, научни чланци треба да буду груписани и јасно издвојени у првом делу свеске.

Стручни чланак је:

– стручни рад (прилог у којем се нуде искуства корисна за унапређење професионалне праксе, али која нису нужно заснована на научном методу);

– информативни прилог (уводник, коментар и сл.);

– приказ (књиге, рачунарског програма, случаја, научног догађаја, и сл).

Пожељно је да обим кратких саопштења буде 4 до 7 страница, научних чланака и студија случаја 10 до 14 страница, док прегледни радови могу бити и дужи. Број страница није строго ограничен и, уз одговарајуће образложење, пријављени чланци такође могу бити дужи или краћи.

Ако су радови који су претходно објављени на конференцији проширени, уредници ће проверити да ли је додато довољно новог материјала који испуњава стандарде часописа и квалификује поднесак за поступак рецензије. Додати материјал не сме бити претходно објављен. Нови резултати нису нужно потребни, али су пожељни. Међутим, поднесак треба да садржи проширене кључне идеје, примере, разраде, итд., који су претходно били садржани у поднеску са конференције.

Језик рада

Језик рада треба да буде енглески.

Текст мора бити језички и стилски дотеран, систематизован, без скраћеница (осим стандардних). Све физичке величине морају бити изражене у Међународном систему мерних јединица – SI. Редослед образаца (формула) означава се редним бројевима, са десне стране у округлим заградама.

Сажетак

Сажетак јесте кратак информативан приказ садржаја чланка који читаоцу омогућава да брзо и тачно оцени његову релевантност. У интересу је уредништава и аутора да сажетак садржи термине који се често користе за индексирање и претрагу чланака. Саставни делови сажетка су увод/циљ истраживања, методи, резултати и закључак. Сажетак треба да има од 100 до 250 речи и треба да се налази између заглавља (наслов, имена аутора и др.) и кључних речи, након којих следи текст чланка.

Кључне речи

Кључне речи су термини или фразе које адекватно представљају садржај чланка за потребе индексирања и претраживања. Треба их додељивати ослањајући се на неки међународни извор (попис, речник или тезаурус) који је најшире прихваћен или унутар дате научне области. За нпр. науку уопште, то је листа кључних речи Web of Science. Број кључних речи не може бити већи од 10, а у

интересу је уредништва и аутора да учесталост њихове употребе буде што већа. У чланку се пишу непосредно након сажетка.

Систем АСИСТЕНТ у ту сврху користи специјалну алатку KWASS: аутоматско екстраховање кључних речи из дисциплинарних тезауруса/речника по избору и рутине за њихов одабир, тј. прихватање односно одбацивање од стране аутора и/или уредника.

Датум прихватања чланка

Датум када је уредништво примило чланак, датум када је уредништво коначно прихватило чланак за објављивање, као и датуми када су у међувремену достављене евентуалне исправке рукописа наводе се хронолошким редоследом, на сталном месту, по правилу на крају чланка.

Захвалница

Назив и број пројекта, односно назив програма у оквиру којег је чланак настао, као и назив институције која је финансирала пројекат или програм, наводи се у посебној напомени на сталном месту, по правилу при дну прве стране чланка.

Претходне верзије рада

Ако је чланак у претходној верзији био изложен на скупу у виду усменог саопштења (под истим или сличним насловом), податак о томе треба да буде наведен у посебној напомени, по правилу при дну прве стране чланка. Рад који је већ објављен у неком часопису не може се објавити у *Војнотехничком гласнику* (прештампати), ни под сличним насловом и измењеном облику.

Табеларни и графички прикази

Пожељно је да наслови свих приказа, а по могућству и текстуални садржај, буду дати двојезично, на језику рада и на енглеском језику.

Табеле се пишу на исти начин као и текст, а означавају се редним бројевима са горње стране. Фотографије и цртежи треба да буду јасни, прегледни и погодни за репродукцију. Цртеже треба радити у програму word или corel. Фотографије и цртеже треба поставити на жељено место у тексту.

За слике и графиконе не сме се користити снимак са екрана рачунара програма за прикупљање података. У самом тексту чланка препоручује се употреба слика и графикона непосредно из програма за анализу података (као што су Excel, Matlab, Origin, SigmaPlot и други).

Навођење (цитирање) у тексту

Начин позивања на изворе у оквиру чланка мора бити једнообразан.

Војнотехнички гласник за референцирање (цитирање и навођење литературе) примењује Харвардски систем референци, односно Харвардски приручник за стил (Harvard Referencing System, Harvard Style Manual). У самом тексту, у обичним заградама, на месту на којем се врши позивање, односно цитирање литературе набројане на крају чланка, обавезно у обичној загради написати презиме цитираног аутора, годину издања публикације из које цитирате и, евентуално, број страница. Нпр. (Petrović, 2012, pp.10–12).

Детаљно упутство о начину цитирања, са примерима, дато је на страници сајта *Упутство за Харвардски приручник за стил*. Потребно је да се позивање на литературу у тексту уради у складу са поменутим упутством.

Систем АСИСТЕНТ у сврху контроле навођења (цитирања) у тексту користи специјалну алатку CiteMatcher: откривање изостављених цитата у тексту рада и у попису референци.

Напомене (фусноте)

Напомене се дају при дну стране на којој се налази текст на који се односе. Могу садржати мање важне детаље, допунска објашњења, назнаке о коришћеним изворима (на пример, научној грађи, приручницима), али не могу бити замена за цитирану литературу.

Листа референци (литература)

Цитирана литература обухвата, по правилу, библиографске изворе (чланке, монографије и сл.) и даје се искључиво у засебном одељку чланка, у виду листе референци. Референце се не преводе на језик рада и набрајају се у посебном одељку на крају чланка.

Војнотехнички гласник, као начин исписа литературе, примењује Харвардски систем референци, односно Харвардски приручник за стил (Harvard Referencing System, Harvard Style Manual).

Литература се обавезно пише на латиничном писму и набраја по абецедном редоследу, наводећи најпре презимена аутора, без нумерације.

Детаљно упутство о начину пописа референци, са примерима, дато је на страници сајта *Упутство за Харвардски приручник за стил*. Потребно је да се попис литературе на крају чланка уради у складу са поменутим упутством.

Нестандардно, непотпуно или недоследно навођење литературе у системима вредновања часописа сматра се довољним разлогом за оспоравање научног статуса часописа.

Систем АСИСТЕНТ у сврху контроле правилног исписа листе референци користи специјалну алатку RefFormatter: контрола обликовања референци у складу са Харвардским приручником за стил.

Изјава о ауторству

Поред чланка доставља се *Изјава о ауторству* у којој аутори наводе свој појединачни допринос у изради чланка. Такође, у тој изјави потврђују да су чланак урадили у складу са *Позивом и упутством ауторима* и *Изјавом о етичком поступању часописа*.

Сви радови подлежу стручној рецензији.

Списак рецензената *Војнотехничког гласника* може се видети на страници сајта *Списак рецензената*. Процес рецензирања објашњен је на страници сајта *Рецензентски поступак*.

Уредништво

Адреса редакције:
Војнотехнички гласник
Вељка Лукића Курјака 33
11042 Београд
e-mail: vojnotehnicki.glasnik@mod.gov.rs.
тел: војни 40-260 (011/3603-260), 066/8700-123

ПРИГЛАШЕНИЕ И ИНСТРУКЦИЯ ДЛЯ АВТОРОВ О ПОРЯДКЕ ПОДГОТОВКИ СТАТЬИ

Инструкция для авторов о порядке подготовки статьи к опубликованию в журнале *«Военно-технический вестник»* разработана согласно Регламенту о категоризации и ранжировании научных журналов Министерства образования, науки и технологического развития Республики Сербия («Службени гласник РС», № 159/20). Применение этого Регламента способствует повышению качества отечественных журналов и их более полному вовлечению в международную систему обмена научной информацией.

Военно-технический вестник (**Vojnotehnički glasnik / Military Technical Courier**), втг.мо.упр.срб, www.vtg.mod.gov.rs/index-ru.html, ISSN 0042-8469 – печатное издание, e-ISSN 2217-4753 – online, UDK 623+355/359, DOI: 10.5937/VojnotehnickiGlasnik; https://doi.org/10.5937/VojnotehnickiGlasnik, является рецензируемым научным журналом.

Собственники журнала: Министерство обороны и Вооруженые силы Республики Србия.

Издатель журнала: Университет обороны в г. Белград (Военная академия).

Программная ориентация журнала основана на ежегодной категоризации журнала, которая производится соответствующим отраслевым министерством, в зависимости от области исследований, а также на его индексировании в международных наукометрических базах данных.

Журнал охватывает научные и профессиональные сферы в рамках учебно-научной области **естественно-математических наук**, а также в рамках учебно-научной области **технико-технологических наук**, особенно в области **оборонных наук и технологии**. В журнале публикуются теоретические и практические достижения, которые способствуют повышению квалификации представителей сербского, регионального и международного академического сообщества, особенно служащих Министерств Обороны и Вооружённых сил. В журнале публикуются статьи со соответствующими обзорами об аналитических, экспериментальных и прикладных исследованиях, а также о численном моделировании, охватывая различные дисциплины. Публикуемые материалы отличаются высоким качеством и актуальностью. Они написаны научным, но понятным и доступным для широкого круга читателей языком. Приветствуются все статьи, сообщающие об оригинальных теоретических и/или практических исследованиях и/или расширенные версии ранее опубликованных статей, представленных на конференциях. Статьи для публикации отбираются путем двойного слепого рецензирования, которое гарантирует оригинальность, актуальность и удобочитаемость. Цель состоит не только в поддержании высокого качества публикуемых статей, но и в обеспечении своевременного, тщательного и соответствующего процесса рецензирования.

Редакционная политика журнала *«Военно-технический вестник»* основана на рекомендациях Комитета по этике научных публикаций (COPE Core Practices), общих принципах прозрачности и лучшей практике издательской деятельности COPE, DOAJ, OASPA и WAME, а также на лучшей практике научно-издательской деятельности. Журнал *«Военно-технический вестник»* является членом COPE (Комитет по этике научных публикаций) со 2 мая 2018 года и членом OASPA (Ассоциация научных издателей открытого доступа) с 27 ноября 2015 года.

Министерством образования, науки и технологического развития Республики Сербия утверждена 27 декабря 2023 г. категоризация журнала *«Военно-технический вестник»* за 2023 год:

- **Область компьютерные науки:**
  ведущий журнал государственного значения **(M51)**,
- **Область электроники, телекоммуникаций и информационных технологий:**
  ведущий журнал государственного значения **(M51)**,
- **Область машиностроения:**
  национальный журнал международного значения **(M24)**,
- **Область материалов и химической технологии:**
  национальный журнал международного значения **(M24)**.

С информацией относительно категоризации за 2023 год можно ознакомиться на странице сайта *«Военно-технического вестника» Категоризация Вестника*.

Более подробную информацию можно найти на сайте Министерства образования, науки и технологического развития Республики Сербия.

С информацией о категоризации можно ознакомиться и на сайте КОБСОН (Консорциум библиотек Республики Сербия по вопросам объединения закупок).

Категоризация Вестника проведена согласно Регламенту о категоризации и ранжировании научных журналов Министерства образования, науки и технологического развития Республики Сербия («Службени гласник РС», № 159/20)

Журнал соответствует стандартам Сербского индекса научного цитирования (СЦИндекс/SCIndeks) - наукометрической базы данных научных журналов Республики Сербия, Научно-информационного система Redalyc, а также Российского индекса научного цитирования (РИНЦ). Журнал постоянно подвергается мониторингу и оценивается количественными наукометрическими показателями отражающими его научную ценность.

С информацией об индексировании можно ознакомиться на странице сайта журнала *Индексирование Вестника*.

«Военно-технический вестник» относительно своего содержания предоставляет пользователям возможность открытого доступа (DIAMOND OPEN ACCESS) и положениями об авторских правах, утвержденными Creative Commons (CC BY). С инструкцией об авторских правах можно ознакомиться на странице сайта журнала *Авторские права и политика самоархивирования*.

Рукописи статей направляются в редакцию журнала с использованием online системы ASSISTANT, запущенной Центром поддержи развития образования и науки (ЦПРОН). Регистрация в системе и оформление прав доступа выполняется по адресу http://www.vtg.mod.gov.rs/index-ru.html, через страницу *ASSISTANT* или *СЦИНДЕКС* (aseestant.ceon.rs/index.php/vtg). С инструкцией по регистрации и правам доступа можно ознакомиться по адресу http://www.vtg.mod.gov.rs/index-ru.html, на странице *Инструкция по ASSISTANT*.

Все авторы, предоставляющие свои рукописи для публикации в редакцию журнала *«Военно-технический вестник»* должны пройти предварительную регистрацию в реестре ORCID (Open Researcher and Contributor ID). Эта процедура осуществляется в соответствии с инструкцией, размещенной на странице сайта *Регистрация в реестре ORCID для присвоения идентификационного кода*.

«Военно-технический вестник» публикует статьи на английском языке (Arial, шрифт 11 pt, пробел Single). Процесс подготовки, написания и редактирования статьи

должен осуществляться в соответствии с принципами *Этического кодекса* (http://www.vtg.mod.gov.rs/etichyeskiy-kodyeks.html). Статья должна содержать резюме с ключевыми словами, введение (цель исследования), основную часть (соответствующий обзор представительного исследования в данной области, четкое изложение научной новизны в представленном исследовании, соответствующую теоретическую основу, один или несколько примеров для демонстрирования и обсуждения представленных тезисов), заключение и список литературы (без нумерации заголовков и подзаголовков). Объем статьи не должен превышать один авторский лист (16 страниц формата А4 с одинарным интервалом, максимум до 24 страниц, включая ссылки и приложения). Статья должна быть набрана на компьютере с использованием специально подготовленного редакцией макета, который можно скачать на странице сайта *Правила и образец составления статьи*.

Заголовок

Заголовок должен отражать тему статьи. В интересах журнала и автора необходимо использовать слова и словосочетания, удобные для индексации и поиска. Если такие слова не содержатся в заголовке, то желательно их добавить в подзаголовок.

Текущий заголовок

Текущий заголовок пишется в титуле каждой страницы статьи с целью упрощения процесса идентификации, в первую очередь копий статьей в электронном виде. Заголовок содержит в себе фамилию и инициал имени автора (в случае если авторов несколько, остальные обозначаются с «et al.» или «и др.»), название работы и журнала (год, том, выпуск, начальная и заключительная страница). Заголовок статьи и название журнала могут быть приведены в сокращенном виде.

ФИО автора

Приводятся полная фамилия и полное имя (всех) авторов. Желательно, чтобы были указаны инициалы отчеств авторов. Фамилия и имя авторов из Республики Сербия всегда пишутся в оригинальном виде (с сербскими диакритическими знаками), независимо от языка, на котором написана работа.

Наименование учреждения автора (аффилиация)

Приводится полное (официальное) наименование и местонахождение учреждения, в котором работает автор, а также наименование учреждения, в котором автор провёл исследование. В случае организаций со сложной структурой приводится их иерархическая соподчинённость (напр. Военная академия, кафедра военных электронных систем, г. Белград). По крайней мере, одна из организаций в иерархии должна иметь статус юридического лица. В случае если указано несколько авторов, и если некоторые из них работают в одном учреждении, нужно отдельными обозначениями или каким-либо другим способом указать в каком из приведённых учреждений работает каждый из авторов. Аффилиация пишется непосредственно после ФИО автора. Должность и специальность по диплому не указываются.

Контактные данные

Электронный адрес автора указываются рядом с его именем на первой страницы статьи.

Категория (тип) статьи

Категоризация статьей является обязанностью редакции и имеет особое значение. Категорию статьи могут предлагать рецензенты и члены редакции, т.е.

редакторы рубрик, но ответственность за категоризацию несет исключительно главный редактор. Статьи в журнале распределяются по следующим категориям:

Научные статьи:

– оригинальная научная статья (работа, в которой приводятся ранее неопубликованные результаты собственных исследований, полученных научным методом);

– обзорная статья (работа, содержащая оригинальный, детальный и критический обзор исследуемой проблемы или области, в который автор внёс определённый вклад, видимый на основе автоцитат);

– краткое сообщение (оригинальная научная работа полного формата, но меньшего объёма или имеющая предварительный характер);

– научная критическая статья (дискуссия-полемика на определённую научную тему, основанная исключительно на научной аргументации) и научный комментарий.

Однако, в некоторых областях знаний научная работа в журнале может иметь форму монографического исследования, а также критического обсуждения научного материала (историко-архивного, лексикографического, библиографического, обзора данных и т.п.) – до сих пор неизвестного или недостаточно доступного для научных исследований. Работы, классифицированные в качестве научных, должны иметь, по меньшей мере, две положительные рецензии. В случае если в журнале объявляются и приложения, не имеющие научный характер, научные статьи должны быть сгруппированы и четко выделены в первой части номера.

Профессиональные статьи:

– профессиональная работа (приложения, в которых предлагаются опыты, полезные для совершенствования профессиональной практики, но которые не должны в обязательном порядке быть обоснованы на научном методе);

– информативное приложение (передовая статья, комментарий и т.п.);

– обзор (книги, компьютерной программы, случая, научного события и т.п.).

Объем кратких сообщений составляет 4-7 страниц, исследовательские статьи и тематические исследования с проблемно-ситуационным анализом − 10-14 страниц, однако объем обзорных статей может быть больше. Ограничения по количеству страниц не являются строгими, следовательно при соответствующем обосновании предоставленные работы могут быть длиннее или короче. В случае подачи расширенных версий ранее опубликованных докладов, представленных на конференции, редакция проверит было ли добавлено достаточно новых материалов для того, чтобы статья соответствовала стандартам журнала и условиям рецензирования. Добавленный материал должен быть новым, неопубликованным ранее. Новые результаты приветствуются, но не являются обязательным условием; однако ключевые тезисы, примеры, разработки и пр. должны быть более подробно представлены в статье по сравнению с первичным докладом на конфереции.

Язык работы

Статья должна быть написана на английском языке. Текст должен быть в лингвистическом и стилистическом смысле упорядочен, систематизирован, без сокращений (за исключением стандартных). Все физические величины должны соответствовать Международной системе единиц измерения – СИ. Очередность формул обозначается порядковыми номерами, проставляемыми с правой стороны в круглых скобках.

Резюме

Резюме является кратким информативным обзором содержания статьи, обеспечивающим читателю быстроту и точность оценки её релевантности. В интересах редакции и авторов, чтобы резюме содержало термины, часто используемые для индексирования и поиска статьей. Составными частями резюме являются введение/цель исследования, методы, результаты и выводы. В резюме должно быть от 100 до 250 слов, и оно должно находится между титулами (заголовок, ФИО авторов и др.) и ключевыми словами, за которыми следует текст статьи.

Ключевые слова

Ключевыми словами являются термины или фразы, адекватно представляющие содержание статьи, необходимые для индексирования и поиска. Ключевые слова необходимо выбирать, опираясь при этом на какой-либо международный источник (регистр, словарь, тезаурус), наиболее используемый внутри данной научной области. Число ключевых слов не может превышать 10. В интересах редакции и авторов, чтобы частота их встречи в статье была как можно большей. В статье они пишутся непосредственно после резюме.

Программа ASSISTANT предоставляет возможность использования сервиса KWASS, автоматически фиксирующего ключевые слова из источников/словарей по выбору автора/редактора.

Дата получения статьи

Дата, когда редакция получила статью; дата, когда редакция окончательно приняла статью к публикации; а также дата, когда были предоставлены необходимые исправления рукописи, приводятся в хронологическом порядке, как правило, в конце статьи.

Выражение благодарности

Наименование и номер проекта, т.е. название программы благодаря которой статья возникла, совместно с наименованием учреждения, которое финансировало проект или программу, приводятся в отдельном примечании, как правило, внизу первой страницы статьи.

Предыдущие версии работы

В случае если статья в предыдущей версии была изложена устно (под одинаковым или похожим названием, например, в виде доклада на научной конференции), сведения об этом должны быть указаны в отдельном примечании, как правило, внизу первой страницы статьи. Работа, которая уже была опубликована в каком-либо из журналов, не может быть напечатана в *«Военно-техническом вестнике»* ни под похожим названием, ни в изменённом виде.

Нумерация и название таблиц и графиков

Желательно, чтобы нумерация и название таблиц и графиков были исполнены на двух языках (на языке оригинала и на английском). Таблицы подписываются таким же способом как и текст и обозначаются порядковым номером с верхней стороны. Фотографии и рисунки должны быть понятны, наглядны и удобны для репродукции. Рисунки необходимо делать в программах Word или Corel. Фотографии и рисунки надо поставить на желаемое место в тексте. Для создания изображений и графиков использование функции снимка с экрана (скриншота) не допускается. В самом тексте статьи рекомендуется применение изображений и графиков, обработанных такими компьютерными программами, как: Excel, Matlab, Origin, SigmaPlot и др.

Ссылки (цитирование) в тексте

Оформление ссылок на источники в рамках статьи должно быть однообразным. *«Военно-технический вестник»* для оформления ссылок, цитат и списка использованной литературы применяет Гарвардскую систему (Harvard Referencing System, Harvard Style Manual). В тексте в скобках приводится фамилия цитируемого автора (или фамилия первого автора, если авторов несколько), год издания и по необходимости номер страницы. Например: (Petrović, 2010, pp.10-20). Рекомендации о способе цитирования размещены на странице сайта *Инструкция по использованию Гарвардского стиля*. При оформлении ссылок, цитат и списка использованной литературы необходимо придерживаться установленных норм. Программа ASSISTANT предоставляет при цитировании возможность использования сервиса CiteMatcher, фиксирующего пропущенные цитаты в работе и в списке литературы.

Примечания (сноски)

Примечания (сноски) к тексту указываются внизу страницы, к которой они относятся. Примечания могут содержать менее важные детали, дополнительные объяснения, указания об использованных источниках (напр. научном материале, справочниках), но не могут быть заменой процедуры цитирования литературы.

Литература (референции)

Цитированной литературой охватываются, как правило, такие библиографические источники как статьи, монографии и т.п. Вся используемая литература в виде референций размещается в отдельном разделе статьи. Названия литературных источников не переводятся на язык работы. *«Военно-технический вестник»* для оформления списка использованной литературы применяет Гарвардскую систему (Harvard Style Manual). В списке литературы источники указываются в алфавитном порядке фамилий авторов или редакторов. Рекомендации о способе цитирования размещены на странице сайта *Инструкция по использованию Гарвардского стиля*. При оформлении списка использованной литературы необходимо придерживаться установленных норм. При оформлении списка литературы программа ASSISTANT предоставляет возможность использования сервиса RefFormatter, осуществляющего контроль оформления списка литературы в соответствии со стандартами Гарвардского стиля. Нестандартное, неполное и непоследовательное приведение литературы в системах оценки журнала считается достаточной причиной для оспаривания научного статуса журнала.

Авторское заявление

Авторское заявление предоставляется вместе со статьей, в нем авторы заявляют о своем личном вкладе в написание статьи. В заявлении авторы подтверждают, что статья написана в соответствии с *Приглашением и инструкциями для авторов*, а также с *Кодексом профессиональной этики журнала*.

Все рукописи статей подлежат профессиональному рецензированию.

Список рецензентов журнала *«Военно-технический вестник»* размещён на странице сайта *Список рецензентов*. Процесс рецензирования описан в разделе *Правила рецензирования*.

Редакция

Почтовый адрес редакции:

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CALL FOR PAPERS AND ARTICLE FORMATTING INSTRUCTIONS

The instructions to authors about the article preparation for publication in the *Military Technical Courier* are based on the Regulations on categorization and ranking of scientific journals of the Ministry of Education, Science and Technological Development of the Republic of Serbia (Official Gazette of the Republic of Serbia, No 159/20). This Regulations aims at improving the quality of national journals and raising the level of their compliance with the international system of scientific information exchange.

The Military Technical Courier / Vojnotehnički glasnik (www.vtg.mod.gov.rs/index-e.html, втг.мо.упр.срб, ISSN 0042-8469 – print issue, e-ISSN 2217-4753 – online, UDC 623+355/359, DOI: 10.5937/VojnotehnickiGlasnik; https://doi.org/10.5937/VojnotehnickiGlasnik), is an peer-reviewed scientific journal.

The owners of the journal are the Ministry of Defence of the Republic of Serbia and the Serbian Armed Forces. The publisher and financier of the *Military Technical Courier* is the University of Defence in Belgrade (Military Academy).

The program of the journal is based on the annual classification of journals performed by a relevant Ministry as well as on its indexing in international indexing databases.

The journal covers scientific and professional fields within the educational-scientific field of **Natural-Mathematical Sciences**, as well as within the educational-scientific field of **Technical-Technological Sciences**, and especially the field of **defense sciences and technologies**. It publishes theoretical and practical achievements leading to professional development of all members of Serbian, regional and international academic communities as well as members of the military and ministries of defence in particular. It publishes papers with balanced coverage of analytical, experimental, and applied research as well as numerical simulations from various disciplines. The material published is of high quality and relevance, written in a manner that makes it accessible to a wider readership. The journal welcomes papers reporting original theoretical and/or practice-oriented research as well as extended versions of already published conference papers. Manuscripts for publication are selected through a double-blind peer-review process to validate their originality, relevance, and readability. This being so, the objective is not only to keep the quality of published papers high but also to provide a timely, thorough, and balanced review process.

The editorial policy of the *Military Technical Courier* is based on the COPE Core Practices, common COPE, DOAJ, OASPA and WAME Principles of Transparency and Best Practice in Scholarly Publishing as well as on the best accepted practices in scientific publishing. The Military Technical Courier has been a COPE (Committee on Publication Ethics) member since 2nd May 2018 and a member of OASPA (Open Access Scholarly Publishers Association) since 27th November 2015.

The Ministry of Education, Science and Technological Development of the Republic of Serbia classified the *Military Technical Courier* for the year 2023, on December 27, 2023

- **on the list of periodicals for computer sciences,**
  category: reputed national journal **(M51)**,
- **on the list of periodicals for electronics, telecommunications and IT,**
  category: reputed national journal **(M51)**,
- **on the list of periodicals for mechanical engineering,**
  category: national journal of international importance **(M24)**,
- **on the list of periodicals for materials and chemical technology,**
  category: national journal of international importance **(M24)**.

The approved lists of national periodicals for the year 2023 can be viewed on the website of the *Military Technical Courier*, page *Journal categorization*.

More detailed information can be found on the website of the Ministry of Education, Science and Technological Development of the Republic of Serbia.

The information on the categorization can be also found on the website of KOBSON (Consortium of Libraries of Serbia for Unified Acquisition).

The periodical is categorized in compliance with the Regulations on categorization and ranking of scientific journals of the Ministry of Education, Science and Technological Development of the Republic of Serbia (Official Gazette of the Republic of Serbia, No 159/20). More detailed information can be found on the website of the Ministry of Education, Science and Technological Development.

The journal is in the Serbian Citation Index – SCIndex (data base of national scientific journals), in the Scientific Information System Redalyc, and in the Russian Index of Science Citation/Российский индекс научного цитирования (RINC/РИНЦ) and is constantly monitored depending on the impact within the bases themselves. More detailed information can be viewed on the website of the *Military Technical Courier*, page *Journal indexing*.

The *Military Technical Courier*, in terms of its content, offers the possibility of open access (DIAMOND OPEN ACCESS) and applies the Creative Commons Attribution (CC BY) licence on copyright. The copyright details can be found on the *Copyright notice and Self-archiving policy* page of the journal's website.

Manuscripts are submitted online, through the electronic editing system ASSISTANT, developed by the Center for Evaluation in Education and Science – CEON.

The access and the registration are through the *Military Technical Courier* site http://www.vtg.mod.gov.rs/index-e.html, on the page *ASSISTANT* or the page *SCINDEKS* or directly through the link (aseestant.ceon.rs/index.php/vtg).

The detailed instructions about the registration for the service are on the website http://www.vtg.mod.gov.rs/index-e.html, on the page *Instructions for ASSISTANT*.

All authors submitting a manuscript for publishing in the *Military Technical Courier* should register for an ORCID ID following the instructions on the web page *Registration for an ORCID identifier*.

The *Military Technical Courier* publishes articles in English, using Arial and a font size of 11pt with Single Spacing.

The procedures of article preparation, writing and editing should be in accordance with the *Publication ethics statement* (http://www.vtg.mod.gov.rs/publication-ethics-statement.html).

The article should contain an abstract with keywords, introduction (motivation for the work), body (adequate overview of the representative work in the field, a clear statement of the novelty in the presented research, suitable theoretical background, one or more examples to demonstrate and discuss the presented ideas), conclusion, and references (without heading and subheading enumeration). The article length should not normally exceed 16 pages of the A4 paper format with single spacing, up to a maximum of 24 pages with references and supplementary material included.

The article should be formatted following the instructions in the Article Form which can be downloaded from website page *Article form*.

Title

The title should be informative. It is in both Journal's and author's best interest to use terms suitable for indexing and word search. If there are no such terms in the title, the author is strongly advised to add a subtitle.

Letterhead title

The letterhead title is given at a top of each page for easier identification of article copies in an electronic form in particular. It contains the author's surname and first name initial (for multiple authors add "et al"), article title, journal title and collation (year, volume, issue, first and last page). The journal and article titles can be given in a shortened form.

Author's name

Full name(s) of author(s) should be used. It is advisable to give the middle initial. Names are given in their original form (with diacritic signs if in Serbian).

Author's affiliation

The full official name and seat of the author's affiliation is given, possibly with the name of the institution where the research was carried out. For organizations with complex structures, give the whole hierarchy (for example, University of Defence in Belgrade, Military Academy, Department for Military Electronic Systems). At least one organization in the hierarchy must be a legal entity. When some of multiple authors have the same affiliation, it must be clearly stated, by special signs or in other way, which department exactly they are affiliated with. The affiliation follows the author's name. The function and title are not given.

Contact details

The postal addresses or the e-mail addresses of the authors are given in the first page.

Type of articles

Classification of articles is a duty of the editorial staff and is of special importance. Referees and the members of the editorial staff, or section editors, can propose a category, but the editor-in-chief has the sole responsibility for their classification.

Journal articles are classified as follows:

Scientific articles:

– Original scientific papers (giving the previously unpublished results of the author's own research based on scientific methods);

– Review papers (giving an original, detailed and critical view of a research problem or an area to which the author has made a contribution demonstrated by self-citation);

– Short communications or Preliminary communications (original scientific full papers but shorter or of a preliminary character);

– Scientific commentaries or discussions (discussions on a particular scientific topic, based exclusively on scientific argumentation) and opinion pieces.

Exceptionally, in particular areas, a scientific paper in the Journal can be in a form of a monograph or a critical edition of scientific data (historical, archival, lexicographic, bibliographic, data survey, etc.) which were unknown or hardly accessible for scientific research.

Papers classified as scientific must have at least two positive reviews.

If the journal contains non-scientific contributions as well, the section with scientific papers should be clearly denoted in the first part of the Journal.

Professional articles:

– Professional papers (contributions offering experience useful for improvement of professional practice but not necessarily based on scientific methods);

– Informative contributions (editorial, commentary, etc.);

– Reviews (of a book, software, case study, scientific event, etc.)

Short communications are usually 4-7 pages long, research articles and case studies 10-14 pages, while reviews can be longer. Page number limits are not strict and, with appropriate reasoning, submitted manuscripts can also be longer or shorter. If extended versions of previously published conference papers are submitted, Editors will check if sufficient new material has been added to meet the journal standards and to qualify such manuscripts for the review process. The added material must not have been previously published. New results are desired but not necessarily required; however, submissions should contain expansions of key ideas, examples, elaborations, etc. of conference papers.

Language

The language of the article should be in English. The grammar and style of the article should be of good quality. The systematized text should be without abbreviations (except standard ones). All measurements must be in SI units. The sequence of formulae is denoted in Arabic numerals in parentheses on the right-hand side.

Abstract and summary

An abstract is a concise informative presentation of the article content for fast and accurate evaluation of its relevance. It contains the terms often used for indexing and article search. A 100- to 250-word abstract has the following parts: introduction/purpose of the research, methods, results and conclusion.

Keywords

Keywords are terms or phrases showing adequately the article content for indexing and search purposes. They should be allocated heaving in mind widely accepted international sources (index, dictionary or thesaurus), such as the Web of Science keyword list for science in general. The higher their usage frequency is, the better. Up to 10 keywords immediately follow the abstract and the summary, in respective languages. For this purpose, the ASSISTANT system uses a special tool KWASS for the automatic extraction of key words from disciplinary thesauruses/dictionaries by choice and the routine for their selection, i.e. acceptance or rejection by author and/or editor.

Article acceptance date

The date of the reception of the article, the dates of submitted corrections in the manuscript (optional) and the date when the Editorial Board accepted the article for publication are all given in a chronological order at the end of the article.

Acknowledgements

The name and the number of the project or programme within which the article was realised is given in a separate note at the bottom of the first page together with the name of the institution which financially supported the project or programme.

Article preliminary version

If an article preliminary version has appeared previously at a meeting in a form of an oral presentation (under the same or similar title), this should be stated in a separate note at the bottom of the first page. An article published previously cannot be published in the *Military Technical Courier* even under a similar title or in a changed form.

Tables and illustrations

All the captions should be in the original language as well as in English, together with the texts in illustrations if possible. Tables are typed in the same style as the text and

are denoted by Arabic numerals at the top. Photographs and drawings, placed appropriately in the text, should be clear, precise and suitable for reproduction. Drawings should be created in Word or Corel.

For figures and graphs, proper data plot is recommended i.e. using a data analysis program such as Excel, Matlab, Origin, SigmaPlot, etc. It is not recommended to use a screen capture of a data acquisition program as a figure or a graph.

Citation in the text

Citation in the text must be uniform. The *Military Technical Courier* applies the Harvard Referencing System given in the Harvard Style Manual. When citing sources within your paper, i.e. for in-text references of the works listed at the end of the paper, place the year of publication of the work in parentheses and optionally the number of the page(s) after the author's name, e.g. (Petrovic, 2012, pp.10-12). A detailed guide on citing, with examples, can be found on *Military Technical Courier* website on the page *Instructions for Harvard Style Manual*. In-text citations should follow its guidelines. For checking in-text citations, the ASSISTANT system uses a special tool CiteMatcher to find out quotes left out within papers and in reference lists.

Footnotes

Footnotes are given at the bottom of the page with the text they refer to. They can contain less relevant details, additional explanations or used sources (e.g. scientific material, manuals). They cannot replace the cited literature.

Reference list (Literature)

The cited literature encompasses bibliographic sources such as articles and monographs and is given in a separate section in a form of a reference list. References are not translated to the language of the article.

In compiling the reference list and bibliography, the *Military Technical Courier* applies the Harvard System – Harvard Style Manual. All bibliography items should be listed alphabetically by author's name, without numeration. A detailed guide for listing references, with examples, can be found on *Military Technical Courier* website on the page *Instructions for Harvard Style Manual*. Reference lists at the end of papers should follow its guidelines. In journal evaluation systems, non-standard, insufficient or inconsequent citation is considered to be a sufficient cause for denying the scientific status to a journal.

Authorship Statement

The Authorship statement, submitted together with the paper, states authors' individual contributions to the creation of the paper. In this statement, the authors also confirm that they followed the guidelines given in *the Call for papers* and the *Publication ethics and malpractice statement of the journal*.

All articles are peer reviewed.

The list of referees of the *Military Technical Courier* can be viewed at website page *List of referees*. The article review process is described on the *Peer Review Process* page of the website.

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СПИСАК РЕЦЕНЗЕНАТА ВОЈНОТЕХНИЧКОГ ГЛАСНИКА
СПИСОК РЕЦЕНЗЕНТОВ ЖУРНАЛА «ВОЕННО-ТЕХНИЧЕСКИЙ ВЕСТНИК»
LIST OF REFEREES OF THE MILITARY TECHNICAL COURIER

Списак рецензената *Војнотехничког гласника* у 2023. години

Име, средње слово и презиме	**Област компетенције (научног интересовања)**	**ORCID iD**	**Web of Science ResearcherID**
Стојан Раденовић	математика	https://orcid.org/0000-0001-8254-6688	https://www.webofscience.com/wos/author/rid/AAT-9467-2020
Зоран Ђ. Миљковић	технологија машинске обраде, роботика, вештачка интелигенција, аутономни системи и машинско учење, вештачке неуронске мреже, интелигентни технолошки системи и процеси, методе одлучивања	https://orcid.org/0000-0001-9706-6134	https://www.webofscience.com/wos/author/rid/J-1423-2014
Душан Никезић	машинско учење, неуронске мреже	https://orcid.org/0000-0002-8885-2683	https://www.webofscience.com/wos/author/rid/AGP-3041-2022
Горан Ћировић	операциона истраживања	https://orcid.org/0000-0001-7419-8695	https://www.webofscience.com/wos/author/rid/KBA-4367-2024
Бобан З. Павловић	телекомуникационе мреже, квалитет сервиса, телекомуникациони саобраћај	https://orcid.org/0000-0002-5476-7894	https://www.webofscience.com/wos/author/rid/P-1904-2016
Андреја Самчовић	електроника, телекомуникације, ИТ, криптозаштита, мултимедија	https://orcid.org/0000-0001-6432-2816	https://www.webofscience.com/wos/author/rid/AFA-1465-2022
Иван А. Тот	базе података, информациони системи, заштита информационих система	https://orcid.org/0000-0002-5862-9042	https://www.webofscience.com/wos/author/rid/ITU-6682-2023
Александар Буквић	машинство	https://orcid.org/0000-0002-3025-8446	https://www.webofscience.com/wos/author/rid/ABZ-0890-2022
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Срећко Стопић	материјали и хемијске технологије	https://orcid.org/0000-0002-1752-5378	https://www.webofscience.com/wos/author/rid/AAC-7097-2021
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Ана Костов	материјали и хемијске технологије	https://orcid.org/0000-0001-6436-9091	https://www.webofscience.com/wos/author/rid/AFO-9003-2022

Име, средње слово и презиме	**Област компетенције (научног интересовања)**	**ORCID iD**	**Web of Science ResearcherID**
Зоран Максимовић	математика	https://orcid.org/0000-0001-9827-2490	https://www.webofscience.com/wos/author/rid/ITV-6823-2023
Рале Николић	математика	https://orcid.org/0000-0002-8703-3029	https://www.webofscience.com/wos/author/rid/Q-7179-2019
Горан Марковић	телекомуникације	https://orcid.org/0000-0003-1271-9277	https://www.webofscience.com/wos/author/rid/AAD-1065-2019
Александар Радевић	грађевински материјали и технологија бетона	https://orcid.org/0000-0002-3224-8145	https://www.webofscience.com/wos/author/record/ABH-5795-2022
Миодраг Регодић	геонауке	https://orcid.org/0000-0003-4675-4150	https://www.webofscience.com/wos/author/rid/IUN-4830-2023
Дејан Драјић	телекомуникације	https://orcid.org/0000-0003-1314-6191	https://www.webofscience.com/wos/author/rid/AFJ-8247-2022
Владимир А. Катић	енергетска електроника, електричне машине, електромоторни погони, квалитет електричне енергије, обновљиви извори електричне енергије	https://orcid.org/0000-0002-0138-8807	https://www.webofscience.com/wos/author/rid/AAT-1114-2021
Димитрије Бујаковић	дигитална обрада сигнала	https://orcid.org/0000-0001-7058-9293	https://www.webofscience.com/wos/author/rid/W-5463-2019
Бобан Саздић-Јотић	вештачка интелигенција, машинско учење, дубоко учење, електронско ратовање,	https://orcid.org/0000-0001-7239-174X	https://www.webofscience.com/wos/author/rid/GVT-2125-2022

Список рецензентов журнала *«Военно-технический вестник» в 2023 году*

ФИО	Области научной деятельности	ORCID iD	Web of Science ResearcherID
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Зоран Дж. Милькович	технология механической обработки, робототехника, искусственный интеллект, автономные системы и машинное обучение, искусственные нейронные сети, интеллектуальные технологические системы и процессы, методы принятия решений	https://orcid.org/0000-0001-9706-6134	https://www.webofscience.com/wos/author/rid/J-1423-2014
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Бобан З. Павлович	телекоммуникационные сети, качество обслуживания, телекоммуникационный трафик	https://orcid.org/0000-0002-5476-7894	https://www.webofscience.com/wos/author/rid/P-1904-2016
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Ана Костов	материалы и химические технологии	https://orcid.org/0000-0001-6436-9091	https://www.webofscience.com/wos/author/rid/AFO-9003-2022
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Горан Маркович	телекоммуникации	https://orcid.org/0000-0003-1271-9277	https://www.webofscience.com/wos/author/rid/AAD-1065-2019
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Миодраг Регодич	геонауки	https://orcid.org/0000-0003-4675-4150	https://www.webofscience.com/wos/author/rid/IUN-4830-2023
Деян Драич	телекоммуникации	https://orcid.org/0000-0003-1314-6191	https://www.webofscience.com/wos/author/rid/AFJ-8247-2022
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The list of the reviewers of the *Military Technical Courier* in 2023

First name, middle initial and last name	Field of competence (scientific interest)	ORCID iD	Web of Science ResearcherID
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Dušan Nikezić	machine learning, neural networks	https://orcid.org/0000-0002-8885-2683	https://www.webofscience.com/wos/author/rid/AGP-3041-2022
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Andreja Samčović	electronics, telecommunications, IT, crypto-protection, multimedia	https://orcid.org/0000-0001-6432-2816	https://www.webofscience.com/wos/author/rid/AFA-1465-2022
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Zoran Maksimović	mathematics	https://orcid.org/0000-0001-9827-2490	https://www.webofscience.com/wos/author/rid/ITV-6823-2023
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Miodrag Regodić	geosciences	https://orcid.org/0000-0003-4675-4150	https://www.webofscience.com/wos/author/rid/IUN-4830-2023

First name, middle initial and last name	Field of competence (scientific interest)	ORCID iD	Web of Science ResearcherID
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Dimitrije Bujaković	digital signal processing	https://orcid.org/0000-0001-7058-9293	https://www.webofscience.com/wos/author/rid/W-5463-2019
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ИЗЈАВА О ЕТИЧКОМ ПОСТУПАЊУ
ЭТИЧЕСКИЙ КОДЕКС
PUBLICATION ETHICS STATEMENT

ИЗЈАВА *ВОЈНОТЕХНИЧКОГ ГЛАСНИКА* О ЕТИЧКОМ ПОСТУПАЊУ

НАПОМЕНА: Уређивачка политика *Војнотехничког гласника* заснива се на препорукама Одбора за етичност у издаваштву (COPE Core Practices) и заједничким принципима транспарентности и најбоље праксе у издаваштву COPE, DOAJ, OASPA и WAME, као и на најбољим прихваћеним праксама у научном издаваштву. *Војнотехнички гласник* је члан COPE (Committee on Publication Ethics) од 2. маја 2018. године и члан OASPA (Open Access Scholarly Publishers Association) од од 27. новембра 2015. године. Уредништво примењује Контролну листу за издаваче отвореног приступа о спровођењу Препоруке УНЕСКО-а о отвореној науци. Овај документ је део Унесковог комплета алата за отворену науку, осмишљеног да подржи имплементацију Препоруке Унеска о отвореној науци. Произведен је у партнерству са OASPA.

Основна делатност научног часописа *Војнотехнички гласник* је објављивање чланака након стручне рецензије. У процесу уређивања, који има за циљ објављивање научних чланака, неопходно је постићи сагласност о етичким начелима у поступцима свих учесника (редакције, тј. уредника, чланова Уређивачког одбора и рецензената часописа, као и самих аутора). Поменута начела и поступци дефинисани су овом Изјавом *Војнотехничког гласника* о етичком поступању.

Мере, радње, одговорности и обавезе Редакције *Војнотехничког гласника*

Уредништво *Војнотехничког гласника* не тражи од аутора, нити од трећих страна, плаћање накнаде за аплицирање чланка за објављивање. Читав поступак уређивања и објављивања чланка за ауторе је потпуно бесплатан, како услуге пријављивања рукописа и њихове обраде, тако и услуге публиковања чланака. Не постоје било какви скривени трошкови.

Уредништво *Војнотехничког гласника* доноси коначну одлуку о томе који ће се рукописи објавити. Одлуке се доносе искључиво на основу вредности рукописа. Морају бити ослобођене расних, полних/родних, верских, етничких или политичких предрасуда. Приликом доношења одлуке о објављивању уредништво се руководи уређивачком политиком, водећи рачуна о законским прописима који се односе на клевету, кршења ауторских права и плагирање.

Рукописи се чувају као поверљив материјал. Информације и идеје садржане у рукописима не смеју се користити у личне сврхе без изричите писане дозволе аутора.

У свом раду, према препоруци Центра за евалуацију у образовању и науци (ЦЕОН), Редакција користи електронски систем уређивања часописа СЦИндекс (Српски цитатни индекс) АСИСТЕНТ (развијен на бази платформе OJS), који омогућава транспарентност и јавност рада, подразумевајући пуну одговорност за прихватање и објављивање чланка.

Процес уређивања чланка у *Војнотехничком гласнику* подразумева следеће обавезе Редакције:

1. Након пријема чланка, Редакција од аутора прибавља Изјаву о ауторству у којој аутори: наводе свој појединачни допринос у изради чланка; потврђују да су упознати са политком часописа у вези са повлачењем већ објављених радова; потврђују да послати рукопис представља оригиналан рад који су написали и потписали наведени аутори и који није објављен раније на неком другом месту, те да

се рукопис не разматра за објављивање на другом месту и није истовремено послат на рецензију у друге часописе; потврђују да чланак и додатни материјали не садрже тврдње које би се могле сматрати клеветом или било какве незаконите тврдње и не садрже материјал који на било који начин угрожава лична или власничка права физичких или правних лица; потврђују да немају сукоб интереса који би могао да доведе у питање интегритет и веродостојност резултата који су објављени у чланку, као и да су добили сагласност од носилаца ауторских права за коришћење свих извода из дела заштићених ауторским правима и других материјала заштићених ауторским правима који су коришћени у рукопису и да су навели изворе у рукопису и додатним материјалима.

2. Пре доделе рукописа уреднику Редакција проверава да ли је садржај рукописа плагијат, ради провере оригиналности приспелих радова и спречавања публиковања плагијата и дупликата. *Војнотехнички гласник* не објављује плагиране радове. Уредништво полази од става да је плагирање, односно преузимање туђих идеја, речи или других облика креативног доприноса и њихово представљање као сопствених, грубо кршење научне и издавачке етике. Плагирање може да укључује и кршење ауторских права, што је законом кажњиво.

Плагирање обухвата:

– дословно (реч по реч) или готово дословно преузимање или смишљено, ради прикривања извора, парафразирање делова текстова других аутора без јасног назначавања извора;

– копирање једначина, података или табела из других докумената без правилног назначавања извора и/или без дозволе изворног аутора или носиоца ауторског права.

Рукопис у којем се утврде јасне индиције да је плагиран биће аутоматски одбијен. У случају да се плагијаризам открије у већ објављеном раду, чланак ће бити опозван (повучен) у складу са процедуром описаном у тачки 6.

Ради спречавања плагијата у часопису рукописи се подвргавају провери уз помоћ система iThenticate/CrossRef у оквиру сервиса СЦИндекс АСИСТЕНТ. Резултате добијене провером верификује уредништво часописа у складу са смерницама и препорукама Комитета за етику публиковања (COPE).

3. Након провере на плагијаризам Редакција додељује приспели рукопис уреднику који ће надаље водити уређивачки процес и одабрати рецензенте. Уредништво и уредник којем је додељен приспели чланак не смеју бити у сукобу интереса у вези са рукописом који разматрају.

Ако такав сукоб интереса постоји, о избору рецензената и судбини рукописа одлучује Уређивачки одбор. Чланови Уређивачког одбора за које се претпостави да би могли бити у сукобу интереса такође не учествују у поступку одлучивања о одређеном рукопису.

4. Рукописи се упућују на рецензију тек након иницијалне оцене да ли су, с обзиром на форму и тематски делокруг, подобни за објављивање у *Војнотехничком гласнику*. Посебна се води рачуна да иницијална оцена не траје дуже него што је неопходно.

Војнотехнички гласник примењује поступак „двоструког анонимног рецензирања свих радова".

Главни уредник и чланови уредништва дужни су да предузму одговарајуће мере да аутори и рецензенти остану међусобно анонимни током и након процеса рецензије, у складу са двоструким слепим процесом рецензије. Поред тога, уредништво *Војнотехничког гласника* може пружити информацију о пристиглом

рукопису само аутору, рецензентима или потенцијалним рецензентима, уколико је то потребно.

Сваки рукопис рецензирају бар два рецензента, независно један од другог, а њихов идентитет је међусобно непознат. Рецензенти се бирају искључиво према томе да ли располажу релевантним знањима за оцену рукописа. Не смеју бити из исте институције као аутори рукописа, нити бити њихови коаутори у скоријој прошлости. Евентуални предлози аутора рукописа да се ангажују одређени рецензенти не уважавају се.

Циљ рецензије јесте да уредништву помогне у доношењу одлуке да ли рад треба прихватити или одбити, као и да се у процесу комуникације с уредником, ауторима и другим рецензентима побољша квалитет рукописа.

Током поступка рецензије главни уредник може да захтева од аутора да доставе додатне информације, укључујући и примарне податке, ако су оне неопходне за доношење суда о рукопису. Уредник и рецензенти морају да чувају такве информације као поверљиве и не смеју их употребити у друге сврхе.

У редовним околностима поступак рецензирања траје највише четири недеље, а само изузетно до три месеца. Период од пријема рада до његовог објављивања траје, у просеку, 90 дана.

У случају да аутори имају озбиљне и основане замерке на рецензију, уредништво проверава да ли је она објективна и да ли задовољава академске стандарде. Ако се посумња у објективност или квалитет рецензије, уредник ангажује додатне рецензенте.

Додатни рецензенти се ангажују и у случају када су одлуке постојећа два рецензента међусобно опречне (одбити/прихватити) или на други начин непомирљиве.

Коначну одлуку о прихватању рукописа за објављивање доноси искључиво уредништво.

5. У изузетним случајевима, а посебно у оним околностима када је избор часописа ограничен због специфичне тематике чланка, чланови уредништва часописа *Војнотехнички гласник* могу бити и аутори његових научних радова. Ипак, у овом случају уредништво спроводи додатно транспарентнији и ригорознији двоструко слепи процес рецензије. То подразумева да ће Редакција часописа уложити напор да одржи интегритет рецензије и необјективност сведе на најмању могућу меру, тако што ће други уредник сарадник водити процедуру рецензије независно од уредника аутора, при чему ће тај процес бити апсолутно транспарентан. Уредништво ће посебно водити рачуна да рецензент не препозна ко је написао рад. Као додатну меру предострожности, ако и када се такав чланак објави, уредништво може објавити пропратни коментар који показује колико је процес уређивања и рецензије био транспарентан.

6. У случају кршења права *Војнотехничког гласника*, носилаца ауторских права или самих аутора, објављивања истог рукописа у више часописа, лажног ауторства, плагијата, манипулације подацима ради преваре или било које друге злоупотребе, објављени рад се мора опозвати.

Чланак се може опозвати и зато да би се исправиле озбиљне и бројне омашке које није могуће обухватити објављивањем исправке. Опозив објављује уредништво, аутор(и) или обе стране споразумно.

Опозив има облик засебног рада који се приказује у садржају свеске и уреднички класификује као Опозив или Ретракција.

Опозиви се публикују према захтевима COPE које је разрадио CEON, као издавач базе у којој се *Војнотехнички гласник* примарно индексира, односно издавач

националног цитатног индекса где се метаподаци опозива и опозваних радова морају означити одговарајућим упозорењима и међусобно повезати унакрсним линковима:

У електронској верзији изворног чланка (оног који се повлачи) успоставља се веза (HTML линк) са обавештењем о повлачењу. Повучени чланак се чува у изворној форми, али са воденим жигом на PDF документу, на свакој страници, који указује да је чланак повучен (RETRACTED).

7. Редакција је отворена за академску, научно засновану, колегијалну и подстицајну размену мишљења и критику, односно за изношење евентуалних неслагања у вези са резултатима објављеним у чланцима *Војнотехничког гласника*, тиме што ће пружити могућност учесницима да њихови предметни дописи или полемике буду објављени у рубрици часописа „Писма уреднику".

Мере, радње, одговорности и обавезе рецензената *Војнотехничког гласника*

Рецензенти су дужни да квалификовано и у задатим роковима доставе уреднику оцену научне, односно стручне вредности рукописа. Рецензент води посебну бригу о стварном доприносу и оригиналности рукописа. Рецензија мора бити сасвим објективна, а суд рецензента јасан и поткрепљен аргументима.

Рецензенти оцењују рукописе у односу на усклађеност садржаја с профилом *Војнотехничког гласника*, значај и корисност садржаја, адекватност примењених метода, научну вредност садржаних информација, стил излагања и опремљеност текста. Рецензија има стандардни формат који обухвата оцене појединих димензија рада, општу оцену и закључну препоруку. Неприхватљива је лична критика аутора.

Рецензент не сме бити у сукобу интереса са ауторима или финансијером истраживања. Уколико такав сукоб постоји, рецензент је дужан да о томе правовремено обавести уредника. Рецензент не прихвата на рецензију радове изван области за коју се сматра потпуно компетентним.

Рецензенти треба да упозоре главног уредника ако основано сумњају или имају сазнање о повредама етичких стандарда од стране аутора рукописа. Дужност рецензента јесте да скрене пажњу уреднику на значајна подударања или сличност рукописа са већ објављеним радом, уколико о томе има лична сазнања. Такође, треба да препозна релевантне изворе који у раду нису узети у обзир. Може да препоручи цитирање одређених референци, али не сме да захтева цитирање радова објављених у часопису *Војнотехнички гласник* или својих радова, ако за то не постоји оправдање.

Од рецензената се очекује да својим сугестијама унапреде квалитет рукописа. Ако оцене да рад заслужује објављивање уз корекције, дужни су да прецизирају начин на који то може да се оствари.

Рукописи који су послати рецензенту морају се сматрати поверљивим документима. Рецензенти не смеју да користе материјал из рукописа за своја истраживања без изричите писане дозволе аутора.

Редакција *Војнотехничког гласника* подстиче рецензенте да рецензије верификују на својим персонализованим страницама на платформи Web of Science (WoS). Када рецензент уради рецензију чланка за *Војнотехнички гласник* биће питан да ли жели да прати, потврди и добије признање за свој рад на платформи WoS. Рецензент затим може користити своју верификовану рецензију као доказ о својим доприносима научној заједници у апликацијама за промоцију, финансирање и сл.

Рецензентска политика часописа:

– омогућава јавно приказивање рецензије (**искључиво након објављивања чланка**),

– рецензентима приказује наслове рецензираног чланка (**искључиво након објављивања чланка**).

Мере, радње, одговорности и обавезе аутора који пишу чланке за *Војнотехнички гласник*

Аутори гарантују да рукопис представља њихов оригиналан допринос, да није објављен раније и да се не разматра за објављивање на другом месту. Истовремено предавање истог рукописа у више часописа представља кршење етичких стандарда, што га искључује из даљег разматрања за објављивање у *Војнотехничком гласнику*. Рад који је већ објављен на неком другом месту не може бити прештампан у часопису *Војнотехнички гласник*.

Аутори сносе сву одговорност за целокупни садржај рукописа. Рукопис не сме да садржи неосноване или незаконите тврдње, нити да крши права других лица.

Аутори су дужни да обезбеде да њихов ауторски тим наведен у рукопису обухвати само она лица која су значајно допринела садржају рукописа. Ако су у битним аспектима истраживачког пројекта и припреме рада учествовала и друга лица, њихов допринос треба навести у фусноти или посебној напомени (Захвалница, Acknowledgements).

Обавеза је аутора да у напомени наведу назив и кодну ознаку научноистраживачког пројекта у оквиру којег је рад настао, као и пун назив финансирајуће институције. У случају да је рад под истим или сличним насловом био изложен на неком скупу у виду усменог саопштења, детаљи о томе треба да буду наведени на истом месту.

Аутори су дужни да потпуно и правилно цитирају изворе који су значајно утицали на садржај истраживања и рукописа. Делови рукописа, укључујући текст, једначине, слике или табеле, који су дословно преузети из других радова, морају бити јасно означени посебном напоменом, нпр. знацима навода са прецизном ознаком места преузимања (броја странице) или, ако су обимнији, наведени у засебном параграфу.

Пуне референце свих навода у тексту (цитата) морају бити наведене у засебном одељку (Литература) и то на једнообразан начин, у складу са цитатним стилом који *Војнотехнички гласник* користи (Harvard Style Manuel). У одељку Литература наводе се само цитирани, а не и остали извори коришћени приликом припреме рукописа.

У случају да аутори открију важну грешку у свом раду након његовог објављивања, дужни су да одмах о томе обавесте главног уредника (или Редакцију *Војнотехничког гласника*) и да сарађују у процесу повлачења или исправљања рада.

Обавеза је аутора да у рукопису наведу да ли су у финансијском или било ком другом битном сукобу интереса који би могао да утиче на њихове резултате или интерпретацију резултата.

Ако се у ауторовом истраживању појављују хемијска једињења, поступци или опрема који су опасни по здравље људи или животиња, то мора бити јасно назначено у рукопису.

Предавањем рукописа аутори се обавезују на поштовање уређивачке политике часописа *Војнотехнички гласник*, што потврђују достављањем Изјаве о ауторству.

Разрешавање спорних ситуација

Сваки појединац или институција могу уреднику и/или уредништву пријавити сазнања о кршењу етичких стандарда и другим неправилностима и о томе доставити веродостојне информације/доказе ради покретања истраге. Поступак провере изнетих доказа одвија се на следећи начин:

– главни уредник доноси одлуку о покретању истраге;

– током тог поступка сви докази се сматрају поверљивим материјалом и предочавају само оним лицима која су директно обухваћена случајем;

– осумњиченим лицима пружа се прилика да одговоре на изнете оптужбе;

– ако се утврди да је заиста дошло до неправилности, оцењује се да ли је реч о мањем прекршају или грубом кршењу етичких стандарда.

Мањи прекршаји, без последица по интегритет рада и *Војнотехничког гласника*, на пример када је реч о неразумевању или погрешној примени публицистичких стандарда, разрешавају се у директној комуникацији с ауторима и рецензентима, без укључивања трећих лица, на неки од следећих начина:

– ауторима и/или рецензентима упућује се писмо упозорења;

– објављује се исправка рада, на пример у случају када се са списка референци изоставе извори који су у самом тексту цитирани на прописан начин;

– објављује се ератум, на примеруколико се испостави да је грешка настала омашком уредништва.

У случају грубог кршења етичких стандарда, уредништво може да предузме различите мере:

– објављује саопштење или уводник у којем се случај описује;

– службено обавештава афилијативну организацију аутора/рецензента;

– повлачи објављени рада;

– изриче забрану објављивања у часопису на одређени период;

– предочава случај надлежним организацијама и регулаторним телима ради предузимања мера из њихове надлежности.

Ове мере могу се примењивати појединачно или истовремено. У процесу разрешавања случаја по потреби се консултују релевантне експертске организације, тела или појединци.

Приликом разрешавања етички спорних поступака уредништво се руководи смерницама Комитета за етику публиковања (COPE).

Одрицање одговорности

Изнесени ставови у објављеним радовима не изражавају ставове уредника, чланова Редакције и Уређивачког одбора часописа *Војнотехнички гласник*. Аутори преузимају правну и моралну одговорност за идеје изнесене у својим радовима. Издавач неће сносити никакву одговорност у случају испостављања било каквих захтева за накнаду штете.

Сукоб интереса

Војнотехнички гласник се придржава политике сукоба интереса коју препоручују COPE и/или друга међународна регулаторна тела (ICMJE, EASE). Од аутора се тражи да се изјасне о свом сукобу интереса у Изјави о сукобу интереса. У Изјави су аутори дужни да наведу: 1) изјаву о свим потенцијалним сукобима интереса за сваког именованог аутора релевантну за садржај чланка или изјаву да немају такве сукобе; 2) тврдња о начину на који је чланак финансиран, конкретно о финансирању, делимично или потпуно, од стране неке компаније или, алтернативно, тврдња да није било тог учешћа и 3) свеобухватно објашњење улоге спонзора у припреми чланка ако је чланак спонзорисан, било у целини или делимично.

Рекламирање

Није дозвољено рекламирање у *Војнотехничком гласнику.*

Детаљи о етичком поступању Војнотехничког гласника доступни су и на страницама часописа: ***Уређивачка политика***, ***Управљање квалитетом часописа***, ***Подршка квалитету радова*** *у Српском цитатном индексу – издавачу базе у којој се Војнотехнички гласник примарно индексира, односно издавачу националног цитатног индекса.*

КОДЕКС ПРОФЕССИОНАЛЬНОЙ ЭТИКИ ЖУРНАЛА *«ВОЕННО-ТЕХНИЧЕСКИЙ ВЕСТНИК»*

ЗАЯВЛЕНИЕ

ПРИМЕЧАНИЕ: Редакционная политика журнала «*Военно-технический вестник*» основана на рекомендациях Комитета по этике научных публикаций (COPE Core Practices), общих принципах прозрачности и лучшей практике издательской деятельности COPE, DOAJ, OASPA и WAME, а также на лучшей практике научно-издательской деятельности. Журнал «*Военно-технический вестник*» является членом COPE (Комитет по этике научных публикаций) со 2 мая 2018 года и членом OASPA (Ассоциация научных издателей открытого доступа) с 27 ноября 2015 года. Редакция применяет Контрольный перечень по выполнению Рекомендации ЮНЕСКО об открытой науке для издателей с открытым доступом. Данный документ является частью инструментария ЮНЕСКО по открытой науке, разработанного с целью поддержки внедрения Рекомендации ЮНЕСКО по открытой науке. Документ составлен при содействии с OASPA.

Публикация статей после их профессиональной рецензии является основной деятельностью научного журнала «*Военно-технический вестник*». В редакционно-издательском процессе в первую очередь необходимо достичь договоренности об этических нормах и принципах, применяемых ко всем участникам, начиная с автора, редакционной коллегии, профессиональных рецензентов до самого издателя. Вышеперечисленные принципы и процедуры утверждены настоящим Заявлением и Кодексом профессиональной этики журнала «*Военно-технический вестник*».

Меры, деятельность, права и обязанности редакции журнала «*Военно-технический вестник*»

Редакция журнала «*Военно-технический вестник*» не взимает плату за подачу и публикацию статей ни с их авторов, ни с третьих лиц. Все процедуры редактирования и публикации абсолютно бесплатны для авторов, включая подачу, прием, редактуру, корректуру, обработку и публикацию статьи. Нет никаких скрытых затрат.

Окончательное решение по выбору статей к публикации принимается редколлегией журнала «*Военно-технический вестник*». Решение принимается исключительно на основании научной ценности статьи. Не допускается дискриминация по признаку расы, пола, религии, этнического происхождения или политических убеждений. При принятии решений редакция руководствуется редакционной политикой, соблюдая положения законодательства, касающихся клеветы, нарушения авторских прав или плагиата.

Рукописи являются конфиденциальным материалом и хранятся соответствующим образом. Пользоваться информацией и идеями из рукописей в личных целях без письменного согласия авторов недопустимо.

По рекомендациям Центра поддержки оценки в образовании и науке (ЦЕОН) редакция журнала в своей работе пользуется электронной системой редактирования SCIndex (Сербский индекс цитирования) ASSISTANT (разработанной на основе платформы OJS), обеспечивающей прозрачность и доступность информации о текущем состоянии рукописи. Редакция несет полную ответственность за принятие решения о её публикации.

Процедура редактирования статьи в журнале «*Военно-технический вестник*» включает следующие обязанности редакции:

1. После приема статьи редакции необходимо получить от автора Авторское заявление, в котором авторы: должны указать свой индивидуальный вклад в создание статьи; подтвердить, что ознакомлены с политикой журнала в отношении отзыва уже опубликованных статей; подтвердить, что представленная рукопись является оригинальной работой, написанной и подписанной указанными авторами, что ранее она не публиковалась, а также, что рукопись не рассматривается другими изданиями для публикации и не проходит рецензирование в других журналах; подтвердить, что статья и дополнительные материалы не содержат никаких ложных высказываний, которые могли бы рассматриваться как клевета, не содержат никаких противоречащих закону утверждений или материалов, которые каким-либо образом могут поставить под угрозу личные или имущественные права физических или юридических лиц; подтвердить, что у них нет конфликта интересов, который мог бы поставить под сомнение целостность и достоверность результатов, представленных в статье, и что авторы получили согласие от правообладателей на использование всех выдержек из трудов и других материалов, защищенных авторским правом, которые использовались в рукописи, а также подтвердить, что они указали цитируемые источники в рукописи и дополнительных материалах.

2. Прежде чем редактор ознакомится с рукописью, редколлегия проверяет содержание рукописи на предмет плагиата, для того чтобы удостовериться в оригинальности представленных статей и предотвратить публикацию плагиата и дублирования. Журнал «*Военно-технический вестник*» не публикует статьи, содержащие плагиат. Редакция придерживается мнения, что плагиат, то есть использование чужих идей, слов или других творческих способов внесения вклада в науку без намеренного указания источника и их представление как своих собственных, является серьезным нарушением исследовательской и публикационной этики. Плагиат является нарушением авторских прав, и он уголовно наказуем.

Под плагиатом понимается:

- Дословное или приблизительное заимствование, а также намеренное перефразирование частей текстов других авторов без четкого указания источника, с целью скрыть источник;
- Копирование уравнений, данных или таблиц из чужих документов без четкого указания источника и/или без согласия автора или правообладателя;

Рукописи с явными признаками плагиата будут автоматически отклонены. Если плагиат выявлен в уже опубликованной статье, то она будет отозвана в порядке, описанном в пункте 6.

В целях предотвращения публикации плагиата в журнале рукописи проверяются с помощью системы iThenticate/CrossRef в рамках платформы SCIndex ASSISTANT. Результаты проверки перепроверяются редакционной коллегией журнала в соответствии с принципами и рекомендациями Комитета по этике научных публикаций (COPE).

3. После проверки на плагиат редколлегия передает рукопись редактору, который в дальнейшем будет вести редакционный процесс и выбирать рецензентов. Редколлегия и редактор, которым направлена представленная статья, не должны иметь конфликта интересов в отношении рассматриваемой ими рукописи.

При наличии такого конфликта интересов о выборе рецензентов и судьбе рукописи решение принимает редакционный совет. Члены редакционного совета, у которых тоже может быть конфликт интересов, также не участвуют в процессе принятия решения по конкретной рукописи.

4. Рукописи представляются на рецензирование только после первичной оценки с учетом соответствия оформления и тематики статьи для публикации в журнале «*Военно-технический вестник*». Особое внимание уделяется продолжительности оценки, которая длится ровно столько, сколько это необходимо.

Редакция журнала «*Военно-технический вестник*» проводит конфиденциальное рецензирование всех статей, применяя «двойной слепой метод».

Главный редактор и члены редколлегии обязаны принять соответствующие меры для того, чтобы авторы и рецензенты оставались анонимными друг для друга во время и после процесса рецензирования, проведенного методом двойного слепого рецензирования. Редакция журнала «*Военно-технический вестник*» при необходимости может предоставить информацию о представленной рукописи только автору, рецензентам или потенциальным рецензентам.

Все рукописи рецензируются как минимум двумя анонимными рецензентами, которые рецензируют рукопись независимо друг от друга. Рецензенты выбираются исключительно на основании их компетенции в области исследования рукописи. Рецензенты не могут быть коллегами авторов, то есть работать в том же учреждении, где работает автор, и они не должны иметь с авторами совместных работ, опубликованных в ближайшем прошлом. Возможные пожелания и предложения авторов о привлечении конкретных рецензентов не принимаются.

Рецензирование проводится с целью оказания помощи редколлегии при принятии решений о публикации статей или отказе авторам, а также улучшения качества статьи путем коммуникации рецензента с редактором, авторами и другими рецензентами.

В процессе рецензирования главный редактор вправе потребовать от автора дополнительную информацию, включая исходные данные, если это необходимо для оценки рукописи. Редактор и рецензенты должны хранить данную информацию в конфиденциальности и не вправе использовать ее в иных целях.

Процесс рецензирования обычно занимает максимум четыре недели и только в исключительных случаях он может длиться до трех месяцев. Период времени от подачи рукописи до ее публикации составляет примерно 90 дней.

Если авторы предъявляют серьезные и обоснованные претензии на рецензию, редколлегия должна проверить являются ли рассматриваемые рецензии объективными и соответствуют ли они академическим стандартам. Если объективность или качество этих рецензий вызывает сомнения, редактор привлекает дополнительных рецензентов.

Дополнительные рецензенты также привлекаются, в случае если решения выбранных рецензентов полностью расходятся (принять/отклонить) или противоречат друг другу по другим признакам.

Окончательное решение о принятии рукописи к публикации принимается исключительно редакционной коллегией.

5. В исключительных случаях, особенно когда выбор журнала ограничен из-за специфической темы статьи, членам редколлегии журнала «*Военно-технический вестник*» допускается публиковаться в нем. В таком случае редколлегия гарантирует, что процесс двойного слепого рецензирования будет еще более прозрачным и строгим. Это означает, что редакция приложит все усилия для того, чтобы сохранить целостность рецензии и свести к минимуму любую предвзятость. Заместитель редактора проведет абсолютно прозрачную процедуру рецензирования независимо от редактора-автора. Редакционная коллегия позаботится о том, чтобы рецензент не узнал кто является автором статьи. В качестве дополнительной меры предосторожности, если и когда такая статья будет опубликована, редколлегия к

статье добавит примечание, содержащее информацию о высоком уровне прозрачности, проведенных процессов редактирования и рецензирования.

6. В случае нарушения прав журнала «*Военно-технический вестник*», авторских прав или самих авторов, а также в случае повторной публикации одной и той же статьи в различных изданиях, присвоения авторства, плагиата, манипулирования данными или другого вида нарушения этических норм, опубликованная статья будет отозвана.

Статья также может быть отозваны с целью исправления многочисленных и/или фундаментальных недостатков, которые не могут быть устранены исправлениями после публикации. Отзыв статьи производится редакцией, автором (авторами) или обеими сторонами по взаимному согласию.

Уведомление об отзыве имеет форму отдельного документа, указанного в содержании выпуска под названием «Отзыв» или «Ретракция».

Отзывы публикуются в соответствии с требованиями COPE, разработанными CEON в его базе данных, где «*Военно-технический вестник*» индексируется в первую очередь, при этом метаданные отозванных и снятых с публикации статей должны быть обозначены соответствующим предупреждением и связаны между собой ссылками.

За статьей (утвержденной к отзыву) в электронном формате закрепляют HTML ссылку с уведомлением о её снятии с публикации. Изъятая статья хранится в исходном виде, но каждая страница ПДФ формата визируется водяным знаком, свидетельствующим об изъятии статьи с публикации (RETRACTED).

7. Редакция открыта для академического, научно обоснованного, коллегиального и продуктивного обмена мнениями и критикой, а также для выражения возможных разногласий относительно результатов в статьях, опубликованных в журнале «*Военно-технический вестник*», предоставляя возможность участникам дискуссии публиковать свои письма по предмету полемики в рубрике: «Письма редактору».

Меры, деятельность, права и обязанности рецензентов журнала «*Военно-технический вестник*»

Рецензенты должны профессионально и объективно аргументировать свою позицию и в указанный срок предоставлять редактору оценку научной ценности и оригинальности рукописи.

Рецензенты, рассматривая работы оценивают соответствие содержания статьи с профилем журнала «*Военно-технический вестник*», релевантность исследуемой области и примененных методов, оригинальность и научную значимость результатов, представленных в рукописи, стиль научного изложения, а также использование в тексте научного аппарата. Рецензия должна быть выполнена в стандартном формате, включающем оценки отдельных аспектов работы, общую оценку и заключительную рекомендацию. Личная критика автора недопустима.

У рецензента не должно быть конфликта интересов с авторами или организацией, финансирующей исследование. При наличии такого конфликта рецензент обязан своевременно сообщить об этом редактору. Рецензент может выполнять оценку только тех рукописей, которые соответствуют его области научных и профессиональных интересов, в которой он считается экспертом.

Рецензенты обязаны уведомлять главного редактора в случае, если они обоснованно подозревают или, если они выявили нарушения этических норм в рукописи.

Рецензенты обязаны идентифицировать релевантные существующие работы, которые автор не цитировал. По любому общему сведению или аргументу

приведенным в работе должны быть указаны соответствующие источники цитирования. Рецензент обязан обратить внимание редактора на значимые сходства работы с другими опубликованными работами, в случае если такое будет обнаружено. Также рецензенты должны рекомендовать релевантные источники для цитирования, которые не были учтены в работе. Однако они не вправе необоснованно требовать от авторов цитирования работ, опубликованных в журнале «*Военно-технический вестник*» или своих собственных работ.

Рецензенты оказывают содействие в улучшении качества рукописи своими предложениями и рекомендациями. Если они считают, что работу можно публиковать только после внесения определенных исправлений, то они обязаны указать каким именно образом это лучше сделать.

Рукописи, представленные рецензенту, считаются конфиденциальным документом. Рецензенты не вправе использовать материалы рукописей в своих собственных исследованиях без письменного согласия автора.

Редакция журнала *«Военно-технический вестник»* призывает рецензентов подтверждать свои рецензии на своей личной странице на платформе Web of Science (WoS). По завершении рецензии статьи, предложенной к публикации в журнале «*Военно-технический вестник*» рецензенты получат вопрос о том, желают ли они чтобы их рецензия была оценена и признана системой WoS. Таким образом, подтверждённую рецензию рецензент сможете использовать в качестве подтверждения научной деятельности, что поможет при подаче заявок на получение научных грантов, их финансирование и т.д.

Политика журнала относительно рецензий:

- обеспечивает публичный доступ к рецензии (**но только после публикации статьи**),
- позволяет рецензентам отображать заголовок рецензируемой статьи (**но только после публикации статьи**).

Меры, деятельность, права и обязанности авторов, публикующихся в журнале «*Военно-технический вестник*»

При подаче рукописи в журнал «*Военно-технический вестник*» автор гарантирует, что рукопись является оригинальной работой, которая не была опубликована ранее и не рассматривается к публикации в других издательствах. Дублирование одной и той же статьи является нарушением этического кодекса, соответственно при обнаружении дублирования автору будет отказано в ее публикации.

Авторы несут ответственность за полное содержание своей рукописи. Рукопись не должна содержать необоснованных или противоречащих закону высказываний, а также не должна нарушать права других лиц.

Авторы должны указать имена, отчества, фамилии всех соавторов, действительно участвующих в процессе исследования и внесших вклад в содержание рукописи. Если в важных аспектах исследовательского проекта и подготовке работы участвовали и другие лица необходимо описать их вклад в сноске или в отдельном примечании (Благодарность, Acknowledgements).

В примечании также должны быть указаны название и кодовый номер научно-исследовательского проекта, в рамках которого была написана статья, а также полное название учреждения/организации, оказавшей финансовую поддержку в осуществлении исследования. В случае, если данное исследование ранее уже было представлено в устной форме, например, на конференции, в примечании необходимо указать название конференции и прочие данные.

Авторы обязаны правильно и полностью цитировать источники, которые оказали значительное влияние на содержание исследования и рукописи. Фрагменты рукописи, включая текст, уравнения, рисунки, графики и таблицы, непосредственно взятые из работ других авторов, должны быть наглядно выделены, например, кавычками с точной ссылкой на первоисточник (номер страницы). Если предмет цитирования длинный, то его следует оформить отдельным абзацем.

Подробная информация о ссылках в тексте (цитирование) должна быть указана в отдельном разделе (Литература) в соответствии со стилем цитирования, используемым журналом «*Военно-технический вестник*» (Harvard Style Manuel). В разделе «Литература» следует указывать не все источники, использованные при подготовке рукописи, а только цитируемые.

Авторы обязаны незамедлительно уведомить главного редактора (или редакцию журнала «*Военно-технический вестник*») и содействовать редакции в процессе отзыва или исправления ошибок, в случае если после публикации статьи ими была обнаружена грубая ошибка в ее содержании.

Авторы обязаны указать в рукописи, если существует финансовый или любой другой конфликт интересов, который может повлиять на результаты или интерпретацию результатов исследования.

Если исследование связано с химическими веществами, видами деятельности или оборудованием, представляющими угрозу здоровью людей или животных, это должно быть четко указано в рукописи.

При подаче рукописи авторы соглашаются соблюдать редакционную политику журнала «*Военно-технический вестник*», подтвердив свое согласие с условиями редакционной политики журнала предоставлением Авторского заявления.

Разрешение спорных ситуаций

Любое лицо либо учреждение вправе в любой момент предъявить претензию редактору или редколлегии в связи с нарушением этических стандартов, подкрепив ее достоверными доказательствами. По получении претензии, подкрепленной доказательствами, редакционная комиссия проведет расследование в соответствии со следующими принципами:

- главный редактор принимает решение о проведении расследования;
- в процессе проверки доказательств все материалы считаются конфиденциальными и будут предоставлены только тем лицам, которые непосредственно причастны к процессу проверки;
- подозреваемым лицам в нарушении этических норм будет предоставлена возможность ответить на выдвинутое против них обвинение;
- если установлено, что нарушение действительно произошло, оценивается степень тяжести нарушения этических норм.

В случае негрубого нарушения (без угрозы репутации журнала „*Военно-технический вестник*“), например, в случае неправильного толкования или применения публикационных стандартов, редакция напрямую без содействия третьих лиц, обращается к нарушителю следующим образом:

- автору/рецензенту, допустившему ошибку/нарушение направляется письменное предупреждение;
- публикуется уведомление об исправлении, например, если источник, цитируемый в тексте статьи не внесен в список литературы;
- публикуется исправление ошибки, в случае если ошибка произошла по вине редакции.

В случае грубого нарушения этических норм редакция принимает решение о дальнейших мерах:

- публикуется отдельная заметка или статья редактора с описанием случая нарушения этических стандартов;
- направляет официальное уведомление руководителям учреждения, в котором работает автор/рецензент;
- редакция производит отзыв опубликованной статьи;
- редакция объявляет запрет к публикации автора/рецензента на определенный срок;
- информирует соответствующие профессиональные организации и компетентные учреждения о случае, в целях привлечения нарушителя к ответственности.

Редакция вправе предпринимать меры одновременно или поочередно по отдельности. В процессе разрешения дела по мере необходимости проводятся консультации с соответствующими экспертными организациями, органами или лицами.

При разрешении спорных ситуаций редакция журнала руководствуется предписаниями и инструкциями Комитета по этике научных публикаций (COPE).

Отказ от ответственности

Выносимые положения в опубликованных статьях не отражают точку зрения редактора, редколлегии и редакционного совета журнала «*Военно-технический вестник*». Авторы несут юридическую и моральную ответственность за представленные в своих работах идеи. Редакция не несет никакой ответственности в случае возникновения требований по возмещению материального ущерба и взысканию компенсации морального вреда.

Конфликт интересов

Журнал *«Военно-технический вестник»* придерживается политики конфликта интересов, рекомендованной COPE и/или другими международными органами, регулирующими публикации научных исследований (ICMJE, EASE). Авторы должны заявить о своем конфликте интересов в Заявлении о конфликте интересов (CoIS). В CoIS каждый названный автор статьи обязан предоставить: (1) Заявление о любых потенциальных конфликтах интересов, имеющих отношение к содержанию, или заявление об отсутствии таких конфликтов. (2) Раскрытие информации о том, как финансируется статья, включая конкретное раскрытие любого и всего финансирования компании (частичного или полного) или заявление об отсутствии такого участия (если применимо). (3) Подробное объяснение роли спонсоров в подготовке статьи, если статья спонсируется частично или полностью.

Реклама

Реклама в журнале *«Военно-технический вестник»* не допускается.

Более подробно с информацией об Этическом кодексе журнала «Военно-технический вестник» можно ознакомиться на интернет-страницах журнала: ***Редакционная политика***, ***Управление качеством журнала***, ***Поддержка качеству работ*** *на сайте Сербского индекса научного цитирования, в базе которой журнал «Военно-технический вестник» первично индексируется.*

STATEMENT OF THE *MILITARY TECHNICAL COURIER* ON ETHICAL CONDUCT

NOTE: The editorial policy of the *Military Technical Courier* is based on the COPE Core Practices, common COPE, DOAJ, OASPA and WAME Principles of Transparency and Best Practice in Scholarly Publishing as well as on the best accepted practices in scientific publishing. The *Military Technical Courier* has been a COPE (Committee on Publication Ethics) member since 2nd May 2018 and a member of OASPA (Open Access Scholarly Publishers Association) since 27th November 2015. The editorial office applies Checklist for open access publishers on implementing the UNESCO Recommendation on Open Science. This document is part of the UNESCO Open Science Toolkit, designed to support implementation of the UNESCO Recommendation on Open Science. It has been produced in partnership with OASPA.

The main scope of the *Military Technical Courier* scientific journal is publishing scientific articles after peer reviewing. In the editing process leading to publishing scientific articles, it is necessary to reach an agreement on ethical principles in the behavior of all parties involved (Editorial Office i.e. Editor, members of the Editorial Board, reviewers, and authors alike). The aforementioned principles and practices are defined by this Statement of the *Military Technical Courier* on Ethical Conduct.

Measures, activities, responsibilities, and duties of the *Military Technical Courie*r Editorial Office

The Editorial Office of the *Military Technical Courier* does not charge for submitting manuscripts from their authors nor from third parties. The whole process of processing and publishing is completely free of charge for authors – from the manuscript submission services through processing to the article publishing services. There are no hidden costs whatsoever.

The Editorial Office decides finally which manuscripts are to be published. Decisions are based only on manuscript values. In making decisions, there is no discrimination on the basis of race, sex/gender, religion, ethnic origin or political beliefs. In making decisions, the Editorial Office is guided by the Journal's policy, complying with legal regulations dealing with libel, copyright infringement and plagiarism.

Manuscripts are kept as confidential material. No information and/or ideas from manuscripts are to be used for private purposes without authors' explicit consent in writing.

In its work, following the recommendations of the Centre for Evaluation in Education and Science (CEON/CEES), the Editorial Office uses the Serbian Citation Index (SCIndeks) ASSISTANT electronic editing system which provides full transparency of the publishing process (developed on the basis of the OJS platform) while being fully responsible for accepting and publishing articles.

The editing process in the *Military Technical Courier* consists of the following steps of the Editorial Office:

1. After receiving manuscripts, the Office asks the authors to fill in the Authorship Statement in which they: specify their contribution to the manuscript; confirm that they are familiar with the Journal's policy regarding the retraction of already published articles; confirm that the submitted manuscript is an original paper written and signed by its authors, not previously published, not considered for publication elsewhere and not concurrently sent for review to other journals; confirm that the manuscript and the additional material contain neither any false statements that could be considered defamation, any false claims nor material that in any way endangers personal or property rights of natural or legal persons; confirm that they do not have a conflict of interest that could cast doubt on the article's

integrity and the credibility of the results published in it; confirm that they have obtained permission from copyright holders to use all content from copyright-protected works and other copyright-protected material used in the manuscript; and confirm that they have acknowledged the sources in the manuscript and supplementary material.

2. Before the Editor attends to the manuscript, the Editorial Office checks the manuscript content for plagiarism in order to establish the originality of submitted papers and prevent plagiarism and duplication. The *Military Technical Courier* does not publish plagiarized papers. The Editorial Office is of the opinion that plagiarism i.e. using another's ideas, words or other creative ways of contributing without acknowledging their source and presenting them as one's own is serious violation of research and publication ethics. Plagiarism may also involve copyright infringement which is violation of law.

Plagiarism involves:

- Verbatim or nearly verbatim copying or paraphrasing parts of other authors' texts without clear citing of the source purposefully, in order to hide the source;
- Copying equations, data or graphical presentations from documents of others without clearly acknowledging the source and/or without the authorization of the original author or copyright holder;

A manuscript showing obvious signs of plagiarism is rejected automatically. In case plagiarism is found in an already published article, the article is revoked (retracted) following the procedure given in point 6.

In order to prevent plagiarism, the Journal uses the iThenticate/CrossRef system within the SCIndeks Assistant service for checking manuscripts. The results obtained by such checking are verified by the Editorial Office in accordance with the COPE guidelines and recommendations.

3. After being checked for plagiarism, a manuscript is dealt with by the Editor who continues the publishing process by choosing peer reviewers. Neither the Editorial Team nor the Editor in charge of the particular manuscript are allowed to be in a conflict of interest in the case of the manuscript in question.

If there is a conflict of interest, it is up to the Editorial Board to decide on peer reviewers and further actions regarding the manuscript. The Editorial Board members who might be in a conflict of interest are also excluded from the decision-making process in the case of the manuscript in question.

4. Manuscripts are sent to reviewers only after the initial assessment stating that, based on their form and content scope, they are eligible for publication in the *Military Technical Courier*. Special care is taken that the initial assessment does not last longer than necessary.

The *Military Technical Courier* makes use of double-blind peer review of all papers.

It is mandatory for the Editor-in-Chief and the Editorial Team members to take appropriate measures that authors and reviewers remain anonymous to each other during and after the reviewing process, in accordance with the double-blind peer review method. The Editorial Team of the *Military Technical Courier* can give information on the submitted manuscript only to the author, reviewers or potential reviewers if necessary.

Every manuscript has to be reviewed by at least two reviewers who are not aware of each other's identity and who review the manuscript independently of each other. Reviewers are chosen solely based on whether they have relevant knowledge for the particular paper review. They must not have the same affiliation as the paper author(s) and they are not allowed to have been co-authors with them in the recent past. Possible suggestions of manuscript authors on engaging particular reviewers are not accepted.

The purpose of a review is to help the Editorial Team make a decision whether the paper should be accepted or rejected and to improve the quality of the manuscript through the process of communication with the Editor, authors and other reviewers. During the reviewing process, the Editor-in-Chief may ask the author to submit additional information, including raw data, if it is necessary for assessing the manuscript. The Editor and the reviewers should treat such information as confidential and should not use it for any other purpose.

The reviewing process usually lasts for four weeks maximum, and only exceptionally up to three months. The period of time from the manuscript submission to its publishing is approximately 90 days.

If authors have some serious and justifiable concern with reviews, the Office checks whether the reviews in question are objective and of academic standard. If the objectivity or quality of these reviews are questionable, the Editor engages additional peer reviewers.

Additional reviewers are also engaged when the decisions of the assigned reviewers are contradictory (accept/reject) or somehow incompatible.

The final decision on the acceptance of a manuscript for publication is made exclusively by the Editorial Team.

5. In extreme cases, especially when the choice of journals is limited due to the paper's narrow subject field, it is acceptable that the members of the Editorial Team of the *Military Technical Courier* may also be authors of scientific articles published in it. However, in this case, the Editorial Team ensures that the double-blind review process is even more transparent and more rigorous. This means that the Editorial Office will make every effort to maintain the integrity of the review and to minimize any bias by having another associate editor handle the review procedure independently of the editor – author in a completely transparent process. The Editorial Team will take special care that a reviewer does not recognize the author's identity. As an extra precaution, if and when such an article is published, the Editorial Team may accompany the article with a note about a high level of transparency of the editing and reviewing processes in question.

6. In case of the violation of the rights of the *Military Technical Courier*, copyright holders or authors as well as in case of multiple publication, fake authorship, plagiarism, data manipulation or any other malpractice, the published article must be retracted.

Articles can also be retracted for correcting numerous and/or fundamental flaws which cannot be dealt with by post-publication corrections. Retractions are issued by the Editorial Team, the author(s) or by both parties based on mutual agreement.

A retraction notice has a form of a separate paper listed in the Contents of an issue, classified as "Retraction".

Retractions are published in accordance with the COPE Guidelines elaborated by the CEON/CEES in its database where the *Military Technical Courier* is primarily indexed.

The CEON/CEES publishes the national citation index where the metadata of retraction notices and related retracted articles must be clearly and appropriately marked and mutually cross-linked. An electronic version of the original article (the one being retracted) is provided with a HTML link to the retraction notice. Retracted articles are retained in their original form but with a watermark on each page of the PDF document indicating that the article in question is RETRACTED.

7. The Editorial Office is open to academic, scientifically based, collegial and productive exchange of opinions and critiques as well as for expressing possible disagreements regarding the results in articles published in the *Military Technical Courier* by enabling polemics and reactions to be published in the Journal's section "Letters to the Editor".

Measures, activities, responsibilities, and duties of the *Military Technical Courier* reviewers

Reviewers are required to assess the scientific and professional values of manuscripts in a qualified and timely manner. They have to focus especially on the genuine contribution and originality of manuscripts. A review should be completely unbiased and the reviewer's assessment unambiguous and backed with arguments.

Reviewers assess manuscripts with regard to the compliance of the content with the Journal's character, importance and effectiveness of the content, convenience of the methods applied, scientific value of the presented information as well as with regard to the style, tone and form of the text. A review has a standard form which comprises assessment of particular elements of a manuscript, general assessment and final recommendation. Personal criticism of the author is unacceptable.

Reviewers must not be in a conflict of interest with authors or research funders. If such a conflict exists, the reviewer is obliged to inform the Editor about it in due time. Reviewers should not accept to review papers out of the scope of their full competence.

They should notify the Editor-in-Chief if they have a reasonable doubt about the author violating ethical standards. A duty of reviewers is to call to the editor's attention any substantial similarity or overlap between the manuscript under consideration and any other published paper of which they have personal knowledge. Also, hey should recognize relevant sources which have not been taken into account in the manuscript. They may recommend citing particular references but must not insist on citing articles published in the *Military Technical Courier* or their own papers if there is no justification for doing so.

Their suggestions should aim at improving the manuscript's quality. If they conclude the paper deserves to be published but with corrections, they are required to provide detailed instructions.

Manuscripts sent to reviewers must be treated as confidential documents. The material from manuscripts must not be used for reviewers' own research without the author's explicit consent in writing.

The Editorial Office of The *Military Technical Courier* encourages reviewers to verify their reviews on their personal profile pages on the Web of Science (WoS) platform. When reviewers submit their peer reviews to The *Military Technical Courier*, they will be asked whether they would like to track, verify and showcase them on the WoS platform. Reviewers can further use their verified peer reviews as evidence of their contribution to the scientific community in applications for promotion, grants, etc.

The reviewing policy of the journal:

- allows visibility of the review in public (**only after the article has been published**),
- shows titles of reviewed articles to reviewers (**only after the article has been published**).

Measures, activities, responsibilities and duties of the *Military Technical Courier* authors

Authors undertake that the manuscripts are their original contribution, that they have not been published before, and that they are not considered for publication elsewhere.

Parallel submission represents violation of ethical codes which eliminates the manuscript in question from being further considered for publication in the *Military Technical Courier*. A paper already published elsewhere cannot be published in the *Military Technical Courier*.

Authors are fully responsible for the complete content of their manuscripts. The manuscript should not contain unfunded or illegal statements nor infringe on the rights of others.

Authors are required to make sure that their team mentioned in the manuscript consisits only of individuals whose contribution to the content of the manuscript is significant. If there were other individuals who participated in some other important moments of the research project or in the manuscript preparation, their contribution is to be mentioned in a footnote or in a separate note (Acknowledgement).

The name and the code number of the research project from which the paper originates must be given in a note, as well as the full name of the funding institution. In case the paper has been presented orally elsewhere with the same title or a similar one, the details of such a communication have to be metioned in a note as well.

Authors' duty is to correctly and completely quote the sources which had a significant influence on the content of the research and the manuscript. Fragments of the manuscript, including the text, equations, graphical presentations, figures and tables, directly included from the works of others, must be clearly marked e.g. by quotation marks with a precise reference to the original source (page number) or in a separate paragraph if they are bigger in size.

Full references of all citations in the main text must be given in a separate section (References) in a uniform way, complying with the citation style used in the *Military Technical Courier* (Harvard Style Manual). The Reference Section contains only the cited sources, not all sources used in the preparation of the manuscript.

In case authors find an error in their article after its publication, they are obliged to promptly notify the Editor-in-Chief (or the Editorial Office) and cooperate in the process of retracting or correcting the article.

Authors are under the obligation to declare in their manuscript whether there is a financial or any other conflict of interest that may influence the results or interpretations of the results.

If the research involves chemicals, activities or equipment posing risk to the health of humans or animals, this must be clearly stated in the manuscript.

When submitting their manuscript, authors agree to comply with the editorial policy of the *Military Technical Courier* and they confirm such compliance by submitting the Authorship Statement.

Handling allegations of misconduct

Any individual or institution may notify the Editor and/or Editorial Team of ethical malpractice and other misconduct by supplying undisputed information/evidence to start an enquiry. The procedure for investigating the case raised with the supplied evidence is as follows:

- Editor-in-Chief determines to start investigation;
- all evidence is considered confidential during investigation and is available only to those directly involved in the case;
- individuals suspected of ethical breaches are given a chance to respond to the allegations;
- if a misconduct is confirmed, it is further established whether there is a minor or a major violation of publication ethics.

Minor issues not affecting either the integrity of the paper or that of the Journal, e.g. misunderstanding or misapplication of publication standards, are dealt with by directly communicating authors and reviewers, without third parties involved, in one of the following ways:

- authors and/or reviewers are sent a letter of warning;
- a correction notice is published, e.g. when a source, otherwise properly cited within the main text, has been omitted from the Reference List;
- an erratum is published, e.g. when an error is made by the Editorial staff.

Serious, major violations of the ethical code may lead to different measures:
- a separate note or a leading article is published, describing the case;
- afilliate institution of the author/reviewer is officially notified;
- the published article is retracted;
- publishing in the Journal is prohibited for a defined period of time;
- relevant organisations and regulatory bodies are informed about the case for taking course of actions within their competence.

These measures may be taken separately or jointly. In the process of handling the case, relevant expert organisations, bodies or individuals are consulted when necessary.

In resolving ethically controversial issues, the Editorial Team follows the guidelines of the Committee on Publication Ethics (COPE).

Disclaimer

The views in the published articles do not represent the views of the Editor, the Editorial Office, the Editorial Team or the Editorial Board of the *Military Technical Courier* journal. Authors take full legal and moral responsibility for the information and opinions expressed in their articles. The publisher will not be held liable in any way for any claims or damages.

Conflict of interest

The *Military Technical Courier* adheres to the conflict of interest policy recommended by COPE and/or other international research publishing regulatory authorities (ICMJE, EASE). The authors must declare their conflicts of interest in the Conflict of Interest Statement (CoIS). In the CoIS, each named author of the article is required to provide: (1) A statement of any potential conflicts of interest relevant to the content or a statement that there are no such conflicts. (2) Disclosure of how the article is funded, including specific disclosure of any and all company funding (partial or total), or a statement that there was no such involvement (if applicable). (3) A comprehensive explanation of the role of sponsors in article preparation if the article is sponsored in part or whole.

Advertising

Advertising in the *Military Technical Courier* is not permitted.

Details on the ethical conduct of the Military Technical Courier are also available on the Journal pages: ***Publication Policy****,* ***Journal Quality Management*** *and* ***Article Quality Support*** *via the website of the Serbian Citation Index (SCIndex) – publisher of the national citation index, i.e. publisher of the base in which the Military Technical Courier is primarily indexed.*

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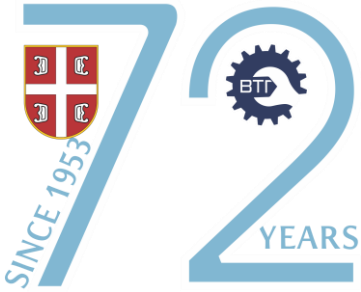
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