ISSN 0042-8469
e-ISSN 2217-4753
УДК 623 + 355/359

Вол. 69, бр. 3
2021

ВТГ

НАУЧНИ ЧАСОПИС МИНИСТАРСТВА ОДБРАНЕ И ВОЈСКЕ СРБИЈЕ

ВОЈНОТЕХНИЧКИ ГЛАСНИК

втг.мо.упр.срб

www.vtg.mod.gov.rs

ВОЈНОТЕХНИЧКИ ГЛАСНИК 3 2021

ISSN 0042-8469
e-ISSN 2217-4753
УДК 623 + 355/359

Том 69, № 3
2021

НАУЧНЫЙ ЖУРНАЛ МИНИСТЕРСТВА ОБОРОНЫ
И ВООРУЖЕННЫХ СИЛ РЕСПУБЛИКИ СЕРБИЯ

ВОЕННО-ТЕХНИЧЕСКИЙ ВЕСТНИК

ВТГ.МО.УПР.СРБ

www.vtg.mod.gov.rs

ВОЕННО-ТЕХНИЧЕСКИЙ ВЕСТНИК
3 2021

ISSN 0042-8469
e-ISSN 2217-4753
UDC 623 + 355/359

Vol. 69, Issue 3
2021

MTC

SCIENTIFIC JOURNAL OF THE MINISTRY OF DEFENCE AND THE SERBIAN ARMED FORCES

MILITARY TECHNICAL COURIER

MILITARY TECHNICAL COURIER
3 2021

ВТГ.МО.УПР.СРБ

www.vtg.mod.gov.rs

ISSN 0042-8469
e-ISSN 2217-4753
UDC 623 + 355/359

НАУЧНИ ЧАСОПИС МИНИСТАРСТВА ОДБРАНЕ И ВОЈСКЕ СРБИЈЕ

ВОЈНОТЕХНИЧКИ ГЛАСНИК

ВОЛУМЕН 69 • БРОЈ 3 • ЈУЛ – СЕПТЕМБАР 2021.

NAUČNI ČASOPIS MINISTARSTVA ODBRANE I VOJSKE SRBIJE

VOJNOTEHNIČKI GLASNIK

VOLUMEN 69 • BROJ 3 • JUL – SEPTEMBAR 2021.

втг.мо.упр.срб
www.vtg.mod.gov.rs
COBISS.SR-ID: 4423938
COBISS.SR-ID: 181287436
DOI: 10.5937/VojnotehnickiGlasnik

ISSN 0042-8469
e-ISSN 2217-4753
UDC 623 + 355/359

НАУЧНЫЙ ЖУРНАЛ МИНИСТЕРСТВА ОБОРОНЫ И ВООРУЖЁННЫХ СИЛ РЕСПУБЛИКИ СЕРБИЯ

ВОЕННО-ТЕХНИЧЕСКИЙ ВЕСТНИК

ТОМ 69•НОМЕР ВЫПУСКА 3•ИЮЛЬ – СЕНТЯБРЬ 2021.

SCIENTIFIC JOURNAL OF THE MINISTRY OF DEFENCE AND SERBIAN ARMED FORCES

MILITARY TECHNICAL COURIER

VOLUME 69•ISSUE 3•JULY – SEPTEMBER 2021

ВТГ.МО.УПР.СРБ
www.vtg.mod.gov.rs
COBISS.SR-ID: 4423938
COBISS.SR-ID: 181287436
DOI: 10.5937/VojnotehnickiGlasnik

ВЛАСНИЦИ:
Министарство одбране и Војска Србије
ИЗДАВАЧ:
Универзитет одбране у Београду, Војна академија
УРЕДНИШТВО: странице чланова уредништва у ORCID iD-у, Google Scholar-у, Web of Science ResearcherID-у, Scopus Author ID-у и РИНЦ-у доступни су на http://www.vtg.mod.gov.rs/urednistvo.html
Главни и одговорни уредник
Др Драган Памучар,
e-mail: dragan.pamucar@va.mod.gov.rs
Уредник за област математике, механике и рачунарских наука
Др Драган Трифковић
Уредник за област електронике, телекомуникација и информационих технологија
Др Бобан Бонџулић
Уредник за област машинства
Др Бранимир Крстић
Уредник за област материјала и хемијских технологија
Др Радован Каркалић
Технички уредник
Мр Небојша Гаћеша,
e-mail: nebojsa.gacesa@mod.gov.rs, tel. 011/3603-260, 066/87-00-123

СОБСТВЕННИКИ:
Министерство обороны и Вооружённые силы Республики Сербия
ИЗДАТЕЛЬСТВО:
Университет обороны в г. Белград, Военная академия
РЕДАКЦИЯ: со страницами членов редакции в ORCID iD, Google Scholar, Web of Science ResearcherID, Scopus Author ID и РИНЦ можно ознакомиться на сайте http://www.vtg.mod.gov.rs/redakcia.html
Главный и ответственный редактор
Д-р Драган Памучар, e-mail: dragan.pamucar@va.mod.gov.rs
Редактор в областях: математика, механика и информатика
Д-р Драган Трифкович
Редактор в областях: электроника, телекоммуникации и информационные технологии
Д-р Бобан Бонджулич
Редактор в области: машиностроение
Д-р Бранимир Крстич
Редактор в областях: материаловедение и химические технологии
Д-р Радован Каркалич
Технический редактор
Кандидат технических наук Небойша Гачеша, e-mail: nebojsa.gacesa@mod.gov.rs, тел. +381 11 3603 260, +381 66 87 00 123

OWNERS:
Ministry of Defence and Serbian Armed Forces
PUBLISHER:
University of Defence in Belgrade, Military Academy
EDITORIAL TEAM: the pages of the Editorial Team's members in ORCID iD, Google Scholar, Web of Science ResearcherID, Scopus Author ID, and РИНЦ can be accessed at http://www.vtg.mod.gov.rs/editorial-team.html
Editor in chief
Dr. Dragan Pamučar
e-mail: dragan.pamucar@va.mod.gov.rs
Editor for Mathematics, Mechanics and Computer Science
Dr. Dragan Trifković
Editor for Electronics, Telecommunications and Information Technology
Dr. Boban Bondžulić
Editor for Mechanical Engineering
Dr. Branimir Krstić
Editor for Materials and Chemical Technologies
Dr. Radovan Karkalić
Technical editor
Nebojša Gaćeša, MSc
e-mail: nebojsa.gacesa@mod.gov.rs, tel. +381 11 3603 260, +381 66 87 00 123

С А Д Р Ж А Ј

С О Д Е Р Ж А Н И Е

C O N T E N T S

ОРИГИНАЛНИ НАУЧНИ РАДОВИ
ОРИГИНАЛЬНЫЕ НАУЧНЫЕ СТАТЬИ
ORIGINAL SCIENTIFIC PAPERS

SPECTRUM AND ENERGY OF THE SOMBOR MATRIX

Ivan Gutman
University of Kragujevac, Faculty of Science,
Kragujevac, Republic of Serbia,
e-mail: gutman@kg.ac.rs,
ORCID iD: https://orcid.org/0000-0001-9681-1550

DOI: 10.5937/vojtehg69-31995; https://doi.org/10.5937/vojtehg69-31995

FIELD: Mathematics (Mathematics Subject Classification: primary 05C50, secondary 05C07)
ARTICLE TYPE: Original Scientific Paper

Abstract:

Introduction/purpose: The Sombor matrix is a vertex-degree-based matrix associated with the Sombor index. The paper is concerned with the spectral properties of the Sombor matrix.

Results: Equalities and inequalities for the eigenvalues of the Sombor matrix are obtained, from which two fundamental bounds for the Sombor energy (= energy of the Sombor matrix) are established. These bounds depend on the Sombor index and on the „forgotten" topological index.

Conclusion: The results of the paper contribute to the spectral theory of the Sombor matrix, as well as to the general spectral theory of matrices associated with vertex-degree-based graph invariants.

Keywords: Sombor matrix, Sombor energy, Sombor index, vertex-degree-based graph invariant, spectrum (of matrix).

Introduction

In this paper, we are concerned with simple graphs, i.e., graphs without directed, weighted, or multiple edges, and without self-loops. Let *G* be such a graph, with the vertex set $V(G)$ and the edge set $E(G)$. Let $|V(G)|=n$ and $|E(G)|=m$ be the number of vertices and edges of *G*. By $uv \in E(G)$ we denote the edge of *G*, connecting the vertices *u* and *v*. The degree (= number of first neighbors) of a vertex $u \in V(G)$ is

denoted by $d(u)$. If $d(u) = r$ for all $u \in V(G)$, then *G* is said to be a regular graph or a degree *r.*

For other graph-theoretical notions, the readers are referred to standard textbooks (Harary, 1969), (Bondy & Murthi, 1975).

In the mathematical and chemical literature, degree-based graph invariants of the form

$$TI(G) = \sum_{uv \in E(G)} f\left(d(u), d(v)\right) \qquad (1)$$

have been and are currently studied, where $f(x, y)$ is an appropriately chosen function with the property $f(x, y) = f(y, x)$. The oldest such invariants were put forward as early as in the 1970s, and by now their number exceeds several dozens (Kulli, 2020), (Todeschini & Consonni, 2009). Among the newest invariants of this type are the *forgotten index* for which $f(x, y) = x^2 + y^2$ (Furtula & Gutman, 2015), and the *Sombor index* for which $f(x, y) = \sqrt{x^2 + y^2}$ (Gutman, 2021). Thus, these indices are defined as

$$F(G) = \sum_{uv \in E(G)} \left[d(u)^2 + d(v)^2 \right] \qquad (2)$$

$$SO(G) = \sum_{uv \in E(G)} \sqrt{d(u)^2 + d(v)^2}\,. \qquad (3)$$

Recall that F is often written in the form

$$F(G) = \sum_{u \in V(G)} d(u)^3$$

which, of course, is equivalent to (2).

The first paper on the Sombor index was published only a few months ago (Gutman, 2021). Because this graph invariant is based on using Euclidean metrics, it promptly attracted the attention of quite a few colleagues. As a consequence of this, numerous papers on Sombor index have already been published (Alikhani & Ghanbari, 2021), (Cruz & Rada, 2021), (Došlić et al, 2021), (Horoldagva & Xu, 2021), (Kulli, 2021), and more will appear in the near future. Bearing this in mind, we were motivated to investigate the matrix constructed from the Sombor index in

an earlier proposed manner (Das et al, 2018), and to study some of its spectral properties.

Let the vertices of the graph *G* be labeled by 1,2,…,*n*. Then the (0,1)-adjacency matrix of *G*, denoted by $A(G)$, is defined as the symmetric square matrix of order *n*, whose (*I,j*)-element is

$$A(G)_{ij} = \begin{cases} 1 & if \quad ij \in E(G) \\ 0 & if \quad ij \notin E(G) \\ 0 & if \quad i = j. \end{cases}$$

The eigenvalues of $A(G)$ form the spectrum of the graph *G*. For the details of the spectral graph theory see (Cvetković et al, 2010).

Some time ago (Das et al, 2018), it was attempted to combine the spectral graph theory with the theory of vertex-degree-based graph invariants. For this, using formula (1), an adjacency-matrix-type square symmetric matrix $A_F(G)$ was introduced, whose (*I,j*)-element is defined as

$$A_F(G)_{ij} = \begin{cases} f\left(d(i), d(j)\right) & if \quad ij \in E(G) \\ 0 & if \quad ij \notin E(G) \\ 0 & if \quad i = j. \end{cases}$$

The theory based on the matrix $A_F(G)$ and its spectrum was recently elaborated in some detail (Li & Wang, 2021), (Shao et al, 2021).

In this paper, we examine a special case of $A_F(G)$, associated with the Sombor index $SO(G)$, Eq. (3). We call it the *Sombor matrix*, denote it by $A_{SO}(G)$, and define via

$$A_{SO}(G)_{ij} = \begin{cases} \sqrt{d(i)^2 + d(j)^2} & if \quad ij \in E(G) \\ 0 & if \quad ij \notin E(G) \\ 0 & if \quad i = j. \end{cases} \qquad (4)$$

The eigenvalues of $A_{SO}(G)$ are denoted by $\sigma_1, \sigma_2, ..., \sigma_n$, and are said to form the Sombor spectrum of the graph *G*. Then, as usual, the Sombor characteristic polynomial is defined as

$$\phi_{SO}(G, \lambda) = \det(\lambda I_n - A_{SO}(G))$$

in analogy to the ordinary characteristic polynomial (Cvetković et al, 2010)

$$\phi(G, \lambda) = \det(\lambda I_n - A(G))$$

where I_n is the unit matrix of order *n*. Recall that $\sigma_1, \sigma_2, ..., \sigma_n$ are the zeros of $\phi_{SO}(G, \lambda)$, i.e., satisfy $\phi_{SO}(G, \sigma_i) = 0$ for 1,2,…,*n*.

Spectral properties of the Sombor matrix

Lemma 1. Let $\sigma_1 \geq \sigma_2 \geq \cdots \geq \sigma_n$ be the eigenvalues of the Sombor matrix. Then,

$$\sum_{i=1}^{n} \sigma_i = 0$$

and

$$\sum_{i=1}^{n} \sigma_i^{\,2} = 2F(G)$$

where $F(G)$ is the forgotten topological index, Eq. (2).

Proof. The first equality is a direct consequence of $A_{SO}(G)_{ii} = 0$ for all 1,2,…,*n.*

The second equality is obtained from (4) as follows. Suppose that the vertices of *G* are labeled by 1,2,…,*n.* Then,

$$\sum_{i=1}^{n} \sigma_i^{\,2} = Tr\left(A_{SO}(G)^2\right) = \sum_{i=1}^{n}\sum_{j=1}^{n} A_{SO}(i,j)\,A_{SO}(j,i)$$

$$= 2\sum_{ij\in E(G)} A_{SO}(i,j)\,A_{SO}(j,i) = 2\sum_{ij\in E(G)} \sqrt{d(i)^2 + d(j)^2}\,\sqrt{d(j)^2 + d(i)^2}$$

$$= 2\sum_{ij\in E(G)} \left[d(i)^2 + d(j)^2\right] = 2F(G).$$

This completes the proof of Lemma 1.

Recalling that the sum of squares of the eigenvalues of the ordinary adjacency matrix is equal to 2*m*, from Lemma 1 we realize that in the spectral theory of the Sombor matrix, the forgotten topological index plays an analogous role as the number of edges plays in the ordinary spectral graph theory. This will be seen from the bounds for the Sombor energy, deduced in the forthcoming section (Theorems 1, 2, and 3).

Lemma 2. Let σ_1 be the greatest eigenvalue in the spectrum of the Sombor matrix. Then,

$$\sigma_1 \geq 2\frac{SO(G)}{n}$$

where $SO(G)$ is the Sombor index, Eq. (3). Equality is attained if and only if the graph *G* is regular.

Proof. According to the Rayleigh-Ritz variational principle, if Ω is any *n*-dimensional column-vector, then

$$\frac{\Omega^T A_{SO}(G)\,\Omega}{\Omega^T\,\Omega} \leq \sigma_1 .$$

Setting $\Omega = (1,1,...,1)^T$, we get

$$\Omega^T A_{SO}(G)\,\Omega = \sum_{i=1}^{n}\sum_{j=1}^{n} A_{SO}(G)_{ij} = 2\sum_{ij\in E(G)} A_{SO}(G)_{ij}$$
$$= 2\sum_{ij\in E(G)} \sqrt{d(i)^2 + d(j)^2} = 2\,SO(G)$$

and

$$\Omega^T\,\Omega = n\,.$$

In the case of regular graphs, $\Omega = (1,1,...,1)^T$ is an eigenvector of $A_{SO}(G)$, corresponding to the eigenvalue σ_1. To see this, note that if *G* is a regular graph of a degree *r,* then $A_{SO}(G) = \sqrt{2r}\,A(G)$. That $\Omega = (1,1,...,1)^T$ is an eigenvector of $A(G)$ is a well-known fact (Cvetković et al, 2010). Then, and only then, equality in Lemma 2 holds.

By this, the proof of Lemma 2 has been completed.

Sombor energy and its bounds

The energy $En(G)$ of a graph *G* is, by definition, equal to the sum of the absolute values of the eigenvalues of $A(G)$. For the details of the mathematical theory of graph energy see (Li et al, 2012). In analogy to this, we define the Sombor energy of *G* as

$$En_{SO}(G) = \sum_{i=1}^{n} |\,\sigma_i\,|\,.$$

It is now reasonable to expect that $En_{SO}(G)$ and $En(G)$ have analogous properties. In what follows, we establish two such results.

Theorem 1. (McClelland-type bound for the Sombor energy)

If *G* is a graph on *n* vertices, and $F(G)$ is its forgotten topological index, then

$$En_{SO}(G) \le \sqrt{2n\,F(G)}\,.$$

This result is the analogue of the classical McClelland bound for graph energy, namely, $En(G) \le \sqrt{2nm}$ (McClelland, 1971).

Proof. Start with the inequality whose validity is obvious:

$$\sum_{i=1}^{n}\sum_{j=1}^{n}\left(|\sigma_i|-|\sigma_j|\right)^2 \geq 0 \qquad (5)$$

and take into account Lemma 1 and the definition of $En_{SO}(G)$. The McClelland-type upper bound for $En_{SO}(G)$ follows then from (5) by direct calculation.

Equality in Theorem 1 will hold if and only if $|\sigma_1|=|\sigma_2|=\cdots=|\sigma_n|$. Graphs that satisfy this equality condition are the edgeless graph (for which $m=0$) and the regular graph of degree 1.

Theorem 2. (Koolen-Moulton-type bound for the Sombor energy)
Let *G* be a graph on *n* vertices, with Sombor and forgotten indices $SO(G)$ and $F(G)$, respectively. Then

$$En_{SO}(G) \leq \frac{2\,SO(G)}{n} + \sqrt{(n-1)\left[2F(G)-\left(\frac{2\,SO(G)}{n}\right)^2\right]}$$

which is the analogue of the Koolen-Moulton bound (Koolen & Moulton, 2001), namely

$$En(G) \leq \frac{2m}{n} + \sqrt{(n-1)\left[2m-\left(\frac{2m}{n}\right)^2\right]}.$$

Proof. We follow the reasoning from the paper (Koolen & Moulton, 2001), modified for the Sombor energy. In an analogous way as in the proof of Theorem 1, our starting point is

$$\sum_{i=2}^{n}\sum_{j=2}^{n}\left(|\sigma_i|-|\sigma_j|\right)^2 \geq 0$$

from which it follows

$$\sum_{i=2}^{n}|\sigma_i| \leq \sqrt{2(n-1)F^*(G)}$$

where

$$2F^*(G) = \sum_{i=2}^{n} \sigma_i^{\,2} = 2F(G) - \sigma_1^{\,2}.$$

This yields

$$En_{SO}(G) - |\sigma_i| \leq \sqrt{(n-1)\left[2F(G) - \sigma_i^{\,2}\right]}$$

and

$$En_{SO}(G) \leq \sigma_i + \sqrt{(n-1)\left[2F(G) - \sigma_i^{\,2}\right]} \qquad (6)$$

since $\sigma_1 > 0$.

Consider the function

$$\psi(x) \leq x + \sqrt{(n-1)\left[2F(G) - x^2\right]}.$$

It monotonously decreases in the interval (*a*, *b*) where

$$a = \sqrt{\frac{2F(G)}{n}} \qquad \text{and} \qquad b = \sqrt{2F(G)}.$$

Therefore, inequality (6) remains valid if on the right-hand side of $\psi(x)$, the variable *x* is replaced by the lover bound for σ_i, from Lemma 2. This results in Theorem 2.

Theorem 3. Let *G* be a bipartite graph on *n* vertices, with Sombor and forgotten indices $SO(G)$ and $F(G)$, respectively. Then

$$En_{SO}(G) \leq \frac{4\,SO(G)}{n} + \sqrt{(n-2)\left[2F(G) - 2\left(\frac{2\,SO(G)}{n}\right)^2\right]}$$

which, again is analogous to another Koolen-Moulton bound (Koolen & Moulton, 2003):

$$En(G) \leq \frac{4m}{n} + \sqrt{2(n-2)\left[m - \left(\frac{2m}{n}\right)^2\right]}.$$

Proof. Theorem 3, valid for bipartite graphs, is deduced in an analogous manner as Theorem 2, by starting with

$$\sum_{i=2}^{n-1}\sum_{j=2}^{n-1}\left(|\sigma_i| - |\sigma_j|\right)^2 \geq 0$$

and by taking into account that for bipartite graphs $|\sigma_i| = |\sigma_n|$.

References

Alikhani, S. & Ghanbari, N. 2021. Sombor index of polymers. MATCH Communications in Mathematical and in Computer Chemistry, 86, pp.715-728.

Bondy, J. A. & Murty, U.S.R. 1976. Graph Theory with Applications. New York: Macmillan Press. ISBN: 0-444-19451-7.

Cruz, R. &, Rada, J. 2021. Extremal values of the Sombor index in unicyclic and bicyclic graphs. Journal of Mathematical Chemistry, 59, pp.1098-1116. Available at: https://doi.org/10.1007/s10910-021-01232-8.

Cvetković, D., Rowlinson, P. & Simić, K. 2010. An Introduction to the Theory of Graph Spectra. Cambridge: Cambridge University Press. ISBN: 9780521134088.

Das, K.C., Gutman, I., Milovanović, I., Milovanović, E. & Furtula, B. 2018. Degree-based energies of graphs. Linear Algebra and its Applications, 554, pp.185-204. Available at: https://doi.org/10.1016/j.laa.2018.05.027.

Došlić, T., Reti, T. & Ali, A. 2021. On the structure of graphs with integer Sombor indices. Discrete Mathematics Letters, 7, pp.1-4. Available at: https://doi.org/10.47443/dml.2021.0012.

Furtula, B. & Gutman, I. 2015. A forgotten topological index. Journal of Mathematical Chemistry, 53, pp.1184-1190. Available at: https://doi.org/10.1007/s10910-015-0480-z.

Gutman, I. 2021. Geometric approach to degree-based topological indices: Sombor indices. MATCH Communications in Mathematical and in Computer Chemistry, 86, pp.11-16.

Harary, F. 1969. Graph Theory. Reading: Addison—Wesley. ISBN: 9780201410334.

Horoldagva, B. & Xu, C. 2021. On Sombor index of graphs. MATCH Communications in Mathematical and in Computer Chemistry, 86, pp.793-713.

Koolen, J. & Moulton, V. 2001. Maximal energy graphs. Advances in Applied Mathematics, 26(1), pp.47-52. Available at: https://doi.org/10.1006/aama.2000.0705.

Koolen, J. & Moulton, V. 2003. Maximal energy bipartite graphs. Graphs and Combinatorics, 19, pp.131-135. Available at: https://doi.org/10.1007/s00373-002-0487-7.

Kulli, V.R. 2020. Graph indices. In: Pal, M., Samanta, S. & Pal, A. (Eds.), Handbook of Research of Advanced Applications of Graph Theory in Modern Society, pp.66-91. Hershey, USA: IGI Global. Available at: https://doi.org/10.4018/978-1-5225-9380-5.ch003.

Kulli, V.R. 2021. Sombor index of certain graph operators. International Journal of Engineering Sciences & Research Technology, 10(1), pp.127-134. Available at: https://doi.org/10.29121/ijesrt.v10.i1.2021.12.

Li, X., Shi, Y. & Gutman, I. 2012. Introduction. In: Graph Energy, pp.1-9. New York, NY: Springer Science and Business Media LLC. Available at: https://doi.org/10.1007/978-1-4614-4220-2_1.

Li, X. & Wang, Z. 2021. Trees with extremal spectral radius of weighted adjacency matrices among trees weighted by degree-based indices. Linear Algebra and Its Applications, 620, pp.61-75. Available at: https://doi.org/10.1016/j.laa.2021.02.023.

McClelland, B.J. 1971. Properties of the latent roots of a matrix: The estimation of π-electron energies. Journal of Chemical Physics, 54(2), pp.640-643. Available at: https://doi.org/10.1063/1.1674889.

Shao, Y., Gao, Y., Gao, W. & Zhao, X. 2021. Degree-based energies of trees. Linear Algebra and Its Applications, 621, pp.18-28. Available at: https://doi.org/10.1016/j.laa.2021.03.009.

Todeschini, R. & Consonni, V. 2009. Molecular Descriptors for Chemoinformatics. Weinheim: Wiley-VCH. ISBN: 978-3-527-31852-0.

СПЕКТР И ЭНЕРГИЯ СОМБОРСКОЙ МАТРИЦЫ

Иван Гутман

Крагуевацкий университет, естественно-математический факультет, г. Крагуевац, Республика Сербия

РУБРИКА ГРНТИ: 27.00.00 МАТЕМАТИКА;
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: Сомборская матрица выведена из индекса Сомбора на основании степени вершин. В данной статье представлены спектральные свойства сомборской матрицы.

Результаты: Получены равенства и неравенства собственных значений сомбоской матрицы, из которых выведены два фундаментальных ограничения сомборской энергии (= энергии сомборской матрицы). Данные ограничения зависят от индекса Сомбора и от так называемого «забытого» топологического индекса.

Выводы: Результаты исследования, представленные в данной статье, вносят вклад в спектральную теорию сомборской матрицы, а также в общую спектральную теорию матриц, связанных с инвариантами графов, основанных на степени вершин.

Ключевые слова: Сомборская матрица, энергия Сомбора, индекс Сомбора, инварианты графа, зависящие от степени вершин, спектр (матрицы).

СПЕКТАР И ЕНЕРГИЈА СОМБОРСКЕ МАТРИЦЕ

Иван Гутман

Универзитет у Крагујевцу, Природно-математички факултет,
Крагујевац, Република Србија

ОБЛАСТ: математика
ВРСТА ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Сомборска матрица зависна је од степена чворова, а изведена је из сомборског индекса. У раду су приказане неке њене спектралне особине.

Резултати: Добијене су једнакости и неједнакости за сопствене вредности сомборске матрице. Из њих су изведене две фундаменталне границе за сомборску енергију (енергија сомборске матрице). Ове границе зависе од сомборског индекса, као и од такозваног „заборављеног" тополошког индекса.

Закључак: Резултати изложени у раду представљају допринос спектралној теорији сомборске матрице, као и општој теорији спектара матрица зависних од степена чворова.

Кључне речи: сомборска матрица, сомборска енергија, сомборски индекс, инваријанте зависне од степена чворова, спектар (матрице).

Paper received on / Дата получения работы / Датум пријема чланка: 25.04.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 03.05.2021.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 05.05.2021.

A NEW VERSION OF THE RESULTS OF U_n–HYPERMETRIC SPACES

Akbar Dehghan Nezhad[a], *Ahmadreza* Forough[b], *Nikola* Mirkov[c], *Stojan* Radenović[d]

[a] Iran University of Science and Technology, School of Mathematics, Narmak, Tehran, Islamic Republic of Iran,
e-mail: dehghannezhad@iust.ac.ir,
ORCID iD: https://orcid.org/0000-0003-4200-6892

[b] Islamic Azad University, Department of Mathematics, North Branch, Tehran, Islamic Republic of Iran,
e-mail: a_forough@iau-tnb.ac.ir,
ORCID iD: https://orcid.org/0000-0001-6774-3560

[c] University of Belgrade, VINČA Institute of Nuclear Sciences - - National Institute of the Republic of Serbia, Belgrade, Republic of Serbia,
e-mail: nmirkov@vin.bg.ac.rs, **corresponding author**,
ORCID iD: https://orcid.org/0000-0002-3057-9784

[d] University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Republic of Serbia,
e-mail: radens@beotel.rs,
ORCID iD: https://orcid.org/0000-0001-8254-6688

DOI: 10.5937/vojtehg69-32197;https://doi.org/10.5937/vojtehg69-32197

FIELD: Mathematics
ARTICLE TYPE: Original scientific paper

Abstract:

Introduction/purpose: The aim of this paper is to present the concept of a universal hypermetric space. An n-dimensional $(n \geq 2)$ hypermetric distance over an arbitrary non-empty set X is generalized. This hypermetric distance measures how separated all n points of the space are. The paper discusses the concept of completeness, with respect to this hypermetric as well as the fixed point theorem which play an important role in applied mathematics in a variety of fields.

Methods: Standard proof based theoretical methods of the functional analysis are employed.

Results: The concept of a universal hypermetric space is presented. The universal properties of hypermetric spaces are described.

ACKNOWLEDGMENT: The author Nikola Mirkov is grateful for the financial support from the Ministry of Education and Science and Technological Development of the Republic of Serbia.

Conclusion: This new version of the results for U_n-hypermetric spaces may have applications in various disciplines where the degree of clustering is sought for.

Key words: U_n-hypermetric spaces, OG-metric, G-metric.

Introduction

The role of distance in understanding the world is undeniable. Our intuitive understanding of the concept of distance in the real world, however, is different from the one proposed in mathematics. Some of the properties that belong to our understanding of distance from the real world, such as symmetry and single-valuedness, are not necessarily established within certain abstract distances.

This will, in fact, be our main motivation for presenting a generalized concept of distance as a set-valued function in this paper.

The notion of 2-metric spaces, as a possible generalization of metric spaces, was introduced by Gähler (Gähler, 1963), (Gähler, 1964), (Gähler, 1966). See also (Diminnie et al, 2017), (Ha et al, 1990) for further developments. The 2-metric $d(x, y, z)$ is a function of 3 variables, and Gähler geometrically interpreted it as an area of a triangle with the vertices at x , y and z, respectively.

This led B. C. Dhage, in his PhD thesis in 1992, to introduce the notion of D-metric (Dhage et al, 2000) that does, in fact, generalize metric spaces. Subsequently, Dhage published a series of papers attempting to develop topological structures in such spaces and prove several fix point results.

Most of the claims, however, concerning the fundamental topological properties of D-metric spaces, are incorrect. In 2003, Mustafa and Sims demonstrated that in a strong remark (Mustafa & Sims, 2003). This led them to introducing the notion of a G-metric space (Mustafa & Sims, 2006), as a generalization of metric spaces. In this type of spaces, a non-negative real number is assigned to every triplet of elements.

In an attempt to generalize the notion of a G-metric space to more than three variables, Khan first introduced the notion of a K-metric, and later the notion of a generalized n-metric space (for any $n \geq 2$) (Khan, 2012), (Khan, 2014). He also proved a common fixed point theorem for such spaces.

G-metric spaces were generalized to universal metrics in (Dehghan Nezhad & Mazaheri, 2010), (Dehghan Nezhad & Aral, 2011), (Dehghan

Nezhad & Khajuee, 2013), (Dehghan Nezhad et al, 2017). The interpretation of the perimeter of a triangle is applied, but this time on G-metric spaces. Since then, many authors have obtained fixed point results for G-metric spaces.

The main purpose of this paper is a generalization of universal metric spaces into universal hypermetric spaces of the n-dimension (see (Kelly, 1975) for a discussion on hypermetric spaces). In the first part, we generalize an n-dimensional $(n \geq 2)$ hypermetric distance over an arbitrary non-empty set X. This hypermetric measures how separated all n points of the space are. The hyperdistance function is defined in any way we like, the only constraint being the simultaneous satisfaction of the three properties, viz non-negativity and positive-definiteness, symmetry and triangle inequality. In the second part, we discuss the concept of completness, with respect to this hypermetric, and the fixed point theorem, which play an important role in applied mathematics in a variety of fields. Examples show a fundamental difference between our results and the well-known ones. This concept is the first view of novel methods for selecting the clusters by hypermetric. The purpose definition is applicable for engineering science (for example, the theory of clustering).

By a strict order relation of a set X, we mean a binary relation " $<$ ", which is transitive ($\alpha < \beta$ and $\beta < \gamma$ implies $\alpha < \gamma$), such that $\alpha < \beta$ and $\beta < \alpha$ cannot both hold. It is a strict total order relation, if for every α,β belonging to X, exactly one and only one of $\alpha < \beta$, $\beta < \alpha$ or $\alpha = \beta$ holds. A group G is called left-ordered, if endowed with a strict total relation " $<$ " which is left invariant, meaning that $\alpha < \beta$ implies $\gamma + \alpha < \gamma + \beta$, for all α,β,$\gamma \in G$. We will say that G is bi-ordered, if it admits the left and right invariant properties simultaneously (historically, this has been called simple-ordered). We refer to the ordered pair $(G, <)$ as an ordered group (Cohen & Goffman, 1949). From now on, we assume that 1 denotes the identity element of G. It should be noted that, for abelian additive groups, the identity element may be denoted by 0. This is common to an ordered group with the symbol " $\leq$ " that has the obvious meaning : $\alpha \leq \beta$ means $\alpha < \beta$ or $\alpha = \beta$. We denote G^+ a set of non-negative elements of G, namely $G^+ := \{g \in G \| e \leq g\}$. Two positive elements, x, y, of an ordered group are relatively Archimedean if there are positive integers m, n such that $mx \geq y$ and $ny \geq x$. If every two positive elements of an ordered group are relatively Archimedean, then the ordered group is Archimedean.

Every Archimedean ordered group is isomorphic to an ordered subgroup of the additive group of the real numbers. An ordered group G is order complete if every non-empty subset of G that has an upper bound has a least upper bound.

Universal hypermetric spaces of the dimension n

The goal of this section is to describe a few properties of the universal hypermetric spaces.

Definition 1. *Let G be an ordered group. An ordered group metric (or OG-metric) on a non-empty set X is a symmetric non-negative function d_G from $X \times X$ into G such that $d_G(x, y) = 0$ if and only if $x = y$ and such that the triangle inequality is satisfied; the pair (X, d_G) is an ordered group metric space (or OG-metric space).*

Now we first recall and introduce some notation. For $n \geq 2$, let X^n denote the n-times Cartesian product $\underbrace{X \times \ldots \times X}_{n-times}$ and G be an ordered group. Let $P^*(G)$ denote the family of all non-empty subsets of G. We begin with the following definition.

Definition 2. *Let X be a non-empty set. Let $\mathbb{U}_n : X^n \to P^*(G^+)$ be a function that satisfies the following conditions:*

- *(U1)* $\mathbb{U}_n(x_1, \ldots, x_n) = \{0\}$, *if* $x_1 = \ldots = x_n$,
- *(U2)* $\mathbb{U}_n(x_1, \ldots, x_n) \supset \{0\}$, *for all* $x_1, ..., x_n$ *with* $x_i \neq x_j$, *for some* $i, j \in \{1, ..., n\}$,
- *(U3)* $\mathbb{U}_n(x_1, \ldots, x_n) = \mathbb{U}_n(x_{\pi_1}, \ldots, x_{\pi_n})$, *for every permutation* $(\pi_{(1)}, ..., \pi_{(n)})$ *of* $(1, 2, ..., n)$,
- *(U4)* $\mathbb{U}_n(x_1, x_2, \ldots, x_{n-1}, x_{n-1}) \subseteq \mathbb{U}_n(x_1, x_2, \ldots, x_{n-1}, x_n)$, *for all* $x_1, \ldots, x_n \in X$,
- *(U5)* $\mathbb{U}_n(x_1, x_2, \ldots, x_n) \subseteq \mathbb{U}_n(x_1, a, ..., a) + \mathbb{U}_n(a, x_2, ..., x_n)$, *for all* $x_1, \ldots, x_n, a \in X$.

Let A_i be subsets of X, $i = 1, \ldots, n$. We define

$$\mathbb{U}_n(A_1, \ldots, A_n) = \bigcup \Big\{ \mathbb{U}_n(x_1, \ldots, x_n) \mid x_i \in A_i, \quad i = 1, \ldots, n \Big\}, \text{ and}$$

$$A_i + A_j = \{x_i + x_j \mid x_i \in A_i, x_j \in A_j; 1 \leq i, j \leq n\},$$

Dehghan Nezhad, A.D. et al, A new version of the results of U_n–hypermetric space results, pp.562–577

We will use the following abbreviated notation: The function $\mathbb{U}_n$ is called a *universal ordered hypermetric group* of the dimension n, or more specifically an UO_n-hypermetric (or U_n-hypermetric) on X, and the pair $(X, \mathbb{U}_n)$ is called an U_n-hypermetric space. For example, we can set $G^+ = \mathbb{Z}^0_+$ or $\mathbb{R}^0_+$, where $\mathbb{Z}^0_+ := \mathbb{N} \cup \{0\} = \{0, 1, 2, \dots\}$ and $\mathbb{R}^0_+ := [0, +\infty)$.

In the sequel, for simplicity we assume that $G^+ = \mathbb{R}^0_+$. The following useful properties of a U_n-hypermetric are easily derived from the axioms.

Proposition 1. *(example) Let* $X = \{a_1, \dots a_\ell\}$ *be an* ℓ*-element set and* $\mathbb{N}_\ell = \{1, \dots, \ell\}$*. Define*

$$\mathbb{F}_2 : X \times X \to P^*(\mathbb{R}^0_+)$$

with,

$$\mathbb{F}_2(a_i, a_j) = \begin{cases} \big\{\{0\}, \dots, \{j\}\big\} & ; \quad i < j \\ \big\{\{0\}, \dots, \{i-1\}\big\} & ; \quad i = j \\ \big\{\{0\}, \dots, \{i\}\big\} & ; \quad i > j \end{cases} \qquad ; \qquad (for\ all \quad i, j \in \mathbb{N}_\ell)$$

and also assume $A + B = A \cup B$*, for all* $A, B \subseteq P(\mathbb{R}^*_+)$*. Then* $\mathbb{F}_2$ *is a* U_2*-hypermetric space.*

Proof. It is sufficient to show that $\mathbb{F}_2$ satisfies all the properties $[(U1)], [(U2)], \dots, [(U5)]$. The proofs of $[(U1)], \dots, [(U4)]$, follow immediately from the definition of $\mathbb{F}_2$. We only need to show that $\mathbb{F}_2$ satisfies the following relation

$$\mathbb{F}_2(a_i, a_j) = \mathbb{F}_2(a_i, a_k) + \mathbb{F}_2(a_k, a_j) \qquad ; \qquad (for\ all \quad i, j, k \in \mathbb{N}_\ell),$$

so we prove that in the following cases.

(i) $(i = j)$

We have $\big\{\{0\}, \dots, \{j-1\}\big\} \subseteq \big\{0, \dots, k\big\}$, if $j < k$ and also, $\big\{\{0\}, \dots, \{j-1\}\big\} = \big\{\{0\}, \dots, \{k-1\}\big\}$, if $j = k$. Finally we have $\big\{\{0\}, \dots, \{j-1\}\big\} \subseteq \big\{\{0\}, \dots, \{j\}\big\}$, if $j > k$

(ii) $(i < j)$

We have $\big\{\{0\}, \dots, \{j\}\big\} \subseteq \big\{\{0\}, \dots, \{j\}\big\}$, if $j > k$, and $\big\{\{0\}, \dots, \{j\}\big\} \subseteq \big\{\{0\}, \dots, \{k\}\big\}$, if $k > j$, and at last the equality holds if $i = j$.

(iii) $(i > j)$

The same reasoning applies to this case, with j replaced by i in (ii) and the proof is completed.

□

Proposition 2. *Let* $(X, \mathbb{U}_n)$ *be a* U_n*-hypermetric space, then for any* $x_1, ..., x_n, a \in X$ *it follows that:*
(1) If $\mathbb{U}_n(x_1, ..., x_n) = \{0\}$*, then* $x_1 = ... = x_n$*,*
(2) $\mathbb{U}_n(x_1, ..., x_n) \subseteq \sum_{j=2}^{n} \mathbb{U}_n(x_1, ..., x_1, x_j)$*,*
(3) $\mathbb{U}_n(x_1, ..., x_n) \subseteq \sum_{j=1}^{n} \mathbb{U}_n(x_j, a, ..., a)$*,*
(4) $\mathbb{U}_n(x_1, x_2, ..., x_2) \subseteq (n-1)\mathbb{U}_n(x_1, ..., x_1, x_2)$*.*

Proposition 3. *Let* $(X, \mathbb{U}_n)$ *be a* U_n*-hypermetric space, then* $\{0\} \subseteq \mathbb{U}_n(x_1, ..., x_n)$ *for all* $x_1, ..., x_n \in X$*.*

Proof. By the condition $(U4)$ of the definition of a U_n-hypermetric space, we have $\{0\} = \mathbb{U}_n(x_1, ..., x_1) \subseteq \mathbb{U}_n(x_1, ..., x_n)$. □

Proposition 4. *Every* U_n*-hypermetric space* $(X, \mathbb{U}_n)$ *defines a* U_2*-hypermetric space* $(X, \mathbb{U}_2)$ *as follows:*

$$\mathbb{U}_2(x, y) = \mathbb{U}_n(x; y, \ldots, y) + \mathbb{U}_n(y; x, \ldots, x); \quad for\ all \quad x, y \in X.$$

Proposition 5. *Let* e *be an arbitrary positive real value number, and* (X, d) *be a metric space. We define an induced hypermetric,*

$$\mathbb{U}_2^e : X \times X \to P^*(\mathbb{R}_+^0)$$

$$\mathbb{U}_2^e(x, y) = \begin{cases} \big(d(x,y) - e, d(x,y) + e\big) \cup \{0\} & ; \quad x \neq y, \quad d(x,y) \geq e \\ \big(d(x,y) - e, d(x,y) + e\big) \cap \mathbb{R}_+^0 & ; \quad x \neq y, \quad d(x,y) < e \\ \{0\} & ; \quad x = y. \end{cases}$$

Then $(X, \mathbb{U}_2^e)$ *is a* U_2*-hypermetric space.*

Main results

Let $(X, \mathbb{U}_n)$ be a U_n-hypermetric space and $\widetilde{X}$ be a partition of X. For each point $p \in X$, we denote $\widetilde{p}$ a point in $\widetilde{X}$ containing p, and we denote the equivalent relation induced by the relation by $\sim$.

Definition 3. *Let* $(X, \mathbb{U}_n)$ *be a* U_n*-hypermetric space. Let* $p_1, \ldots, p_n \in X$*, and consider* $\widetilde{p_1}, \ldots, \widetilde{p_n} \in \widetilde{X}$*. A quotient* U_n*-hypermetric of the points of* $\widetilde{X}$ *induced by* $\mathbb{U}_n$ *is the function*
$\widetilde{\mathbb{U}}_n : \widetilde{X}^n \longrightarrow P^*(\mathbb{R}^+)$ *given by* $\widetilde{\mathbb{U}}_n(\widetilde{p_1}, \ldots, \widetilde{p_n}) = \bigcap_{p_i \in \widetilde{p_i}} \mathbb{U}_n(p_1, \ldots, p_n)$.

Dehghan Nezhad, A.D. et al, A new version of the results of U_n–hypermetric space results, pp.562–577

Proposition 6. *The quotient U_n-hypermetric induced by $\mathbb{U}_n$ is well-defined and is a U_n-hypermetric on $\widetilde{X}$.*

Proof. $\widetilde{\mathbb{U}}_n$ satisfies all the properties $(U1)-(U4)$.

$$\widetilde{\mathbb{U}}_n(\widetilde{p}_1,\ldots,\widetilde{p}_n) \subseteq \widetilde{\mathbb{U}}_n(\widetilde{p}_1,\widetilde{q},\ldots,\widetilde{q}) + \widetilde{\mathbb{U}}_n(\widetilde{q},\widetilde{p}_2,\ldots,\widetilde{p}_n)$$

$$\bigcap_{p_i\in\widetilde{P}_i} \mathbb{U}_n(p_1,\ldots,p_n) \subseteq \bigcap_{\substack{p_i\in\widetilde{P}_i\\ q\in\widetilde{q}}} \Big(\mathbb{U}_n(p_1,q,\ldots,q) + \mathbb{U}_n(q,p_2,\ldots,p_n)\Big)$$

$$= \bigcap_{\substack{p_i\in\widetilde{P}_i\\ q\in\widetilde{q}}} \mathbb{U}_n(p_1,q,\ldots,q) + \bigcap_{\substack{p_i\in\widetilde{P}_i\\ q\in\widetilde{q}}} \mathbb{U}_n(q,p_2,\ldots,p_n)$$

$$= \bigcap_{\substack{p_i\in\widetilde{P}_i\\ q\in\widetilde{q}}} \Big(\mathbb{U}_n(p_1,q,\ldots,q) + \mathbb{U}_n(q,p_2,\ldots,p_n)\Big).$$

□

Let $(X,\mathbb{U}_n)$ be a U_n-hypermetric space of a dimension $n>2$. For any arbitrary a in X, define the function $\mathbb{U}_{n-1}$ on X^{n-1} by

$$\mathbb{U}_{n-1}(x_1,\ldots,x_{n-1}) := \mathbb{U}_n(x_1,\ldots,x_{n-1},a).$$

Then we have the following result.

Proposition 7. *The function $\mathbb{U}_{n-1}$ defines a U_{n-1}-hypermetric on X.*

Proof. We will verify that $\mathbb{U}_{n-1}$ satisfies the five properties of a U_{n-1}-hypermetric. □

Proposition 8. *Let $f: X\to Y$ be an injection from a set X to a set Y. If $\mathbb{U}_n: X^n \to P^*(\mathbb{R}^0_+)$ is a U_n-hypermetric on the set Y, then $\overline{\mathbb{U}}_n: X^n \to P^*(\mathbb{R}^0_+)$, given by the formula $\overline{\mathbb{U}}_n(x_1,\ldots,x_n) = \mathbb{U}_n(f(x_1),\ldots,f(x_n))$ for all $x_1,\ldots,x_n\in X$, is a U_n-hypermetric on the set X.*

Proposition 9. *Let $(X, \mathbb{U}_n)$ be any U_n-hypermetric space. Let λ be any positive real number. Then $(X, \mathbb{U}_n^{\lambda})$ is also a U_n-hypermetric space where $\mathbb{U}_n^{\lambda}(x_1, \ldots, x_n) := \{A \cap [0, \lambda) | A \in U_n(x_1, \ldots, x_n)\}$.*

So, on the same X many U_n-hypermetrics can be defined, as a result of the procedure in which the same set X is endowed with different metric structures. Another structure in the next proposition is useful for scaling the U_n-hypermetric, so we need the following explanation.

For any non-empty subset A of $\mathbb{R}_+^0$, and $\lambda \in \mathbb{R}^+$ we define a set $\lambda.A$ to be $\lambda.A := \{\lambda.a \mid a \in A\}$.

Proposition 10. *Let $(X, \mathbb{U}_n)$ be any U_n-hypermetric space. Let Λ be any positive real number. We define $\dot{\mathbb{U}}_n^{\Lambda}(x_1, \ldots, x_n) = \lambda.\mathbb{U}_n(x_1, \ldots, x_n)$. Then $(X, \dot{\mathbb{U}}_n^{\lambda})$is also a U_n-hypermetric space.*

A sequence $\{x_m\}$ in a U_n-hypermetric space $(X, \mathbb{U}_n)$ is said to converge to a point s in X, if for any $\epsilon > 0$ there exists a natural number N such that for every $m_1, \ldots, m_{n-1} \geq N$,

$$\mathbb{U}_n(x_{m_1}, ..., x_{m_{n-1}}, s) \subseteq [0, \epsilon),$$

then we write,

$$\lim_{m_1, ..., m_{n-1} \longrightarrow +\infty} \mathbb{U}_n(x_{m_1}, ..., x_{m_{n-1}}, s) = \{0\}.$$

We say that a sequence $\{x_m\}$ has a cluster point x if there exists a subsequence $\{x_{m_k}\}$ of $\{x_m\}$ that converges to x.

Proposition 11. *Let $(X, \mathbb{U}_n)$ and $(X', \mathbb{U}'_n)$ be two U_n-hypermetric spaces. Then a function $f : X \to X'$ is U_n-continuous at a point $x \in X$, if and only if it is U_n-sequentially continuous at x; that is, whenever sequence $\{x_m\}$ is U_n-convergent to x one has $\{f(x_m)\}$ which is U_m convergent to $f(x)$.*

Definition 4. *Let $(X, \mathbb{U}_n)$ be a U_n-hypermetric space, and $A \subseteq X$. The set A is U_n-compact if for every U_n-sequence $\{x_m\}$ in A, there exists a subsequence $\{x_{m_k}\}$ of $\{x_m\}$ such that U_n-converges to $x_0 \in A$.*

Proposition 12. *Let $(X, \mathbb{U}_n)$ and $(X', \mathbb{U}'_n)$ be two U_n-hypermetric spaces and $f : X \to X'$ a U_n-continuous function on X. If X is U_n-compact, then $f(X)$ is U_n-compact.*

Definition 5. *Let $(X, \mathbb{U}_n)$ be a U_n-hypermetric space, then for $x_0 \in X$, $r > 0$, the U_n-hyperball with a center x_0 and a radius r is*

$$B_{U_n}(x_0, r) = \{y \in X : \mathbb{U}_n(x_0, y, ..., y) \subseteq [0, r)\}.$$

Proposition 13. *Let $(X, \mathbb{U}_n)$ be a U_n-hypermetric space, then for $x_0 \in X$, $r > 0$,*
(i) If $\mathbb{U}_n(x_0, x_2, ..., x_n) \subseteq [0, r)$, then $x_2, ..., x_n \in B_{U_n}(x_0, r)$,
(ii) If $y \in B_{U_n}(x_0, r)$, then there exists, $\delta > 0$ such that $B_{U_n}(y, \delta) \subseteq B_{U_n}(x_0, r)$.

Proof. The proof of (i) is trivial. In (ii) it suffices to show that for every U_n-hyperball $B_{U_n}(x, r)$ and every $y \in B_{U_n}(x, r))$, there exists $\delta > 0$ such that, $y \in B_{U_n}(y, \delta) \subseteq B_{U_n}(x, r)$. So let $y \in B_{U_n}(x, r)$. Then $\mathbb{U}_n(x, \ldots, x\,; y) - \mathbb{U}_n(x, \ldots, x\,; x) \subseteq [0, r)$. Set

$$[0, \delta) := [0, r) - \mathbb{U}_n(x, \ldots, x\,;\, y) + \mathbb{U}_n(x, \ldots, x\,;\, x).$$

then $\delta > 0$, and hence $y \in B_{U-n}(y, \delta)$.

Now let $z \in B_{U_n}(y, \delta)$, i.e, $\mathbb{U}_n(y, \ldots, y\,;\, z) - \mathbb{U}_n(y, \ldots, y\,;\, y) \subseteq [0, \delta)$, then

$$\begin{array}{rcl} \mathbb{U}_n(x, \ldots, x\,;\, z) & \subseteq & \mathbb{U}_n(x, \ldots, x\,;\, y) + \mathbb{U}_n(y, \ldots, y\,;\, z) - \mathbb{U}_n(y, \ldots, y\,;\, y) \\ & - & \mathbb{U}_n(x, \ldots, x\,;\, x) \\ & \subseteq & \mathbb{U}_n(x, \ldots, x\,;\, y) - \mathbb{U}_n(x, \ldots, x\,;\, x) + [0, \delta) \\ & \subseteq & [0, r). \end{array}$$

Thus, $z \in B_{U_n}(x, r)$, and hence $B_{U_n}(y, \delta) \subseteq B_{U_n}(x, r)$. □

Proposition 14. *The set of all $\mathbb{U}_n$-balls, $\mathcal{B}_n = \{B_{U_n}(x, r) : x \in X, r > 0\}$, forms a basis for a topology $\mathcal{T}(U_n)$ on X.*

Definition 6. *Let $(X, \mathbb{U}_n)$ be a U_n-hypermetric space. The sequence $\{x_n\} \subseteq X$ is U_n-convergent to x if it U_n-converges to x in the U_n-hypermetric topology, $\mathcal{T}(U_n)$.*

Proposition 15. *Let $(X, \mathbb{U}_n)$ be a U_n-hypermetric space. Then for a sequence $\{x_m\} \subseteq X$, and a point $x \in X$ the following are equivalent:*
(1) $\{x_m\}$ is $\mathbb{U}_n$-convergent to x,
(2) $\mathbb{U}_n(x_m, ..., x_m, x) \to 0$,
(3) $\mathbb{U}_n(x_m, x, ..., x) \to 0$.

Definition 7. *Let $(X, \mathbb{U}_n)$, $(Y, \mathbb{V}_m)$ be universal hypermetric spaces of the dimensions n, m, respectively, a function $f : X \longrightarrow Y$ is $U_{n,m}$-continuous at a point $x_0 \in X$, if $f^{-1}(B_{V_m}(f(x_0), r)) \in \mathcal{T}(U_n)$, for all $r > 0$.*

We say f is $U_{n,m}$-continuous if it is $U_{n,m}$-continuous at all points of X; that is, continuous as a function from X with the $\mathcal{T}(U_n)$-topology to Y with the $\mathcal{T}(V_m)$-topology.

In the sequel, for simplicity we assume that $n = m$. Since U_n-hypermetric topologies are metric topologies, we have:

Definition 8. *Let $(X, \mathbb{U}_n)$ and $(Y, \mathbb{V}_n)$ be two U_n-hypermetric spaces and $f : (X, \mathbb{U}_n) \to (Y, \mathbb{V}_n)$ be a function. The function f is called U_n-continuous at a point $a \in X$ if and only if, for given $\epsilon > 0$, there exists $\delta > 0$ such that $x_1, \ldots, x_{n-1} \in X$ and the subset relation $\mathbb{U}_n(a, x_1, \ldots, x_{n-1}) \subseteq [0, \delta)$ implies that $\mathbb{V}_n(f(a), f(x_1), \ldots, f(x_{n-1})) \subseteq [0, \epsilon)$.*

A function f is U_n-continuous on X if and only if it is U_n-continuous at all $a \in X$.

Proposition 16. *Let $(X, \mathbb{U}_n)$, $(Y, \mathbb{V}_n)$ be U_n-hypermetric spaces, a function $f : X \longrightarrow Y$ is U_n-continuous at point $x \in X$ if and only if it is U_n-sequentially continuous at x; that is, whenever $\{x_n\}$ is U_n-convergent to x we have that $(f(x_n))$ is U_n-convergent to $f(x)$.*

Proposition 17. *Let $(X, \mathbb{U}_n)$ be a U_n-hypermetric space. Then the function $\mathbb{U}_n(z_1, z_2, ..., z_n)$ is jointly U_n-continuous in all n of its variables.*

Definition 9. *A map $f : X \longrightarrow Y$ between U_n-hypermetric spaces $(X, \mathbb{U}_n)$ and $(Y, \mathbb{U}'_n)$ is an iso-hypermetry when $\mathbb{U}_n(x_1, ..., x_n) = \mathbb{U}'_n(f(x_1), ..., f(x_n))$ for all $x_1, \ldots, x_n \in X$. If the iso-hypermetry is injective, we call it iso-hypermetric embedding. A bijective iso-hypermetry is called an iso-hypermetric isomorphism.*

We discuss now about the concept of completeness of U_n-hypermetric spaces.

Definition 10. *Let $(X, \mathbb{U}_n)$ be a U_n-hypermetric space, then a sequence $\{x_m\} \subseteq X$ is said to be U_n-Cauchy if for every $\varepsilon > 0$, there exists $N \in \mathbb{N}$ such that $\mathbb{U}_n(x_{m_1}, x_{m_2}, ..., x_{m_n}) < \varepsilon$ for all $m_1, m_2, ..., m_n \geq N$.*

The next proposition follows directly from the definitions.

Proposition 18. *In a U_n-hypermetric space, $(X, \mathbb{U}_n)$, the following are equivalent.*
(i) The sequence $\{x_m\}$ is U_n-Cauchy.
(ii) For every $\varepsilon > 0$, there exists $N \in \mathbb{N}$ such that $\mathbb{U}_n(x_l, x_m, ..., x_m) < \varepsilon$, for all $l, m \geq N$.
(iii) $\{x_m\}$ is a Cauchy sequence in the metric space (X, d_U).

Corollary 1. **(i)** *Every U_n-convergent sequence in a U_n-hypermetric space is U_n-Cauchy.*
(ii) *If a U_n-Cauchy sequence in a U_n-hypermetric space $(X, \mathbb{U}_n)$ contains a U_n-convergent subsequence, then the sequence itself is U_n-convergent.*

Definition 11. *A U_n-hypermetric space $(X, \mathbb{U}_n)$ is said to be U_n-complete if every U_n-Cauchy sequence in $(X, \mathbb{U}_n)$ is U_n-convergent in $(X, \mathbb{U}_n)$.*

Proposition 19. *A U_n-hypermetric space $(X, \mathbb{U}_n)$ is U_n-complete if and only if (X, d_U) is a complete metric space.*

Definition 12. *Let $(X, \mathbb{U}_n)$ and $(Y, \mathbb{U}_n{}')$ be two U_n-hypermetric spaces. A function $f : X \longrightarrow Y$ is called a U_n-contraction if there exists a constant $k \in [0, 1)$ such that $\mathbb{U}_n{}'(f(x_1), ..., f(x_n)) = k\mathbb{U}_n(x_1, ..., x_n)$ for all $x_1, \ldots, x_n \in X$.*

It follows that f is U_n-continuous because $\mathbb{U}_n(x_1, ..., x_n) \subseteq [0, \delta)$ with $k \neq 0$ and $\delta := \epsilon/k$ implies $\mathbb{U}_n{}'(f(x_1), ..., f(x_n)) \subseteq [0, \epsilon)$.

Theorem 1. *Let $(X, \mathbb{U}_n)$ be a U_n-complete space and let $T : X \to X$ be a U_n-contraction map. Then T has a unique fixed point $T(x) = x$.*

Proof. We consider $x_{m+1} = T(x_m)$, with x_0 being any point in X. We have, by repeated use of the rectangle inequality and the application of contraction property, the following:

$$\mathbb{U}_n(x_m, x_{m+1}, \ldots, x_{m+1}) \subseteq k^m \mathbb{U}_n(x_0, x_1, \ldots, x_1),$$

for all $m, s_1 \in \mathbb{N}$ which $m < s_1$ and $k \in [0, 1)$.

$$\begin{array}{rcl}
\mathbb{U}_n(x_m, x_{s_1}, \ldots, x_{s_1}) & \subseteq & \mathbb{U}_n(x_m, x_{m+1}, \ldots, x_{m+1}) \\
& + & \mathbb{U}_n(x_{m+1}, x_{m+2}, \ldots, x_{m+2}) \\
& + & \mathbb{U}_n(x_{m+2}, x_{m+3}, \ldots, x_{m+3}) \\
& + & \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \\
& + & \frac{k^m(1-k^{s-m})}{1-k}\mathbb{U}_n(x_0, x_1, \ldots, x_1) \\
& \subseteq & (k^m + k^{m+1} + \ldots + k^{s_1-1})\mathbb{U}_n(x_0, x_1, \ldots, x_1) \\
& = & \frac{k^m(1-k^{s_1-m})}{1-k}\mathbb{U}_n(x_0, x_1, \ldots, x_1).
\end{array}$$

Then we have

$$\lim_{m\,, s_1 \to +\infty} \mathbb{U}_n(x_m, x_{s_1}, \ldots, x_{s_1}) = \{0\},$$

since

$$\lim_{m\,, s_1 \to +\infty} \frac{k^m(1-k^{s_1-m})}{1-k}\mathbb{U}_n(x_0, x_1, \ldots, x_1) = \{0\}.$$

For $m \leq s_1 \leq s_2 \in \mathbb{N}$ and $(U5)$ implies that

$$\begin{array}{rcl}
\mathbb{U}_n(x_m, x_{s_1}, x_{s_2} \ldots, x_{s_2}) & \subseteq & \mathbb{U}_n(x_m, x_{s_1}, \ldots, x_{s_1}) \\
& + & \mathbb{U}_n(x_{s_1}, x_{s_1}, \ldots, x_{s_2}),
\end{array}$$

now taking the limit as $m, s_1, s_2 \to +\infty$, we get

$$\mathbb{U}_n(x_m, x_{s_1}, x_{s_2} \ldots, x_{s_2}) \to \{0\}.$$

Now for $m \leq s_1 \leq s_2 \leq \ldots \leq s_{n-1} \in \mathbb{N}$, we will have

$$\mathbb{U}_n(x_m, x_{s_1}, \ldots, x_{s_n}) \to \{0\}; \quad whenever, \quad m, s_1, \ldots, s_{n-1} \to +\infty,$$

then $\{x_m\}$ is a Cauchy sequence. By completeness of $(X, \mathbb{U}_n)$, there exists $a \in X$ such that $\{x_n\}$ is $\mathbb{U}_n$-convergent to a. The fact that the limit x_m is a fixed point of T follows the $\mathbb{U}_n$-continuity of T, and

$$Ta = T \lim_{m\to+\infty} x_m = \lim_{m\to+\infty} Tx_m = \lim_{m\to+\infty} x_{m+1} = a.$$

Finally, if a and b are two fixed points, then

$$\begin{array}{rcl}
\{0\} \subseteq \mathbb{U}_n(a, b, \ldots, b) & = & \mathbb{U}_n\Big(T(a), T(b), \ldots, T(b)\Big) \\
& \subseteq & k\mathbb{U}_n(a, b, \ldots, b).
\end{array}$$

Since $k < 1$, we have $\mathbb{U}_n(a, b, \ldots, b) = \{0\}$, so $a = b$ and the fixed point is unique. □

Conclusions

In this article, we have put forward a development of the results of U_n-hypermetric spaces, covering a variety of topics relevant for understanding their properties including completeness and the fixed-point theorem. We believe this work may be relevant from both the theoretical standpoint and the point of view of applications in contemporary problems such as those of clusterings which often appear in practice.

References

Cohen, L.W. & Goffman, C. 1949. The topology of ordered Abelian groups. *Transactions of the American Mathematical Society*, 67, pp.310-319. Available at: https://doi.org/10.1090/S0002-9947-1949-0032648-5.

Dehghan Nezhad, A. & Aral, Z. 2011. The topology of GB-metric spaces. *International Scholarly Research Notices*, art.ID:523453. Available at: https://doi.org/10.5402/2011/523453.

Dehghan Nezhad, A. & Khajuee, N. 2013. Some new results on complete $\mathbb{U}_n^*$-metric space. *Journal of Nonlinear Sciences and Applications*, 6(3), pp.216-226. Available at: http://dx.doi.org/10.22436/jnsa.006.03.07.

Dehghan Nezhad, A., Khajuee, N. & Mustafa, Z. 2017. Some new results on Universal metric spaces. *Thai Journal of Mathematics*, 15(2), pp.429-449 [online]. Available at: http://thaijmath.in.cmu.ac.th/index.php/thaijmath/article/view/623 [Accessed: 10 May 2021].

Dehghan Nezhad, A. & Mazaheri, H. 2010. New results in G-best approximation in G-metric spaces. *Ukrainian Mathematical Journal* 62(4), pp.648-654. Available at: https://doi.org/10.1007/s11253-010-0377-8.

Dhage, B.C., Pathan, A.M. & Rhoades, B.E. 2000. A general existence principle for fixed point theorems in d-metric spaces. *International Journal of Mathematics and Mathematical Sciences*, 23(7), art.ID:695952, pp.441-448. Available at: https://doi.org/10.1155/S0161171200001587.

Diminnie, C., Gahler S. & White, A. 2017. 2-inner product spaces, II1. *Demonstratio Mathematica*, 10(1), pp.169-188. Available at: https://doi.org/10.1515/dema-1977-0115.

Gähler, S. 1963. 2-metrische Räume und ihre topologische Struktur. *Mathematische Nachrichten*, 26(1-4), pp.115-148. Available at: https://doi.org/10.1002/mana.19630260109.

Gähler, S. 1964. Lineare 2-normietre Räume. *Mathematische Nachrichten*, 28(1-2), pp.1-43. Available at: https://doi.org/10.1002/mana.19640280102.

Gähler, S. 1966. Zur geometric 2-metrische räume. *Revue Roumaine de Mathématiques Pures et Appliquées*, 11, pp.664-669.

Ha, K.S., Cho, Y.J., Kim, S.S. & Khan, M.S. 1990. Strictly Convex Linear 2-Normed Spaces, *Mathematische Nachrichten*, 146(1), pp.7-16. Available at: https://doi.org/10.1002/mana.19901460102.

Kelly, J.B. 1975. Hypermetric spaces. In: *Kelly, L.M. (eds) The Geometry of Metric and Linear Spaces. Lecture Notes in Mathematics*, 490, pp.17-31. Berlin, Heidelberg: Springer. Available at: https://doi.org/10.1007/BFb0081128.

Khan, K.A. 2012. On the possibitity of n-topological spaces. *Internatial Journal of Mathematical Archive*, 3(7), pp.2520-2523 [online]. Available at: http://www.ijma.info/index.php/ijma/article/view/1442 [Accessed: 10 May 2021].

Khan, K.A. 2014. Generalized n-metric spaces and fixed point theorems. *Journal of Nonlinear and Convex Analysis*, 15(6), pp.1221-1229 [online]. Available at: http://www.yokohamapublishers.jp/online2/jncav15.html [Accessed: 10 May 2021].

Mustafa, Z. & Sims, B. 2003. Some remarks concerning D-metric spaces. In: *Proceeding of the International Conferences on Fixed Point Theory and Applications*, Valencia (Spain) 13-19 July 2003, Eds. J. G. Falset and Enrique Llorens Fuster and B. Sims, pp.189-198. Available at: https://carma.newcastle.edu.au/brailey/Research_papers/SOME%20REMARKS%20CONCERNING%20D-METRIC%20SPACES%20Mustafa%20and%20Sims.pdf [Accessed: 10 May 2021].

Mustafa, Z. & Sims, B. 2006. A new approach to generalized metric spaces. *Journal of Nonlinear Convex Analysis*, 7(2), pp.289-297 [online]. Available at: https://carma.edu.au/brailey/Research_papers/A%20new%20Approach%20to%20Generalized%20Metric%20Spaces.pdf [Accessed: 10 May 2021].

О НОВОЙ ВЕРСИИ РЕЗУЛЬТАТОВ В ОБЛАСТИ U_n-ГИПЕРМЕТРИЧЕСКИХ ПРОСТРАНСТВ

Акбар Дехгхан Незхад[а], *Ахмадреза* Форух[б], *Никола* Мирков[в] *Стоян* Раденович[г]

[а]Иранский университет науки и технологий, математический факультет, Нармак, г. Тегеран, Исламская Республика Иран

[б]Исламский университет Азад, Департамент математики, Северное отделение, г. Тегеран, Исламская Республика Иран

[в]Белградский университет, Институт ядерных исследований «Винча» - Национальный институт Республики Сербия, г. Белград, Республика Сербия, **корреспондент**,

[г]Белградский университет, машиностроительный факультет, г. Белград, Республика Сербия

РУБРИКА ГРНТИ: 27.00.00 МАТЕМАТИКА:
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: Целью данной статьи является представление концепции универсального U_n-гиперметрического пространства. Обобщено n-мерное $(n \geq 2)$ гиперметрическое расстояние на произвольном непустом множестве X, при этом данная так называемая гиперметрика вычисляет расстояние между всеми n точками пространства. В статье обсуждается концепция полноты в отношении гиперметрики, а также теорема о неподвижной точке, которые играют важную роль в разных направлениях прикладной математики.

Методы: В статье применялись теоретические методы функционального анализа.

Результаты: Представлена концепция универсального U_n-гиперметрического пространства. Описаны универсальные свойства U_n-гиперметрических пространств.

Выводы: Новая версия результатов в области U_n-гиперметрических пространств может применяться в различных дисциплинах, в которых требуется степень кластеризации.

Ключевые слова: U_n-гиперметрические пространства, OG-метрика, G-метрика.

НОВА ВЕРЗИЈА РЕЗУЛТАТА U_n-ХИПЕРМЕТРИЧКИХ ПРОСТОРА

Akbar Dehghan Nezhad[а], *Ahmadreza* Forough[б], *Никола* Мирков[в] *Стојан* Раденовић[г]

[а]Ирански универзитет за науку и технологију, Математички факултет, Нармак, Техеран, Исламска Република Иран

[б]Исламски универзитет Азад, Одељење за математику, Северно одељење, Техеран, Исламска Република Иран

[в]Универзитет у Београду, Институт за нуклеарне науке "Винча" - Национални институт Републике Србије, Београд, Република Србија, **аутор за преписку**,

[г]Универзитет у Београду, Машински факултет, Београд, Република Србија.

ОБЛАСТ: математика
ВРСТА ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/Циљ: У раду је представљен концепт универзалног U_n-хиперметричког простора. Генерализује се n-димензионално $(n \geq 2)$ хиперметричко растојање на произвољном непразном скупу X. Притом, ова тзв. хиперметрика изражава колико је међусобно растојање свих n тачака простора. Анализира се појам комплетности, у односу на хиперметрику, као и теорема непокретне тачке, која има значајну улогу у примењеној математици на разним пољима.

Методе: Примењене су стандардне теоријске методе функционалне анализе.

Резултати: Представљен је концепт генерализованог U_n-хиперметричког простора. Описане су и универзалне особине U_n-хиперметричких простора.

Закључци: Нова верзија резултата U_n-хиперметричких простора може имати примену у разнородним дисциплинама у којима је захтевано да се квантификује степен груписања.

Кључне речи: U_n-хиперметрички простори, OG-метрика, G-метрика.

Paper received on / Дата получения работы / Датум пријема чланка: 11.05.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 14.06.2021.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 16.06.2021.

CURRENT STATE OF THE APPLICATION OF ARTIFICIAL INTELLIGENCE IN RELIABILITY AND MAINTENANCE

Slavko J. Pokorni
Information Technology School, Belgrade, Republic of Serbia,
e-mail: slavko.pokorni@its.edu.rs,
ORCID iD: http://orcid.org/0000-0002-3173-597X

DOI: 10.5937/vojtehg69-30434; https://doi.org/10.5937/vojtehg69-30434

FIELD: Logistics, IT
ARTICLE TYPE: Original scientific paper

Abstract:

Introduction/purpose: At the end of 2019, the Government of the Republic of Serbia adopted the Strategy for the Development of Artificial Intelligence in the Republic of Serbia for the 2020-2025 period. This was a motivation for the author of this paper to try to give an overview of the current artificial intelligence (AI) applications in the field of reliability and maintenance, as well as its future applications.

Methods: The overview is done mainly using available literature, mostly from the Science Direct database, using abstracts generally, and in some cases whole papers.

Results: The result of this research is an overview of the artificial intelligence applications in the field of reliability and maintenance in the past thirty years. It also showed that AI systems can also be unreliable and need maintenance.

Conclusion: Artificial intelligence is and can be applied in reliability and maintenance. The research of available literature showed that AI is more applied in maintenance than in reliability. The progress in AI is inevitable, so it is important to understand its potentials for application in reliability and maintenance as well as its possible drawbacks.

Key words: artificial intelligence, reliability, maintainability, maintenance.

Introduction

The fact that the Government of the Republic of Serbia adopted the Strategy for the Development of Artificial Intelligence in the Republic of Serbia for the 2020-2025 period (Government of the Republic of Serbia, 2019), and that the author of this paper was a coauthor of a conference

paper in 2003 in which a posibility of improvement of jet engine diagnostics by applying neural networks was suggested (Siladić et al, 2003), and the fact that the author of this paper has been working in the area of reliability and maintainability as a professor and practitioner for more than thirty years was a motivation to try to give an overview of the current applications of artificial intelligence (AI) in the field of reliability and maintenance as well as its future applications.

Since there is information that AI can also fail (Bathaee, 2018), how to avoid AI to fail is also discussed.

The ultimate objective of this paper is to see possibilities of AI application to achieve more effective reliability and maintenance.

The definition of artificial intelligence (AI) is given first followed by the definition of reliability and maintainability which is briefly discussed; after that, the application of AI in the area of reliability and maintenance is given in the paper, and, finally, how to avoid AI failure is discussed as well as how to maintain it, based on the available literature. The literature review was done using the Science Direct database search using the key term *artificial intelligence*, and then mostly using abstracts, and in some cases whole papers.

This paper is also based on the paper accepted and presented at the OTEH 2020 Conference (Pokorni, 2020).

Artificial Intelligence

There is no generally accepted definition of artificial intelligence (Government of the Republic of Serbia, 2019). According to the Encyclopedia Britannica dictionary (Copeland, 1998) artificial intelligence is the ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings. According to the Merriam-Webster dictionary (Merriam-Webster, 2020), AI is a branch of computer science dealing with the simulation of intelligent behavior in computers, or the capability of a machine to imitate intelligent human behavior.

In (Government of the Republic of Serbia, 2019), the accepted definition of AI is also used in (European Commission, 2019): “Artificial intelligence (AI) refers to systems that display intelligent behavior by analyzing their environment and taking actions – with some degree of autonomy – to achieve specific goals.”

In (European Commission, 2019), it is also stated that “AI-based systems can be purely software-based, acting in the virtual world (e.g. voice assistants, image analysis software, search engines, speech and

face recognition systems) or AI can be embedded in hardware devices (e.g. advanced robots, autonomous cars, drones or Internet of Things applications)."

Obviously, the essential word is *intelligence*. That word is also discussed in (European Commission, 2019) where it is considered as "a vague concept", studied by different research in different scientific disciplines, and that "AI researchers use mostly the notion of rationality", which "refers to the ability to choose the best action to take in order to achieve a certain goal, given certain criteria to be optimized and the available resources". In accordance with that, in (European Commission, 2019), an updated definition of AI is proposed.

Artificial intelligence was founded as an academic and scientific discipline in the middle of fifties of the last century, and since then development has gone in different directions, being divided in sub-fields. Therefore, it is not a surprise that the definition of AI has been changed during time.

In the history of AI, there have been ups and downs, starting with the logic-based approach (during the 1950s and 1960s), the knowledge-based expert systems approach (1970s and 1980s), and the data-based approach (since 2000) years onwards - with periods of disappointment and reduced investment (Government of the Republic of Serbia, 2019). In the last decades, AI is defined as a study of intelligent agents - any device that percepts its environment and takes actions (by learning or using knowledge) to achieve its goals.

The term *artificial intelligence* is frequently applied to the project of developing systems endowed with the intellectual processes characteristic of humans, such as the ability to reason, discover meaning, generalize, or learn from past experience (Copeland, 1998). That is also the case in the area of reliability prognostic and maintenance management. So the goal can be, more or less, replacing human reasoning with machine reasoning with fewer errors and faster decision making.

Essentially, the use of AI is an attempt to replace human intelligence with machine intelligence. Because of that, sometimes, AI is called machine intelligence.

Progress in AI is evident in many areas, especially in the last decade. It seems that the area of reliability and maintainability is not an exception.

Reliability and maintenance

Reliability is defined as the ability of an item to perform a required function under stated conditions for a stated period of time (Bauer & Adams, 2012).

Maintenance is usually characterized with maintainability which refers to the ability how fast and easy an item can be fixed and modified.

Quantitatively, reliability and maintainability are expressed in probability, and both are very important in reducing downtime and operational and maintenance cost of an item or a system. Reliability and maintenance are mutually connected. Higher reliability means less costly maintenance.

High reliability is very important, especially in professional equipment, and it comprises hardware reliability, software reliability, and human reliability (Pokorni, 2018).

Reliability prediction has been done for almost 60 years, mostly by MIL-HDBK-217, but about 30 years ago, it was identified that new approaches are needed (Pokorni, 2016).

Can AI help to solve these problems, or can AI solve these problems better than people can?

Reliability is built in during design, provided in production and supported in use. It is also connected with cost. More reliable equipment is more expensive, but more reliable equipment is also cheaper for maintenance.

Reliability is also connected with the process of production and use or exploitation of the equipment which is designed to be reliable.

The right maintenance can save both cost and downtime, and achieve higher availability. Different maintenance strategies are in use. The basic ones are corrective (reactive, replacing an item after it fails) and preventive (proactive, replacing an item before it fails) maintenance. More used in modern equipment are predictive maintenance or condition monitoring (just in time maintenance, optimization, the best of corrective and preventive maintenance, replacing an item which is close to failure). Also, combinations of the previously mentioned ones are used. Such a combination is, for example, reliability-centered maintenance.

As connectivity and data accessibility become cheaper and more widespread nowadays, many companies are looking at predictive maintenance, or condition-based maintenance, powered by machine learning and analytics (Uptake, 2020). Obviously, there is a place for the application of AI.

Pokorni, S., Current state of the application of artificial intelligence in reliability and maintenance, pp.578-593

AI in reliability and maintenance

According to the available literature, studied for this work, the application of artificial intelligence in reliability and maintenance started about forty years ago.

At the end of the eighties of the previous century, the Rome Air Development Center (RADC) investigated a so-called Smart BIT – a program of research of development and the application of AI techniques to effect built-in test (BIT) improvement (Richards, 1989), for diagnosis and management of faults.

Twenty years ago, the author of this paper was involved in one attempt to propose applying an intelligent system for the maintenance of a jet engine. In the abstract of this work (Siladić et al, 2003), it is concluded that continuous monitoring of the jet engine working process is considered to be one of the most efficient methods for engine condition assessment, and that the integration of airplane and jet engine built-in information-displaying systems with nondestructive testing, spectral oil analysis, and total accumulating cycle into a diagnostic system has shown to be a reliable method of establishing a specific form of jet engine oncondition maintenance. However, in spite of that, such kind of a diagnostic system suffers from the absence of prognostic capability which is necessary to predict future engine components behavior; therefore, there is a need to upgrade these systems with intelligent features that are able to recognize error patterns and make automatic decisions about engine work.

In (Singh & Wang, 2008), it is stated that artificial intelligence techniques have drawn much attention in dealing with complex and challenging problems in power systems, and that reliability evaluation is a type of representative applications. In that paper, some concepts on reliability evaluation based on population-based intelligent search as well as a neural network enhanced Monte Carlo simulation were presented. Also, some case studies were presented to demonstrate the effectiveness of the proposed methods. According to that paper, it appears that the intelligence based methods hold promise for reliability studies and deserve to be further investigated.

In (Singh & Wang, 2008), the conceptual basis of an overall reliability evaluation process and the role of artificial intelligence methods were examined. It also provided some examples of AI application to the reliability analysis of hybrid systems involving conventional and alternative energy sources.

The author in (Kobbacy, 2012) found that relevant publications of AI applications in planning and modelling in maintenance started to appear from the mid 1980s.

In (Kobbacy, 2012), which is a good review of AI application in maintenance management, it is stated that during more than two decades (up to 2012) many attempts were made to apply AI techniques in maintenance modeling and management. The AI techniques used are numerous, ranging from classic expert systems that utilize rule based reasoning to more cumbersome optimization techniques used in Genetic Algorithms. It is stated that in the first decade of this century there was a shift towards developing hybrid intelligent management systems in operations that use more than one AI technique. The application areas of AI in maintenance extend widely from intelligent maintenance optimization models to more practical applications such as cost budgeting of maintenance projects and selecting optimal repair methods.

(Kobbacy, 2012) also presents an overview of the applications of AI techniques in maintenance, over the two decades, identifying specific applications and the extent of the use of techniques as well as near future trends. This was done by using the Science Direct database to carry out the literature search using the names of AI techniques, mostly using abstracts.

The author in (Kobbacy, 2012) classified artificial intelligence techniques in seven areas:

- Genetic Algorithms (GAs),
- Case Based Reasoning (CBR),
- Neural Networks (NNs),
- Knowledge Based Systems (KBs),
- Fuzzy Logic (FL),
- Data Mining (DM), and
- Hybrid Systems.

The review in (Kobbacy, 2012) showed that over the two decades, up to June 2012, many AI techniques were applied in maintenance management and modelling with the following conclusion:

- The most popular of the AI techniques applied in maintenance was GAs (due to its nature which offers powerful optimisation tools that can deal with complex maintenance planning problems),
- Both KBs and FL received moderate interest in maintenance applications,

- A few applications were found on CBR and NNs in maintenance but none using DM (with the expectation that DM will be used in the future).
- A few hybrid systems were developed in the maintenance area, but the number of publications with FL and hybrid systems increased.

In (Cheng et al, 2008), which is included in the review (Kobbacy, 2012), in order to improve the efficiency of the reliability-centered maintenance (RCM) analysis, case-based reasoning (CBR), as a kind of artificial intelligence (AI) technology, was successfully introduced into the RCM analysis process, and the framework for the intelligent RCM analysis (IRCMA) was studied.

As an addition to the review from (Kobbacy, 2012), we will include some examples from sources after 2012, also using the Science Direct database and the key word *artificial intelligence*.

In (Blache, 2017), it is written about the case of Lufthansa Airlines, which maintains more than 1,000 planes and uses machine learning in real-time data collection and decision making, where recommended failure-avoidance actions come as a result of error messages and sensor data, among other things.

In (Diryag et al, 2014), the study presents a novel approach to a prediction of robot execution failures based on neural networks. Real data consisting of robot forces and torques recorded immediately after the system failure are used for neural network training. The multilayer feedforward neural networks are employed in order to find an optimal solution for the failure prediction problem.

In (Otto, 2019), it is concluded that emerging technologies such as the Internet of Things (IoT), Big Data, analytics, and cloud data storage are enabling more equipment to share condition-based data with a centralized server, making fault detection easier, more practical, and more direct.

Because this paper is motivated by the Strategy for the Development of Artificial Intelligence in the Republic of Serbia, it is worth mentioning that the Faculty of Mechanical Engineering (FME), in cooperation with the Faculty of Mathematics of the University of Belgrade, Serbia, organized a master study named *Industry 4.0* in which two study subjects are dealing with artificial intelligence, and there is a possibility to apply it also in the area of reliability and maintenance, as the authors from the FME have already done in (Diryag et al, 2014).

In (Bhargava, 2019), it is stated that AI Techniques for Reliability Prediction for Electronic Components provide emerging research exploring the theoretical and practical aspects of prediction methods using artificial intelligence and machine learning in the manufacturing field.

As mentioned before, the production process is also important for reliability. A poor quality production process can degrade reliability built in during the design phase. In (Alsina et al, 2018), it is studied how machine learning models can fit the reliability estimation function in comparison with traditional approaches (e.g., Weibull distribution), having in mind that the reliability estimation of engineered components is fundamental for many optimization policies in a production process. Four diverse machine learning approaches are implemented: artificial neural networks, support vector machines, random forest, and soft computing methods.

A new method for hull structural plate corrosion damage detection and recognition based on artificial intelligence using the convolutional neural network (CNN) is proposed in (Yao et al, 2019), which makes up for the research gap of applying deep learning into corrosion damage detection in the field of naval architecture and ocean engineering.

In (Zhao et al, 2019), data driven-based and knowledge driven-based fault detection and diagnosis (FDD) methods for building energy systems are reviewed, and the strengths and shortcomings of the existing artificial intelligence-based methods are analysed.

In (Lee et al, 2019), the AI-based algorithms (data-driven modeling approach) for predictive maintenance are presented and applied to monitor two critical machine tool system elements: the cutting tool and the spindle motor.

Everyday life shows that faults of elements and systems are inevitable. But are near-zero-failure systems possible? In (Foresti et al, 2020), it is found that the results obtained in 12 international companies demonstrate a possible global standardization of operative processes, leading to the design of a near-zero-failure intelligent system that is able to learn and upgrade itself, which is exploitable in any context of Society 5.0, thus reducing the risk factors at all management levels and ensuring quality and sustainability.

Reliability of AI

Everything can fail, and AI is not an exception. If AI is an attempt to replace human intelligence with machine intelligence, and human reasoning can sometimes fail, so AI can fail in a similar way. So, is the

Pokorni, S., Current state of the application of artificial intelligence in reliability and maintenance, pp.578-593

reason of erroneous reasoning (erroneous concluding, decisioning) in wrong learning? Or can we raise the question about the reliability of AI, or how to avoid AI fails?

This is an important question which attracted the attention of ISO/IEC. In (ISO, 2020), there are surveys of topics related to the so-called trustworthiness in AI systems, including the following: (1) approaches to establish trust in AI systems through transparency, explainability, controllability, etc.; (2) engineering pitfalls and typical associated threats and risks to AI systems, along with possible mitigation techniques and methods; and (3) approaches to assess and achieve availability, resiliency, reliability, accuracy, safety, security, and privacy of AI systems. In this document, trustworthiness is defined as an ability to meet stakeholders expectations in a verifiable way, including the characteristics of trustworthiness such as reliability, availability, resilience, security, privacy, safety, accountability, transparency, integrity, authenticity, quality, and usability.

(Heaven, 2019) discussed why deep learning AI is so easy to fool. An example is in a self-driving car application in a real situation. It is, however, said that ih can happen in the case of sabotage as well.

In (University of Cambridge, 2016) under the headline “Enhanching the reliabiliy of artificial intelligence“, it is stated that “Computers that learn for themselves are with us now. As they become more common in 'high-stakes' applications like robotic surgery, terrorism detection and driverless cars, researchers ask what can be done to make sure we can trust them.“ So, are they reliable? Or, can they fail?

There are examples of erroneous AI. Some examples can be found in (Bathaee, 2018): AI failures from IBM, Microsoft, Apple, and Amazon. The example from IBM happened in 2013, when IBM partnered with the University of Texas MD Anderson Cancer Center which developed a new “Oncology Expert Advisor” system with the goal to cure cancer (Blier, 2020). In July 2018, StatNews reviewed internal IBM documents and found that IBM’s Watson was making erroneous, downright dangerous cancer treatment advice. In (Bathaee, 2018), it is concluded that, probably, the reason is because the software is trained on a small number of hypothetical cancer patients, rather than on real patient data.

There are authors who ask questions about potential risks, such as whether AI will pose an existential threat to humanity, or whether AI technology will be concentrated in the hands of the few (Bathaee, 2018), but this author thinks that is not the question of AI application in the area of reliability and maintainability, at least not in the near future.

There is also a question raised whether AI can fail to function as expected, and the reason is because of the nature of the machine-learning algorithms on which modern AI techniques are commonly built. These algorithms are capable of learning from massive amounts of data, and once that data is internalized, they are capable of making decisions experientially or intuitively like humans. This means that for the first time, computers are no longer merely executing detailed pre-written instructions but are capable of arriving at dynamic solutions to problems based on patterns in data that humans may not even be able to perceive. This new approach comes at a price, because many of these algorithms can be black boxes, even to their creators (Bathaee, 2018). But in the area of maintenance, the problem is more often that we do not have enough data.

One of the important questions is whether AI can work on a small number of data, for example, the number of failures. In (Microsoft, 2020), it is concluded that model's predictive accuracy depends on the relevancy, sufficiency, and quality of the training and test data. Two questions are commonly asked with regard to failure history data: (1) How many failure events are required to train a model? And (2) How many records is considered as "enough"? (Microsoft, 2020).

As a conclusion for AI reliability, or trustworthiness (which is a broader term), let us use the statement from (Draft, 2020): „Having the capability to generate tremendous benefits for individuals and society, AI also gives rise to certain risks that should be properly managed„ and „It is known that humans are biased in their decision making. Since AI systems are designed by humans, it is possible that humans inject their bias into them, even in an unintended way.“

Maintaining of AI

An AI system also needs maintenance, not only because AI can fail. In (Blier, 2020), AI is compared to a car engine in a way that maintaining AI can be as easy as replacing the cabin air filter, or as complicated as rebuilding the transmission, and that is considered as a reason why it is important to understand some basic AI maintenance best practices.

So, just like any other product, AI requires maintenance to remain robust and valuable, and as a car, AI can experienced a sudden, catastrophic failure if it is not kept up-to-date.

To build successful AI, there is a need to be familiar with cases when AI initiatives failed in order not to make the same mistakes. Also there is a need to be familiar with data science.

Conclusion

Progress in AI is inevitable, so it is important to understand its potentials for the application in reliability and maintenance and also possible pitfalls of it.

The review of the available literature shows that AI is more applied in maintenance than in reliability. Kobbacy's paper gives a good review of AI application in maintenance management at the end of the last century and the beginning of this century. It shows that the most popular techniques in maintenance were Genetic Algorithms, then Knowledge Based Systems (or expert systems) and Fuzzy Logic with moderate interest, and Case Based Reasoning, Neural Networks and Hybrid Systems with only a few applications. Nowadays, there is much more interest in machine learning (as a subset of AI), deep learning (as a subset of machine learning), and intelligent agents. Machine learning and intelligent agents can be applied more in reliability and predictive maintenance in the future.

Artificial intelligence can be applied in reliability and maintenance. In both cases, a problem is data. The problem is how to cope with large amounts of data on the one hand, and with very small amounts of data on the other hand, because both can be the case in reliability and maintenance.

Everything can fail, and AI is not an exception. So, an AI system also needs maintenance. Also, an important question is how to avoid failure of AI.

References

Alsina, E.F., Chica, M., Trawinski, K. & Regattieri, A. 2018. On the use of machine learning methods to predict component reliability from data-driven industrial case studies. *The International Journal of Advanced Manufacturing Technology,* 94, pp.2419-2433. Available at: https://doi.org/10.1007/s00170-017-1039-x.

Bathaee, Y. 2018. The Artificial Intelligence Black Box and the Failure of Intent and Causation. *Harvard Journal of Law & Technology,* 31(2) [online]. Available at: https://jolt.law.harvard.edu/assets/articlePDFs/v31/The-Artificial-Intelligence-Black-Box-and-the-Failure-of-Intent-and-Causation-Yavar-Bathaee.pdf [Accessed: 15.01.2021].

Bauer, E. & Adams, R. 2012. *Reliability and Availability of Cloud Computing*. Hoboken, NJ: John Wiley & Sons. ISBN: 978-1-118-17701-3.

Bhargava, C. 2019. *AI Techniques for Reliability Prediction for Electronic Components*. Hershey, PA: IGI Global. Available at: https://doi.org/10.4018/978-1-7998-1464-1. ISBN: 9781799814641

Blache, K.M. 2017. AI and Reliability: How Much, How Fast? *Efficient Plant*, 14 November [online] Available at: https://www.efficientplantmag.com/2017/11/ai-reliability-much-fast/ [Accessed: 15.01.2021].

Blier, N. 2020. Stories of AI Failure and How to Avoid Similar AI Fails. *Lexalytics,* 30 January [online]. Available at: https://www.lexalytics.com/lexablog/stories-ai-failure-avoid-ai-fails-2020 [Accessed: 15.01.2021].

Cheng, Z., Jia, X., Gao, P., Wu, B. & Wang, J. 2008. A framework for intelligent reliability centered maintenance analysis. *Reliability Engineering & System Safety,* 93(6), pp.806-814. Available at: https://doi.org/10.1016/j.ress.2007.03.037.

Copeland, B.J. 1998. Artificial intelligence In: *Encyclopedia Britannica*. London: Encyclopedia Britannica, Inc. [online]. Available at: https://www.britannica.com/technology/artificial-intelligence [Accessed: 15.01.2021].

Diryag, A., Mitić, M. & Miljković, Z. 2014. Neural Networks for Prediction of Robot Failures. In: *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science,* 228(8), pp.1444-1458. Available at: https://doi.org/10.1177/0954406213507704.

-European Commission. 2019. *A definition of AI: Main capabilities and scientific disciplines.* Brussels: European Commission Independent High-Level Expert Group on Artificial Intelligence [online]. Available at: https://ec.europa.eu/digital-single-market/en/news/definition-artificial-intelligence-main-capabilities-and-scientific-disciplines [Accessed: 15.01.2021].

Foresti, R., Rossi, S., Magnani, M., Lo Bianco, C.G. & Delmonte, N. 2020. Smart society and artificial intelligence: big data scheduling and theglobal standard method applied to smart maintenance. *Engineering*, 6(7), pp.835-846. Available at: https://doi.org/10.1016/j.eng.2019.11.014.

-Government of the Republic of Serbia. 2019. *Strategy for the Development of Artificial Intelligence in the Republic of Serbia for the period 2020-2025* [online]. Available at: https://www.srbija.gov.rs/tekst/en/149169/strategy-for-the-development-of-artificial-intelligence-in-the-republic-of-serbia-for-the-period-2020-2025.php [Accessed: 15.01.2021].

Heaven, D. 2019. Why deep-learning AIs are so easy to fool. *Nature*, 09 October [online]. Available at: https://www.nature.com/articles/d41586-019-03013-5 [Accessed: 15.01.2021].

-ISO. 2020. *ISO/IEC TR 24028:2020 Information technology — Artificial intelligence — Overview of trustworthiness in artificial intelligence* [online]. Available at: https://www.iso.org/standard/77608.html?browse=tc [Accessed: 15.01.2021].

Kobbacy, K.A.H. 2012. Application of Artificial Intelligence in Maintenance Modelling and Management. *IFAC Proceedings Volumes*, 45(31), pp.54-59. Available at: https://doi.org/10.3182/20121122-2-ES-4026.00046.

Lee, W.J., Wu, H., Yun, H., Kim, H., Jun, M.B.G. & Sutherland, J.W. 2019. Predictive Maintenance of Machine Tool Systems Using Artificial Intelligence Techniques Applied to Machine Condition Data. *Procedia CIRP*, 80, pp.506-511. Available at: https://doi.org/10.1016/j.procir.2018.12.019.

-Merriam-Webster. 2020. Artificial intelligence. In: *Merriam-Webster.com dictionary* [online]. Available at: https://www.merriam-webster.com/dictionary/artificial%20intelligence [Accessed: 15.01.2021].

-Microsoft. 2020. *Azure AI guide for predictive maintenance solutions* [online]. Available at: https://docs.microsoft.com/en-us/azure/machine-learning/team-data-science-process/predictive-maintenance-playbook [Accessed: 15.01.2021].

Otto, S. 2019. Artificial intelligence for predictive maintenance. *Aerospace Manufacturing and Design*, 6 Febrauary [online]. Available at: https://www.aerospacemanufacturinganddesign.com/article/artificial-intelligence-for-predictive-maintenance. Accessed: 15.01.2021.

Pokorni, S. 2016. Reliability prediction of electronic equipment: problems and experience. In: *7th International Scientific Conference on Defensive Technologies OTEH 2016*, Belgrade, pp.695-700, 6-7 October. ISBN 978-86-81123-82-9.

Pokorni, S. 2018. Reliability of Internet of Things. In: *8th International Scientific Conference on Defensive Technologies OTEH 2018*, Belgrade, pp.567-570, 11-12 October [online]. Available at: http://www.vti.mod.gov.rs/oteh18/elementi/rad/027.htm. ISBN 978-86-81123-88-4. [Accessed: 15.01.2021].

Pokorni, S. 2020. Artificial Intelligence in Reliability and Maintainability. In: *9th International Scientific Conference on Defensive Technologies OTEH 2020*, Belgrade, 15-16 October [online]. Available at: http://www.vti.mod.gov.rs/oteh/elementi/rad/114.pdf [Accessed: 15.01.2021].

Richards, D.W. 1989. Smart BIT: A plan for intelligent built-in test. *IEEE Aerospace and Electronic Systems Magazine*, 4(1), pp.26-29. Available at: https://doi.org/10.1109/62.16985.

Siladić, M., Pokorni, S. & Rašuo, B. 2003. Possibility of improvement of jet engine diagnostic by applying neural networks (in Serbian). In: *Proceeding of XLVII ETRAN Conference*, Herceg Novi, June 8-13, Vol. I.

Singh, C. & Wang, L. 2008. Role of Artificial Intelligence in the Reliability Evaluation of Electric Power Systems. *Turkish Journal of Electrical Engineering and Computer Science*, 16(3), [online]. Available at: http://journals.tubitak.gov.tr/elektrik/issues/elk-08-16-3/elk-16-3-2-0808-7.pdf [Accessed: 15.01.2021].

-University of Cambridge. 2016. *Enhancing the reliability of artificial intelligence* [online]. Available at: https://phys.org/news/2016-10-reliability-artificial-intelligence.html [Accessed: 15.01.2021].

-Uptake. 2020. *How AI is Making Predictive Maintenance a Reality for the Industrial IoT* [online]. Available at: https://www.uptake.com/blog/how-ai-is-making-predictive-maintenance-a-reality-for-the-industrial-iot [Accessed: 15.01.2021].

Yao, Y., Yang, Y., Wang, Y. & Zhao, X. 2019. Artificial intelligence-based hull structural plate corrosion damage detection and recognition using convolutional neural network. *Applied Ocean Research*, 90(art.number:101823). Available at: https://doi.org/10.1016/j.apor.2019.05.008.

Zhao, Y., Li, T., Zhang, X. & Zhang, C. 2019. Artificial intelligence-based fault detection and diagnosis methods for building energy systems: Advantages, challenges and the future. *Renewable and Sustainable Energy Reviews*, 109, pp.85-101. Available at: https://doi.org/10.1016/j.rser.2019.04.021.

ПРИМЕНЕНИЕ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА В ОБЛАСТЯХ НАДЕЖНОСТИ И ОБСЛУЖИВАНИЯ

Славко Й. Покорни
Колледж информационных технологий, г. Белград, Республика Сербия

РУБРИКА ГРНТИ: 28.00.00 КИБЕРНЕТИКА:
28.23.00 Искусственный интеллект,
28.27.00 Теория надежности,
81.00.00 ОБЩИЕ И КОМПЛЕКСНЫЕ ПРОБЛЕМЫ ТЕХНИЧЕСКИХ И ПРИКЛАДНЫХ НАУК И ОТРАСЛЕЙ НАРОДНОГО ХОЗЯЙСТВА:
81.88.00 Материально-техническое снабжение. Логистика
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В конце 2019 года Правительство Республики Сербия утвердило Стратегию развития искусственного интеллекта в Республике Сербия за период 2020-2025 годов. Настоящий факт побудил автора данной статьи попытаться дать в ней обзор действующих приложений искусственного интеллекта (ИИ) в области надежности и обслуживания, а также разрабатываемых приложений.

Методы: Обзор составлен на основании доступной литературы, в основном из базы данных Science Direct, в первую очередь использовались аннотации, а в некоторых случаях и целые статьи.

Результаты: В результате проведенного исследования был составлен обзор приложений искусственного интеллекта в области надежности и обслуживания за последние тридцать лет. Исследование показало, что система искусственного интеллекта может оказаться ненадежной и требует обслуживания.

Выводы: Искусственный интеллект применяется и может применяться для обеспечения надежности и в области обслуживания. Исследование доступной литературы показало, что ИИ в большей мере применяется в области обслуживания, нежели в области надежности. Прогресс в области искусственного интеллекта неизбежен, поэтому важно понимать его возможности для применения в сфере надежности и обслуживания, а также возможные препятствия, с целью их преодоления.

Ключевые слова: искусственный интеллект, надежность, ремонтопригодность, обслуживание.

ПРЕГЛЕД СТАЊА ВЕШТАЧКЕ ИНТЕЛИГЕНЦИЈЕ У ПОУЗДАНОСТИ И ОДРЖАВАЊУ

Славко Ј. Покорни
Висока школа струковних студија за информационе технологије,
Београд, Република Србија

ОБЛАСТ: логистика, информатика
ВРСТА ЧЛАНКА: оригинални научни чланак

Сажетак:

Увод/циљ: Крајем 2019. године Влада Републике Србије усвојила је Стратегију развоја вештачке интелигенције у Републици Србији за период 2020–2025. године. С тим увези, у овом раду је представљен преглед тренутних примена апликација вештачке интелигенције (ВИ) у области поузданости и одржавања, као и будућих примена.

Методе: Истраживање је реализовано захваљујући доступној литератури, углавном из базе података Science Direct, коришћењем апстракта, а у неким случајевима и читавих радова.

Резултати: Резултат овог истраживања је преглед примена апликација вештачке интелигенције у области поузданости и одржавања у последњих тридесет година. Такође, показано је да систем ВИ може бити непоуздан и да му је потребно одржавање.

Закључак: Вештачка интелигенција може се применити и у поузданости и одржавању. Из доступне литературе може се закључити да се ВИ чешће примењује у одржавању него у поузданости. Напредак у ВИ је неизбежан, па је важно разумети његове потенцијале за примену у поузданости и одржавању, као и могуће замке.

Кључне речи: вештачка интелигенција, поузданост, погодност одржавања, одржавање.

Paper received on / Дата получения работы / Датум пријема чланка: 20.01.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 19.04.2021.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 21.04.2021.

IMPROVEMENT OF SAFETY MEASURES BY APPLYING A TECHNICAL SOLUTION ON THE M-80A INFANTRY COMBAT VEHICLE

Milan N. Končar[a], *Odil* I. Anarbaev[b], *Dobrivoje* R. Mutavdžić[c], *Goran* M. Lazić[d], *Željko* M. Jokić[e]

[a] University of Defense in Belgrade, Military Academy, Department of Army Weapons and Equipment, Belgrade, Republic of Serbia, e-mail: liksko@gmail.com, **corresponding author**, ORCID iD: https://orcid.org/0000-0002-8247-5397

[b] Academy of the Armed Forces of the Republic of Uzbekistan, Department of General Tactics, Tashkent, Republic of Uzbekistan, e-mail: nusmonova516@gmail.com

[c] University of Defense in Belgrade, Military Academy, Department of Army Weapons and Equipment, Belgrade, Republic of Serbia, e-mail: undertakerxxx4@gmail.com, ORCID iD: https://orcid.org/0000-0003-0961-4546

[d] University of Defense in Belgrade, Military Academy, Department of Army Weapons and Equipment, Belgrade, Republic of Serbia, e-mail: goran.lazic@va.mod.gov.rs, ORCID iD: https://orcid.org/0000-0001-9752-3956

[e] University of Defense in Belgrade, Military Academy, Department of Army Weapons and Equipment, Belgrade, Republic of Serbia, e-mail: antras1209@gmail.com, ORCID iD: https://orcid.org/0000-0002-3646-1787

DOI: 10.5937/vojtehg69-31837; https://doi.org/10.5937/vojtehg69-31837

FIELD: Mechanical engineering, Weapons
ARTICLE TYPE: Original scientific paper

Abstract:

Introduction/purpose: The paper presents a solution for overcoming a possible problem - breach of safety measures when operating the BVP M-80A Infantry Combat Vehicle on a training ground during tactical exercises and shooting at night. The crux of the problem is that the officer in charge of a tactical exercise and shooting is not in a position to observe in which direction the gunner-operator aims because no device has been installed on the BVP M-80A to signal this.

Methods: After deploying the vehicle in practice and and on the basis of experience during shooting, it was concluded that there is a problem of controlling shooting at night and in reduced visibility conditions.

Results: The paper provides a practical solution to prevent situations such as disorientation, impossibility of observing targets, and turning weapons towards the outside the shooting range boundaries, thus violating the security measures of all participants in the exercise including the BVP M-80A unit itself. A technical improvement was implemented on the vehicle by installing a signaling device that gives visual information to the officer in charge of shooting in which direction the weapon is turned.

Conclusion: The installed signaling device enables the officer who commands the exercise and shooting to be in control in a timely manner, eliminate possible causes of violation of security measures, and successfully implement the planned activity.

Keywords: security measures, control, combat vehicle, technical improvement, signaling device.

Solution applied to improve safety measures

This technical solution belongs to the domain of armored vehicle constructions and has multiple applications. The construction and installation of the signalizer ensure that the officer who commands the tactical exercise and shooting has control over the operation of the BVP M-80A unit at distances of over 600 m. The application of this technical improvement allows complete implementation and respect of safety measures during tactical live-fire exercises at night. In addition to the construction and installation of the signaling device, the construction of additional lighting is also planned with the aim of preparing weapons and ammunition for exercises at night or in reduced visibility conditions. (Školski centar oklopno-mehanizovanih jedinica JNA, 1990)

Construction defect to be corrected by applying this technical solution - improvement

The BVP M-80A is not equipped with a signaling device that provides visual information in which direction the weapon is directed (Savezni sekretarijat za narodnu odbranu, 1988a) unlike the M-84 tank where the headlight is installed on the turret (Novinsko-izdavačka ustanova „Vojska“, 1995). The BVP M-80A is armed with a 20mm cannon and a 7.62mm machine gun (Savezni sekretarijat za narodnu odbranu, 1988b). The officer in charge of a tactical exercise or shooting

is not able to exercise control over the operation of mechanized units in conditions of reduced visibility (rain, fog, snow, etc.) or at night.

Construction defect

The curricula of specialised classes for cadets of the Military Academy and reserve officer training course, armored units, prescribe both day and night-time shooting on the automated shooting range.

On the Orešac automated shooting range (ASR), the track for armored vehicles is about 600 m long. At the end of the track, there is space for turning armored vehicles after shooting has ended. At the command of the officer in charge, the driver starts turning the armored vehicle in order to get back to the starting line and during the turn the weapon should aim at the targets in order not to violate safety measures. At all times, the shooting commander should know/have visual control of the direction the weapon is facing (Školski centar oklopno-mehanizovanih jedinica JNA, 1990). Due to the fact that the BVP M-80A is not equipped with a visual signaling device, the tactical exercise or shooting commander cannot fully control the operation of the mechanized unit crew (Generalštab Vojske Jugoslavije, 1998).

The construction and installation of a signaling device on the BVP M-80A turret solved the problem of observing in which direction vehicle weapons are positioned. In this way, security was improved during activities at night or in conditions of reduced visibility. In addition to the mentioned signaling device, an additional light should be installed to illuminate the turret during the weapon and ammunition preparation (Končar et al, 2016).

During tactical exercises and shooting at night and in reduced visibility conditions, the lecturers at the armored unit training course used the mentioned device and as such it proved to be effective and the security measures were raised to a higher level. There was no engagement in the armored units of the Serbian Army to find a solution to the problem. The explanation given is that, during tactical and shooting exercises, vehicles are occupied by commanders of mechanized units, trained to successfully realize all tasks. However, it is clear that the officer in charge of the exercise still has no control over the activities of the gunner-operator of a mechanized unit.

Description of the technical solution

The BVP M-80A signaling device with additional light is the result of many years of experience of the Military Academy officers, gained in the

realization of shooting training by armored units. This structural element of the BVP M-80A is intended for shooting at night and in conditions of reduced visibility on the automated shooting range of armored units.

The main parts are:

- signaling device,
- distributors with switches and sockets,
- electrical installation kit, and
- extra light.

The parts are structurally adapted to be easy to install and to be operated easily and safely.

Installation:

a) b)

Figure 1 – Signalizer with the mount
Рис. 1 – Сигнализатор с креплением
Слика 1 – Сигнализатор са постољем

In Figure 1a, there is a signaling device on the stand and with a conductor. Figure 1a shows the situation when the signaling device is switched off, and Figure 1b when the signaling device is switched on. The signaling stand is mounted on the launcher of the anti-tank guided

missile and fixed with a screw without violating the purpose of the launcher (Savezni sekretarijat za narodnu odbranu, 1988c).

Figure 2 – Distributor
Рис. 2 – Распределитель
Слика 2 – Разводник

The signaling device is connected to the distributor by a three-pole contact. The distributor is installed on the anti-tank guided missile launcher and secured so that it does not obstruct the launcher operation. There are two three-pole sockets on the distributor.

The three-pole contact of the signaling device is connected to the lower socket while the three-pole contact of the additional light is connected to the upper socket.

A switch intended for switching on the additional light is installed on the distributor (Figures 3a and 3b).

Figure 3a – Additional light - off
Рис. 3а – Дополнительное освещение – выкл.
Слика 3а – Додатно светло – искључено

Figure 3b – Additional light – on
Рис. 3б – Дополнительное освещение – вкл.
Слика 3б – Додатно светло – укључено

A common conducting wire connects all parts in the circuit.

Figure 4 – "+" pole
Рис. 4 – „+“ полюс
Слика 4 – „+” пол

Figure 5 – "-" pole
Рис. 5 – „-“ полюс
Слика 5 – „-” пол

The "+" pole conductor is placed and fastened to the distribution box intended for the installation of the periscope heater for a gunner – operator, Figure 4a (Savezni sekretarijat za narodnu odbranu, 1988a). The "-" pole conductor is placed on the turret edge (Figure 5).

The signalizer and the additional light are switched on in the following order:

- set the "ground" switch to the upper position (Figure 6).

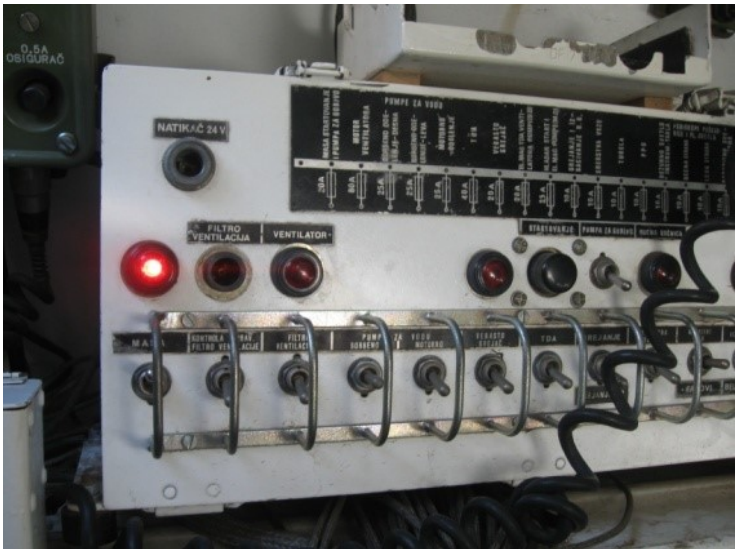


Figure 6 – Control panel in the BVP M-80A control section
Рис. 6 – Панель управления в секции управления БВП М-80А
Слика 6 – Контролна табла у управном одељењу БВП М-80А

- set the gunner's periscope heater switch to the upper position (ON), Figure 7 (Končar & Isailović, 2009).

Figure 7 – Gunner's periscope heater switch
Рис. 7 – Выключатель обогревателя перископа наводчика
Слика 7 – Прекидач грејача перископа нишанџије

Figure 8 shows the BVP M-80A with the signalizer installed and swithed on just before the start of shooting on the automated shooting range.

Figure 8 – BVP M-80A at the starting line
Рис. 8 – БВП М-80А на стартовой точке
Слика 8 – БВП М-80А на полазној линији

Figure 9 shows the BVP M-80A with the signaling device installed and switched on while moving during a night shooting exercise.

The signaling device is clearly visible, sending visual information that the weapon barrel is facing the target. In case that the signal light is not visible, shooting is stopped, the brake is used, and the weapon barrel is directed towards the target(s)(Školski centar oklopno-mehanizovanih jedinica JNA, 1990).

When the signal light is spotted again, shooting continues. In the situation when there is a fault on the signaling device, shooting is stopped until the fault is repaired by an electrical mechanic.

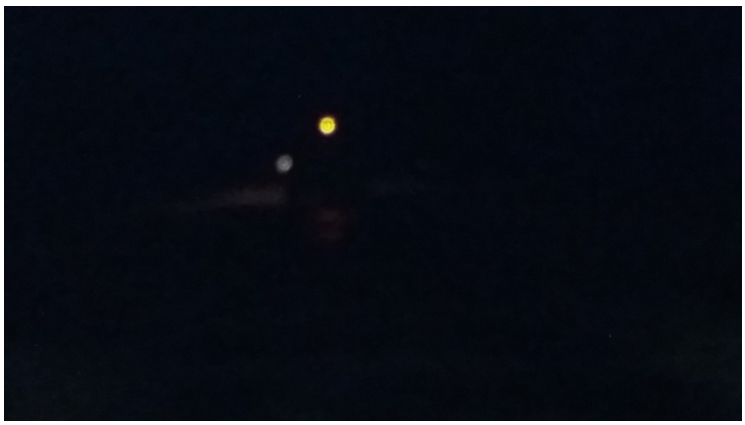


Figure 9 – BVP M-80A firing on the move on the track of the automated shooting range
Рис. 9 – БВП М-80А ведет стрельбу с ходу по трассе автоматизированного стрельбища
Слика 9 – БВП М-80А на стази аутоматизованог стрелишта током кретања реализације гађања

Conclusion

The construction and installation of a signalizer enable a commanding officer in charge of the tactical exercise and shooting to completely control the operation of a mechanized unit at night and in conditions of reduced visibility. Security measures are fully complied with owing to this technical improvement. The construction and installation of an additional light to illuminate the turret enable the gunner-operator to have improved conditions for the weapon and ammunition preparation as well as for eliminating malfunctions and controlling the weapon unloading after the end of shooting.

References

-Generalštab Vojske Jugoslavije. 1998. *Pravilo gađanja naoružanjem OMJ*. Belgrade: Generalštab Vojske Jugoslavije (in Serbian).

Končar, M. & Isailović, M. 2009. *Naoružanje i oprema BVP M-80A, priručnik*. Belgrade: Military Academy (in Serbian).

Končar, M., Mutavdžić, D. & Nikolić, B. 2016. Lighting set tiles infantry fighting vehicle M-80A. In: *II International scientific conference safety and crisis management - theory and practise safety for the future,* Belgrade, pp.96-100, September 29-30 [online]. Available at: https://bekmen.rs/zbornik/2016/2016-Zbornik-SRP.pdf (in Serbian) [Accessed: 9 April 2021]. ISBN: 978-86-80698-01-4.

-Novinsko-izdavačka ustanova „Vojska“. 1995. *Uputstvo i program gađanja naoružanjem oklopnih i mehanizovanih jedinica.* Belgrade: Novinsko-izdavačka ustanova „Vojska“ (in Serbian).

-Savezni sekretarijat za narodnu odbranu (SSNO). 1988a. *Tehničko uputstvo za BVP M-80 i M-80A: Opis, rukovanje, osnovno i tehničko održavanje – knjiga*. Belgrade: Savezni sekretarijat za narodnu odbranu (SSNO) (in Serbian).

-Savezni sekretarijat za narodnu odbranu (SSNO). 1988b. *Borbeno vozilo pešadije M-80 i M-80A: Priručnik za vojnika.* Belgrade: Savezni sekretarijat za narodnu odbranu (SSNO) (in Serbian).

-Savezni sekretarijat za narodnu odbranu (SSNO). 1988c. *Tenk M-84: Opis, rukovanje, osnovno i tehničko održavanje – knjiga 2.* Belgrade: Savezni sekretarijat za narodnu odbranu (SSNO) (in Serbian).

-Školski centar oklopno-mehanizovanih jedinica JNA. 1990. *Naoružanje BVP M-80A: Priručnik za pitomce*. Banja Luka: Školski centar oklopno-mehanizovanih jedinica JNA (in Serbian).

УЛУЧШЕНИЕ МЕР БЕЗОПАСНОСТИ ПУТЕМ ПРИМЕНЕНИЯ ТЕХНИЧЕСКОГО РЕШЕНИЯ НА СУХОПУТНОЙ БОЕВОЙ МАШИНЕ М-80А

Милан Н. Кончар[а], **корреспондент**, *Одил* И. Анарбаев[б], *Добривое* Р. Мутавджич[в], *Горан* М. Лазич[г], *Желько* М. Йокич[д]

[а] Университет обороны в г. Белград, Военная академия, кафедра вооружения и техники сухопутных войск, г. Белград, Республика Сербия

[б] Академиия Вооружённых сил Республики Узбекистан, кафедра общей тактики, г. Ташкент, Республика Узбекистан

[в] Университет обороны в г. Белград, Военная академия, кафедра вооружения и техники сухопутных войск, г. Белград, Республика Сербия

[г] Университет обороны в г. Белград, Военная академия, кафедра вооружения и техники сухопутных войск, г. Белград, Республика Сербия

[д] Университет обороны в г. Белград, Военная академия, кафедра вооружения и техники сухопутных войск, г. Белград, Республика Сербия

РУБРИКА ГРНТИ: 78.00.00 ВОЕННОЕ ДЕЛО:
78.25.00 Вооружение и военная техника;
78.25.10 Бронетанковая техника

ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В данной статье представлено решение по преодолению возможной проблемы − нарушения техники

безопасности при эксплуатации боевой сухопутной машины БВП М-80А на полигоне во время ночных тактических учений и стрельбы. Суть проблемы заключается в том, что командир, отвечающий за тактические учения и управление огнем, не может отслеживать за направлением прицела наводчика-оператора, так как на БВП М-80А не было установлено устройство, сигнализирующее о наводке.

Методы: После практического применения боевой машины и на основании опыта во время стрельбы был сделан вывод, что существует проблема управления огнем ночью и в условиях ограниченной видимости.

Результаты: В статье предложено практическое решение по предотвращению таких ситуаций, как дезориентация, невозможность прицела и поворот вооружения за пределы зоны огня, что нарушает меры безопасности всех участников учений, в том числе и самой боевой машины БВП М-80А. На машине была произведена техническая доработка за счет установки сигнального устройства, которое дает визуальную информацию командиру, руководящему стрельбой, который с ее помощью владеет информацией в каком направлении нацелено танковое вооружение.

Выводы: Установленное сигнальное устройство позволяет оперативно руководить учениями и стрельбой, устранять возможные причины нарушения мер безопасности и успешно выполнять запланированные действия.

Ключевые слова: меры безопаности, контроль, боевая машина, техническое развитие, сигнализатор.

ПОБОЉШАЊЕ МЕРА БЕЗБЕДНОСТИ ПРИМЕНОМ ТЕХНИЧКОГ РЕШЕЊА НА БОРБЕНОМ ВОЗИЛУ ПЕШАДИЈЕ М-80А

Милан Н. Кончар[а], **аутор за преписку**, *Одил* И. Анарбаев[б], *Добривоје* Р. Мутавџић[в], *Горан* М. Лазић[г], *Жељко* М. Јокић[д]

[а] Универзитет одбране у Београду, Војна академија, Катедра наоружања и опреме Копнене војске, Београд, Република Србија

[б] Академија Војске Републике Узбекистан, Катедра за општу тактику, Ташкент, Република Узбекистан

[в] Универзитет одбране у Београду, Војна академија, Катедра наоружања и опреме Копнене војске, Београд, Република Србија

[г] Универзитет одбране у Београду, Војна академија, Катедра наоружања и опреме Копнене војске, Београд, Република Србија

[д] Универзитет одбране у Београду, Војна академија, Катедра наоружања и опреме Копнене војске, Београд, Република Србија

Končar, M. et al, Improvement of safety measures by applying a technical solution on the M-80A infantry combat vehicle, pp.594-606

ОБЛАСТ: машинство, наоружање
ВРСТА ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: У раду је приказан начин превазилажења могућег угрожавања мера безбедности приликом рада са борбеним возилом пешадије М-80А на полигонима приликом извођења тактичких вежби и гађања у ноћним условима. Суштина проблема је у томе да старешина који командује тактичким вежбама и гађањима не може да види у ком смеру нишани нишанџија-оператор, јер на БВП М-80А није уграђен уређај који би то сигнализирао.

Методе: На основу искуства приликом реализације гађања дошло се до закључка да извршилац гађања на овом возилуима проблем при контроли гађања ноћу и у условима отежане видљивости.

Резултати: У раду се предлаже практично решење проблема дезоријентације, немогућности осматрања мета и окретања наоружања ван граница поља гађања, а тиме и нарушавања мера безбедности свих учесника вежбе и извршилаца гађања и покретних средстава. Техничко унапређење на возилу остварено је уградњом сигнализатора који старешини који руководи гађањем даје визуелну информацију о смеру у којем је окренуто наоружање.

Закључак: Уградњом сигнализатора старешина који командује вежбом и гађањем правовремено може да оствари контролу, отклони могуће узроке нарушавања мера безбедности и успешно реализује планирану активност.

Кључне речи: мере безбедности, контрола, борбено возило, техничко унапређење, сигнализатор.

Paper received on / Дата получения работы / Датум пријема чланка: 14.04.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 20.06.2021.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 22.06.2021.

POSITIVE AND NEGATIVE ROLE OF NEGATIVE IONS IN COSMIC EXPLORATION

Leonid I. Gretchikhin
Belarusian State Academy of Communications,
Minsk, Republic of Belarus,
e-mail: gretchihin@yandex.ru,
ORCID iD: https://orcid.org/0000-0002-5358-9037

DOI: 10.5937/vojtehg69-32109; https://doi.org/10.5937/vojtehg69-32109

FIELD: Physical mechanics, Aeronautics
ARTICLE TYPE: Original scientific paper

Abstract:

Introduction/purpose: At altitudes of 80 to 40 km, while the spacecraft made of duralumin without a thermal-protective coating was descending from the flight orbit at the first and second cosmic velocities, data were obtained on the increase in density, pressure, and temperature behind the shock front, as well as on the backout of the shock wave from the surface of the descending spacecraft.

Methods: Calculations were made of the energy fluxes on the surface of the spacecraft for every 10 km, for convective and radiative heat transfer, as well as for the impact of electrons produced due to ionization of negative ions.

Results: At the first cosmic velocity, the greatest energy flux is realized under the influence of an electron flux, and at the second cosmic velocity, radiative heat transfer occurs. In the shock-compressed gas at all the considered altitudes, pressure increases instantly to a value of 109 ÷ 1011 Pa, which leads to a sequential explosion with increasing power resulting in shock waves in the surrounding atmosphere and compression waves in the entire aircraft structure. The last most powerful explosion occurs at an altitude of approx. 40 km.

Conclusion: The descending aircraft is destroyed into separate small parts to the size of small dust particles.

Key words: negative ions, spacecraft, charging, convective heat transfer, radiative heat transfer, ionization phenomenon, shock waves, explosion.

Introduction

During flights of rockets and spacecraft in near and far space, as well as in the Earth's atmosphere, many new discoveries were made due

to the interaction of aircraft with the environment. Let us list some of them:

1. When rockets fly at an altitude of 91–131 km, only negative ions of atoms and molecules, both of the surrounding space and of various particles adsorbed on the rocket surface, are present in the boundary layer near the rocket surface (Johnson & Keppner, 1956).
2. At high altitudes above the Karman line, a powerful charging of rockets and spacecraft occurs (Gretchikhin, 2018a).
3. During the reentry, the heat-protective coating burns at the first and the second cosmic velocities (Gretchikhin, 2018c).
4. There is a loss of radio communication with descending Earth satellites aircraft at altitudes of 80–20 km (Gretchikhin, 2016, and Gretchikhin, 1986).
5. In the free-molecular and transient flow regimes, the "Gretchikhin's effect" occurs (Gretchikhin, 2018a), (Gretchikhin, 2018c), (Gretchikhin, 2016), (Gretchikhin, 1986) and (Gretchikhin, 2003).
6. When charged bodies fly in the process of interaction with a physical vacuum, friction occurs (Gretchikhin, 2018b), which prevents flights in deep vacuum.
7. During aircraft reentry with a second or higher cosmic velocity, a cascade of explosions of the boundary layer occurs (the Chelyabinsk meteor).

Some of these problems are solved and practically used, but most of them require in depth studies or creation of new theories, identification of new properties and making new discoveries. Let us take a closer look at the level at which a particular problem has been solved and outline the ways to improve them.

Negative ions on the surface of the condensed matter

The condensed matter in the form of a solid body consists of clusters. Clusters are formed by diatomic or triatomic molecules. In a solid, the interaction of clusters determines a different crystal structure with its distribution of atoms within the crystal. Between the clusters, a free space is formed, in which the initial particles of matter, which perform translational movement between the clusters, are located. The density of particle-particle packing in the cluster corresponds to the crystal packing density (0.68–0.74). The packing density of free matter particles in the intercluster volume is 0.44–0.47 (Elanskij, 1991). This is

an experimental fact obtained using the molecular dynamics method together with the X-ray diffraction analysis.

In the formation of cluster structures, the valence electrons of molecules and atoms are generalized and create a cloud of free electrons. Previously, it was believed that the electrons in such a cloud follow the Fermi-Dirac distribution by energies. This is a rather rough representation. Experimentally, the distribution of free electrons by energies for a number of metals was obtained using the X-ray diffraction analysis. For example, Figure 1 shows such a distribution for an aluminum crystal, obtained from the K- and L-bands of characteristic X-ray radiation. The theory of this phenomenon is developed and presented in works (Gretchikhin, 2004) and (Gretchikhin, 2008). The calculation results are shown in Fig. 1 for aluminum and in Fig. 2 for chromium.

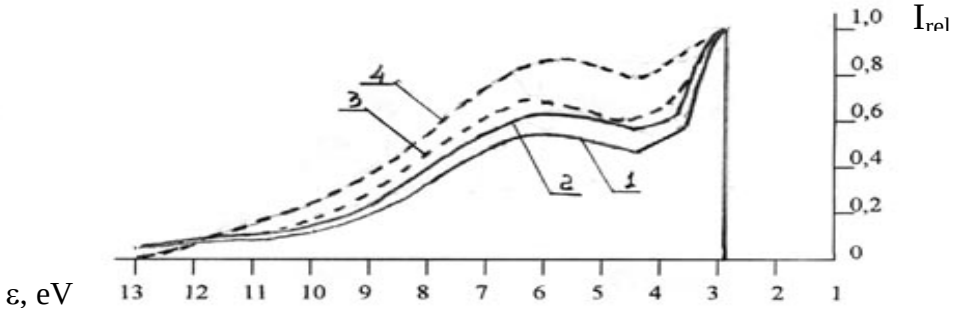


Figure 1 – Distribution of the electron density of valence electrons by energies for aluminum:
1 – theoretical calculation;
2 – theoretical calculation taking into account the U-shaped hardware broadening with an energy of 0.05 eV;
3 – experimental distribution from the L-band and 4 – from the K-band

Рис. 1 – Распределение электронной плотности валентных электронов по энергиям для алюминия:
1 – теоретический расчет;
2 – теоретический расчет с учетом П-образного аппаратного уширения с энергией 0,05 эВ;
3 – экспериментальное распределение из L- полосы и 4 – из К-полосы

Слика 1 – Расподела електронске густине валентних електрона по енергијама за алуминијум:
1 – теоријски прорачун;
2 – теоријски прорачун који узима у обзир проширивање хардвера П-облика енергијом од 0,05 eV;
3 – експериментална расподела из зоне Л и 4 – из зоне К

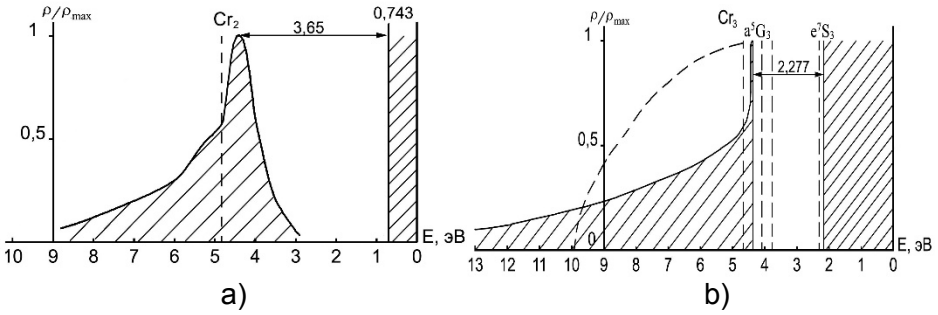


Figure 2 – Distribution of the electron density of valence electrons by energies for chromium:
a) – clusters of diatomic molecules;
b) – clusters of triatomic molecules (the dotted line shows the distribution obtained using the band theory of metals)
Рис. 2 – Распределение электронной плотности валентных электронов по энергиям для хрома:
а) – кластеры из двухатомных молекул;
б) – кластеры из трехатомных молекул (пунктиром показано распределение, полученное с применением зонной теории металлов).
Слика 2 – Расподела електронске густине валентних електрона по енергијама за хром:
а) кластери двоатомских молекула;
б) кластери троатомских молекула (испрекидана линија показује расподелу добијену коришћењем теорије зона метала)

The electron density distribution varies depending on the type of cluster structures. This is clearly seen for chromium when clusters are formed by diatomic or triatomic molecules (Fig. 2). As a result of this phenomenon, a double electric layer is formed above the crystal surface. If the atoms of a crystal have an affinity for an electron, then, on the surface, they capture electrons from the double layer and remain in the form of negative ions. This fact was experimentally established and described in works (Gretchikhin, 2019) and (Shmermbekk et al, 2020). When such a crystal is placed in a vacuum, then due to thermal emission, free negative ions will appear on the surface of the crystal, which was discovered when the first rockets were launched into space (Johnson & Keppner, 1956).

Under the influence of the incoming flux of neutral atoms and molecules of the environment, negative ions leave the surface of the solid body, and a double electric layer is created with the laying of a positive potential on a moving object in space. There is a spacecraft charging phenomenon.

Spacecraft charging in space

At high altitudes, artificial Earth satellites (AES) fly in the free-molecular flow regime. The atoms and molecules of the environment bombard the surface of the aircraft. At high altitudes, oxygen atoms are present in a fairly large amount in the Earth's atmosphere. Due to physical adhesion, oxygen atoms surround the surface of the aircraft and create an oxygen film. Under the action of the incoming flux, the atoms of the incoming flux are exchanged with oxygen atoms, which leave the surface of the aircraft in the form of negative ions. As a result, the aircraft surface is positively charged. The charging theory was developed and it was found that the induced potential on the surface of the aircraft flying at altitudes above 1.000 km can reach approx. 1.5 kV. This potential disables all the electronics of the artificial Earth satellite through the common wire. During the first flights of the AES, this phenomenon was observed. It was necessary to put electrostatic sensors on the satellites and compensate for the satellite potential. Now this is all in the past, when, in the initial period of space exploration, it was not clear why satellites fail at high altitudes.

Burning of heat-protective coating at the first and second cosmic velocities

With the development of rocket technology, the space development began. The aircraft return from space takes place at the first cosmic velocity of approx. 7.5 km/s, and at the second cosmic velocity, it is approx. 11.2 km/s. At such velocities, powerful shock waves occur. The air is heated to high temperatures behind the shock wave. Various heat-barrier materials were used to protect descending spacecraft from the effects of emerging heat fluxes. For the first cosmic velocity, pyrolytic graphite with a thickness of up to 5 cm was used in the front hemisphere. This thickness was sufficient, since the thermal-protective coating of no more than 3 cm in size burned out.

During the spacecraft reentering at the second cosmic velocity, the heat-protective coating should be destroyed more intensively. The problem appeared: how can descending spacecraft be safely retrieved under such conditions? The temperature is very high in the emerging shock wave. Intense convective and radiative heat transfer occurs. Without taking into account the effects of negative ions, the theoretical calculation has allowed to establish that the thickness of burn-out of the

Gretchikhin, L.I., Positive and negative role of negative ions in cosmic exploration, pp.607-637

thermal-protective coating can be approx. 2 m. This result was shocking. Then the effects of negative ions had to be taken into account.

Ionization of negative ions produces an intense flux of electrons to the surface of the thermal-protective coating, and in combination with the radiative and convective heat flux forms such a net energy flux that an explosion of the skin layer occurs. At this moment, heat stops coming to the spacecraft surface. The theory of such a phenomenon was developed and the calculations performed showed that the heat-protective coating at the second cosmic velocity should burn less than at the first cosmic velocity. After a circumlunar flight followed by the descent of the spacecraft at the second cosmic velocity, the thickness of the burned-out thermal-protective coating turned out to be approx. 2 cm, i.e. less than at the first cosmic velocity with burn-out thickness of approx. 3 cm. The combustion of the heat-protective material at the second cosmic velocity does not occur continuously, but in separate explosive pulses, and they shield the heat flux to the surface of the spacecraft.

Loss of radio communication with the descending spacecraft

The first launchings of geophysical rockets of the R-1, R-2, and R-5 type in the USSR allowed establishing that the loss of the radio communication occurs at the most important section of the rocket descent from flight altitudes from 80 km to 20 km. From 1959, preparations for a human flight into space began. However, the main obstacle to the implementation of such a flight was the lack of reliable radio communication in a particularly dangerous area of the flight, where powerful shock waves occur, and radio communication is lost. Theoretical calculations of the plasma parameters under the influence of aerodynamic heat fluxes showed that communication in the meter range of radio waves should not be disrupted. In the event of a breakdown of communication flight segment when entering dense layers of the atmosphere, where powerful shock waves are formed, a person cannot be launched into space. Burning of the heat-protective coating consisting of pyrolytic graphite began to be studied.

When the satellite descends at the active part of the flight, the air behind the shock wave heats up to a temperature of over 1.000 K with a maximum at the first cosmic velocity of up to 10.000 K, and at the second one – up to 15.000 K. At such high temperatures, the heat-protective coating in the form of pyrolytic graphite is intensively destroyed. The phenomenon of ablation occurs. The destruction products of duralumin

contain triatomic molecules, for which the electron affinity is approx. 1.785 eV. In case of graphite destruction, the emission occurs mainly of nitrogen dioxide and triatomic molecules, which have an electron affinity of 2.42 and 2.5 eV, respectively (Babichev et al, 1991), and, therefore, mainly leave the satellite surface in the form of negative ions. As a result, a double electric layer appears at the surface of the satellite, within which plasma with a high concentration of charged particles corresponding to an arc discharge is created. The calculation of the charged particles concentration for the descending spacecraft in the form of a ball with a radius of 1 m is shown in Fig. 3 (Gretchikhin, 2016). If radio communication is carried out in the meter or decimeter wavelength range, then, starting from an altitude of 80 km, it completely stops. To ensure that radio communication is not disrupted, there are two possibilities: either to introduce a substance with a low ionization energy (alkali metals) into the double electric layer, which will sharply reduce the plasma temperature and stop the ionization of negative ions, or to impose a magnetic field on the plasma of the double layer. The first possibility is simpler and was therefore applied, but without much justification.

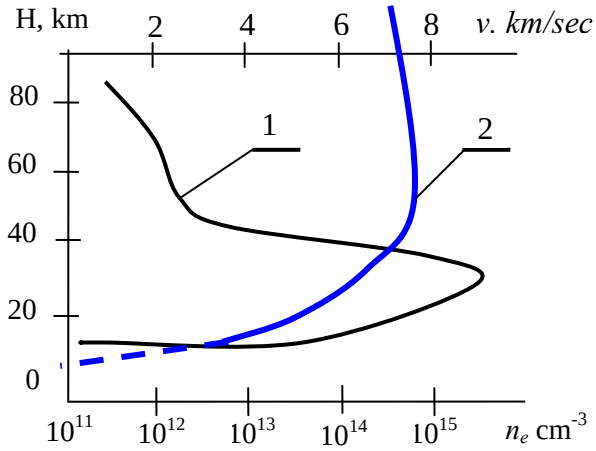


Figure 3 – Electron concentration of the double electric layer (1) and the flight velocity (2), depending on the altitude of the satellite's descent at the first cosmic velocity
Рис. 3 – Концентрация электронов двойного электрического слоя (1) и скорость полета (2) в зависимости от высоты снижения спутника при первой космической скорости
Слика 3 – Концентрација електрона двоструког електричног слоја (1) и брзина лета (2) у зависности од надморске висине спуштања сателита првом космичком брзином

When an artificial Earth satellite reenters at an altitude of 50 km, the flight velocity reaches approx. 7.5 km/s. Radio communication with the satellite is carried out at the frequency *f* of approx. 640 MHz, for which the critical concentration of charged particles is $5.076 \cdot 10^{15}$ m^{-3}.

In order for the radio signal to pass completely through the plasma, the concentration of charged particles in the double electric layer must be by an order lower, i.e. $5.076 \cdot 10^{14}$ m^{-3}. In reality, the concentration of charged particles in the double electric layer at an altitude of 50 km is $n_e \approx 2 \cdot 10^{17}$ m^{-3} at a plasma temperature of 4,000–3,000 K. The plasma frequency is equal to $f_0 \cong 4 \cdot 10^9$ Hz. Therefore, the frequency of $6.4 \cdot 10^8$Hz from the plasma with a concentration of $n_e \approx 2 \cdot 10^{17}$ m^{-3} will be completely reflected. For radio communication, it is necessary to clear the plasma, which was practically implemented by introducing a liquid crystal coolant into the combustion zone.

The introduction of a liquid crystal coolant into the front hemisphere of the descending AES aircraft is schematically shown in Fig. 4. In case of continuous flow in the front hemisphere of the AES 1 moving at supersonic speed 4, a shock wave 2 occurs. The normal shock has the form of a circle with a diameter equal to the size of the descending spacecraft. The shock wave backout is approx. 17÷25 cm. In the process of injection of a liquid metal coolant, the shock wave is straightened. The shock wave backout increases slightly, and the Mach cone increases in size. The resistance to movement increases noticeably. The temperature behind the shock wave decreases due to an increase in the gas density and due to the course of endothermic chemical reactions. This is the active thermal protection for supersonic aircraft. The decrease in temperature due to an increase in the gas density can be ignored, since usually a small portion of foreign matter is injected, which also leads to a relatively weak shock wave backout from the streamlined body. Consequently, the cooling of the gas behind the shock wave with active thermal protection occurs mainly due to the course of endothermic chemical reactions. In aviation, a sodium-potassium alloy is used as a liquid metal coolant. The mass of potassium is 77.2 % and the mass of sodium is 22.8 %. This alloy has a melting point of minus 12.8 $^{\circ}$C and a high heat transfer coefficient. What is the reason for this?

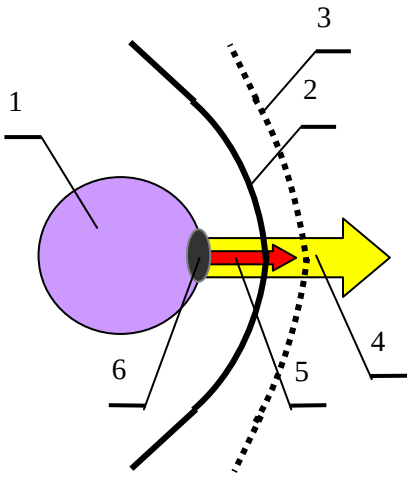


Figure 4 – General scheme of injection of the coolant into the front hemisphere: 1 – AES; 2 – shock wave before the injection of the coolant; 3 – after the injection of the coolant; 4 – speed of AES movement; 5 – speed of the injection of the coolant; 6 – hole for the injection of the coolant

Рис. 4 – Общая схема впрыска теплоносителя в переднюю полусферу: 1 – ИСЗ; 2 – ударная волна до впрыска теплоносителя; 3 – после впрыска теплоносителя; 4 – скорость движения ИСЗ; 5 – скорость впрыска теплоносителя; 6 – отверстие для впрыска теплоносителя

Слика 4 – Општа шема убризгавања расхладног средства у предњу хемисферу: 1 – вештачки сателит; 2 – ударни талас пре убризгавања расхладног средства; 3 – после убризгавања расхладног средства; 4 – брзина кретања вештачког сателита; 5 – брзина убризгавања расхладног средства; 6 – отвор за убризгавање расхладног средства

In the liquid state, at the melting point, the bonds between the cluster formations are broken, and at the boiling point, the cluster formations break up into individual molecules. In the solid state, sodium and potassium form a volume-centered structure. This structure is formed by diatomic molecules. The standard enthalpy of atomization at 25 °C is 91.7 kJ/mol for sodium and 90.3 kJ/mol for potassium. At a temperature of 298 K and even at a temperature of 3.000 K, the decomposition of diatomic molecules Na_2 and K_2, which have a dissociation energy of 0.75 and 0.5 eV, respectively, into individual atoms is very unlikely. When a volume-centered cluster decays, it is necessary to break 8 pairs of bonds between diatomic molecules. Taking this into account, it appears that the bond breaking between

the molecules in the sodium and potassium cluster is 0.119 and 0.117 eV, and on average, one molecule of potassium or sodium accounts for approx. 0.059 eV.

For a heat-protective coating at a temperature of 3,000 K, ionization of negative nitrogen dioxide ions and triatomic carbon molecules occurs. The degree of their ionization decreases by an amount of $\eta = 5.076 \cdot 10^{14} / 2 \cdot 10^{17} = 2.54 \cdot 10^{-3}$. The temperature at which the degree of ionization decreases by $2.54 \cdot 10^{-3}$ is determined from the Saha equation

$$\frac{n_e n_i}{n_a} = c' T^{3/2} \exp\left(-\frac{EA}{k_Б T}\right), \quad (1)$$

where, $\ln c' = 15{,}38$ EA = 2.5 eV, $k_Б$ is the Boltzmann constant, and n_e, n_i, n_a are the concentrations of electrons, ions, and molecules, respectively.

Based on (1), a decrease in the degree of negative ions of triatomic carbon molecules ionization to $2.54 \cdot 10^{-3}$ will occur at a temperature of 1,440 K. This temperature is higher than the boiling point of sodium and potassium. Therefore, clusters of sodium and potassium will not form. The air density behind the shock wave front at an altitude of 50 km

$$\rho = \rho_\infty \left(\frac{\gamma - 1}{\gamma + 1} + \frac{2}{\gamma + 1}\frac{1}{M^2}\right)^{-1} \cong 7.49 \cdot 10^{-3} \text{ kg/m}^3. \quad (2)$$

The number of particles per volume unit will be approx. $3.032 \cdot 10^{23}$ 1/m^3. Each particle of air reduces its kinetic energy by the amount of $k_Б T_2 - k_Б T_1 \approx 0.143$ eV, and the number of sodium or potassium molecules that will provide such a reduction in energy equals to $N = 0.143 / 0.059 \approx 2{,}424$. Then the value of the coolant mass, which will reduce the temperature to 1.440 K, will be

$$\Delta m = \rho N \overline{M} \pi R^2 \Delta \approx 0.0463 \text{ kg}, \quad (3)$$

that is, only 46.3 grams of a liquid crystal coolant.

At the first cosmic velocity, the emission of negative ions from the surface of the heat-protective coating due to the course of catalytic reactions is not sufficiently intense. However, the energy flux that free electrons transfer due to the ionization of negative ions to the surface of the satellite should not be neglected when the spacecraft is moving at either the first or the second cosmic velocity.

Interaction of artificial Earth satellites with the environment in the free molecular flow regime. Gretchikhin's effect

Starting from altitudes of 100 km and above, the continuum flow changes to the free-molecular regime. In this flight mode, in 1969, the phenomenon of emission of negative oxygen ions with the formation of a double electric layer was predicted, in which powerful violet-blue luminance was formed in the front hemisphere around the AES to flight altitudes of 500 km with a maximum at an altitude of 110–140 km, mainly in the Earth's shadow zone. In 1971, during the emergency descent of the Soyuz-10 spacecraft in the Earth's shadow zone, cosmonauts visually observed this luminance.

On the basis of theoretical calculations of the thickness of the double electric layer at different altitudes of flight, the concentration of electrons and their energy distribution function were obtained. Based on this, the nonequilibrium radiation of this layer in different spectral lines and molecular bands of nitrogen and oxygen is calculated. The calculation results for a ball with a radius of 1 *m* moving at a speed of 7.5 *km/s* are shown in Fig. 5. The luminance of the double electric layer at altitudes below 180 *km* significantly exceeds the luminance of the daytime sky and even the polar glows. At a flight altitude of approx. 120 *km*, the nonequilibrium luminance is comparable to the amount of solar radiation in the range of 400–500 *nm* (approx. 9.6 $W/m^2 av$). The luminance changes according to the cosine law depending on the angle of attack.

The maximum energy value of the nonequilibrium luminance corresponds to the flight altitude of approx. 110 *km* both in the Earth's shadow zone and in the illuminated zone. In the Earth's shadow zone, the Meynel bands and the first negative system of nitrogen molecules at an altitude of 120÷140 km give a clearly defined maximum and have the highest radiation energy.

In accordance with the predictions of the theory, full-scale measurements were carried out on the long-term space station "Salyut-4", specially developed in 1974 by the photometric equipment SFM-4M. At a flight altitude of 350 *km*, luminance was detected that corresponded in brightness to the theoretical calculation in the spectral lines of oxygen, nitrogen, and in the molecular nitrogen band. The cosine distribution of the luminance over the angle of attack is obtained, as predicted by the theory. The results of these calculations are shown in Figure 5.

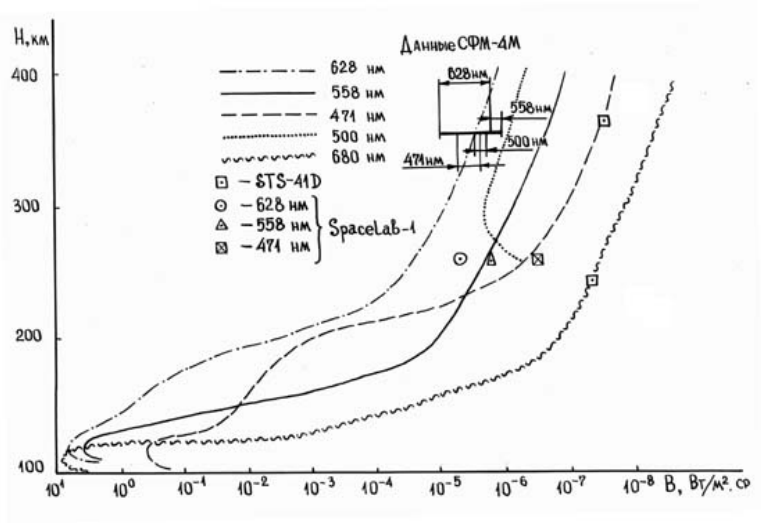


Figure 5 – Calculation of the height range of the brightness of nonequilibrium luminance in comparison with experimental data
Рис. 5 – Расчет высотного хода яркости неравновесного свечения в сравнении с экспериментальными данными
Слика 5 – Израчунавање опсега јачине неравнотежне сјајности у поређењу с експерименталним подацима

Similar results in the United States were obtained on the Shuttle, STS-41, and Spacelab-1 spacecraft (McMahon et al, 1983) and (Prince, 1985) ten years later. The results of these measurements, which coincided with the theoretical calculation, are also shown in Figure 5. The explanation of the observed frontal luminance by chemiluminescence Prince (Prince, 1985) and Engebretson and Hedin (Engebretson & Hedin, 1986) and the Papadopoulos discharge model (Papadopoulos, 1983) is not able to withstand criticism.

Another phenomenon caused by the interaction of a solid body with particles of near-Earth space with the participation of negative ions should be noted. Under dynamic equilibrium conditions, the flow of ambient electrons is partially compensated by the flow of negative ions that escape into the surrounding space. As a result of the chemical reactions of negative ion ionization, superthermal electrons with an energy in the range of 0.4...3.6 *eV* appear. Such electrons lead to the effective excitation of the energy levels of atoms and molecules,

the spontaneous emission of which for forbidden oxygen lines is significantly delayed. Therefore, at some distance from the spacecraft, a pink-red halo should appear, and the satellite trail should also have the same color. A pink-red halo was indeed detected with a maximum at a distance of approx. 1 *m* from the spacecraft (Papadopoulos, 1983).

In outer space, plasma and ion engines are used to perform various maneuvers. When such engines are running, the spacecraft is negatively charged to significant potentials. The movement of a charged body in a vacuum has a noticeable friction. Let us consider this phenomenon in more detail.

Interaction of charged particles with vacuum

When charged bodies move in vacuum, their kinetic energy decreases due to the vacuum polarization (Gretchikhin, 2018b). Spacecraft that use plasma or ion engines are effectively charged, and there is noticeable friction against vacuum. A charged spherical body with the radius *R* when moving in vacuum creates a spherically symmetric electric field, and this field polarizes the quantons[1)] of the physical vacuum. As a result, at a distance *r* from the charged body in the spherical volume $4\pi r^2 dr$ element, each quanton is polarized to form a dipole electric moment. The energy spent on creating such a dipole will be

$$\Delta U = -p_э E_э , \qquad (4)$$

where $p_э$ is the induced dipole electric moment of the quanton and $E_э$ is the electric field strength generated by a charged cosmic body. An increase in the intensity of the external field increases the internal energy of the quanton, and a decrease in the external field leads to dipole-dipole radiation of the quanton energy into the surrounding space.

The mechanism of such friction has yet to be studied in detail.

It is especially important to justify the influence of negative ions on the processes of energy release in the boundary layer during the launching and the reentry of spacecraft.

[1)] Full justification of the quanton is given in work (Gretchikhin, 2016).

Explosion of the boundary layer. Gretchikhin's theory

During the exploration of space, there was a problem of retrieving spacecraft reentering the Earth's atmosphere at the first and the second cosmic velocity. The formation of powerful shock waves leads to a noticeable heating of the surface of the descending spacecraft due to convective and radiative heat exchange with the high-temperature gas behind the shock wave. To ensure the safety of the descending spacecraft, a heat-protective coating was used, the destruction of which did not allow heat energy to penetrate into the spacecraft. A mixture of air heated by the shock wave with debris of the thermal-protective coating emerges between the shock wave and the surface of the descending spacecraft. The chemical reactions taking place in such a mixture have been beyond our vision for a long time.

Depending on the type of the chemical reaction (endothermic or exothermic), additional cooling or heating of the heated air behind the shock wave takes place. Exothermic reactions with the release of energy are especially dangerous. Therefore, let us have a closer look at the dynamics of the destruction of the descending spacecraft surface determining the number of atoms and molecules that mix with the heated air behind the shock wave, and how much energy is released in various exothermic reactions. It is necessary to find out what energy is released and how it will affect the dynamics of the descending spacecraft flight. It is important to find out what happens when space bodies descend at the first and, especially, at the second cosmic velocity.

When a spacecraft descends from the orbit, a shock wave begins to form at an altitude of approx. 80 km. As the altitude decreases, the velocity increases slightly, reaching a maximum at an altitude of 40 km. The change in flight velocity with altitude for the descending Soyuz series spacecraft is given in Table 1. Flight velocities are much higher than the velocity of sound. In this case, the density, pressure, and temperature of the gas in the shock wave can be determined by the formulas (Gretchikhin et al, 2012).

Table 1 – Parameters of the air behind the shock wave at the first and second cosmic velocity

Таблица 1 – Параметры воздуха за ударной волной при первой и второй космических скоростях

Табела 1 – Параметри ваздуха иза ударног таласа при првој и другој космичкој брзини

Parameters	Altitude, km				
	40	50	60	70	80
First cosmic velocity, *M* Second cosmic velocity, *M*	22.35 33.92	23.82 35.56	25.34 37.04	25.80 38.11	26.42 39.39
Density, ρ / ρ_∞	5.940 5.974	5.947 5.976	5.954 5.978	5.955 5.979	5.957 5.981
Density, ρ / ρ_∞	584 1.343	663 1.476	750.1 1.602	777.6 1.695	815 1.811
Shock wave backout distance, *m*	0.112 0.1115	0.112 0.1115	0.1119 0.11147	0.1118 0.11145	0.1118 0.1114
Temperature at the wave front, *K*	25.746 58.913	27.532 61.013	29.357 62.423	28.595 62.096	28.057 62.081
Temperature of the shock-compressed gas, *K*	6.437 14.728	6.883 15.253	7.339 15.606	7.149 15.524	7.014 15.520
Effective temperature of the compressed gas, *K*	6.434 14.725	6.880 15.250	7.337 15.602	7.146 15.521	7.012 15.517
Convective heat transfer, W/m^2	$2.01 \cdot 10^7$ $7.78 \cdot 10^7$	$5.48 \cdot 10^6$ $1.82 \cdot 10^7$	$2.24 \cdot 10^6$ $7.735 \cdot 10^7$	$3.85 \cdot 10^5$ $1.24 \cdot 10^6$	$5.57 \cdot 10^4$ $2.02 \cdot 10^5$
Penetration depth, *m*	$7.51 \cdot 10^{-2}$ 0.169	$1.98 \cdot 10^{-2}$ $4.395 \cdot 10^{-2}$	$7.81 \cdot 10^{-3}$ $1.68 \cdot 10^{-2}$	$1.36 \cdot 10^{-3}$ $3.00 \cdot 10^{-3}$	$2.00 \cdot 10^{-4}$ $4.45 \cdot 10^{-4}$
Radiative heat transfer, W/m^2	$4.86 \cdot 10^6$ $1.33 \cdot 10^8$	$6.35 \cdot 10^6$ $1.533 \cdot 10^8$	$8.21 \cdot 10^6$ $1.68 \cdot 10^8$	$7.39 \cdot 10^6$ $1.65 \cdot 10^8$	$6.85 \cdot 10^6$ $1.64 \cdot 10^8$
Electron flux heat transfer, W/m^2	$2.56 \cdot 10^7$ $8.9 \cdot 10^7$	$6.98 \cdot 10^6$ $2.31 \cdot 10^7$	$2.85 \cdot 10^6$ $8.86 \cdot 10^6$	$4.90 \cdot 10^5$ $1.56 \cdot 10^6$	$7.09 \cdot 10^4$ $2.34 \cdot 10^5$
Pressure in the boundary layer, *Pa*	$5.485 \cdot 10^{10}$	$1.62 \cdot 10^{10}$	$5.938 \cdot 10^9$	$7.088 \cdot 10^9$	$1.059 \cdot 10^{10}$
Energy released on the surface, *J*	$4.477 \cdot 10^6$	$1.092 \cdot 10^6$	$1.096 \cdot 10^5$	$1.367 \cdot 10^5$	$1.921 \cdot 10^5$

$$\rho = \rho_\infty \left(\frac{\gamma - 1}{\gamma + 1} + \frac{2}{\gamma + 1} \frac{1}{M^2} \right)^{-1}; \quad P = P_\infty \left(1 + \frac{2\gamma}{\gamma + 1} M^2 \right); \quad T = T_0 \frac{\rho_\infty}{\rho} \frac{P}{P_\infty} \quad (5)$$

where γ is the ratio of the specific heat capacities of the gas at constant volume and constant pressure; *M* is the Mach number. Specific calculations for a sphere with a radius of 1 m at different altitudes are given in Table 1. Directly in the front of the shock wave at all altitudes of flight in the compression shock wave, the temperature is very high.

The backout distance of the shock wave from the nose of a hypersonic vehicle of a given geometry for a direct shock wave can be determined as follows (Gretchikhin et al, 2012):

$$\Delta = R \frac{\rho_\infty}{\rho} \left(1 - \frac{\rho_\infty}{\rho} + \sqrt{\frac{8}{3} \frac{\rho_\infty}{\rho}} \right)^{-1} . \quad (6)$$

High temperatures behind the direct shock wave cause significant heating of the air atmosphere. Diatomic molecules of nitrogen and oxygen completely dissociate. Since this requires energy, the temperature in the shock wave decreases. The number of particles doubles. Also, the ionization of oxygen and nitrogen atoms takes place, which leads to a decrease in the adiabatic index. Taking into account the dissociation process, the temperature of the air behind the shock wave (Zeldovich & Raizer, 1966) is

$$T_B = T_0 \frac{\rho_\infty}{\rho} \frac{P}{P_\infty} \alpha .$$

At temperatures above 10.000 K, nitrogen and oxygen molecules will dissociate completely, and then $\alpha \cong 0.5$. As a result of ionization, the air temperature will decrease due to the formation of plasma. Then (Zeldovich & Raizer, 1966)

$$T_{эфф.} \approx \frac{T_B}{3 - \gamma} . \quad (7)$$

For dry air at a temperature of 2,000 K, the adiabatic index is $\gamma = 1.088$. For higher temperatures, we can assume $\gamma \approx 1$.

The results of calculation according to (7) are shown in Table 1. The temperature of the shock-compressed gas is high, and such a gas should be considered as plasma. Charged particles are produced in plasma as a result of ionization of predominantly negative ions. Therefore, thermal energy is transferred to the surface of the descending spacecraft due to convective and radiative heat transfer, as well as due to the flow of

electrons when passing through the electrical double layer. The input data on the energies of dissociation of diatomic molecules, the detachment of atoms in triatomic molecules, and the electron affinity for aluminum are given in Table 2.

Table 2 – Energy of dissociation and electron separation in a negative aluminum ion

Таблица 2 – Энергия диссоциации и отрыва электрона в отрицательном ионе алюминия

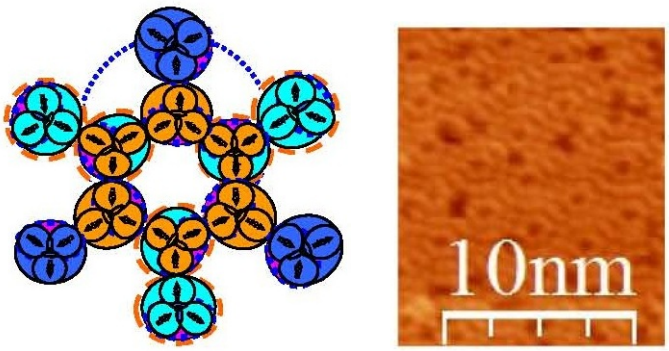
Табела 2 – Енергија дисоцијације и сепарације електрона у негативном јону алуминијума

Atoms, molecules	Energy, eV	
	dissotiation of	electron detachment
Al_3^-	~ 0.406	~ 1.785
Al_2^-	2.0	2.42
Al^- (3P)	-	0.44
Al^- (1D2)	-	0.33
AlO_-	5.14	3.6
AlO_2^-	~ 2.51	4.1

The "~" symbol means that this value is obtained by extrapolation

Convective heat transfer

In convective heat transfer, energy is transferred by the collision of heated gas particles with the surface of the spacecraft. Each solid is formed by an intercluster lattice structure. The clusters themselves are formed by diatomic or triatomic molecules. What are clusters of diatomic molecules with experimental justification is considered in (Gretchikhin et al, 2015a) and of triatomic molecules in (Gretchikhin et al, 2015b). Aluminum clusters are formed by triatomic molecules as shown in Fig. 6.



a) b)

Figure 6 – Cluster of triatomic molecules:
a) theoretical calculation; b) experimental confirmation
Рис. 6 – Кластер трехатомных молекул:
а) теоретический расчет; б) экспериментальное измерение
Слика 6 – Кластер триатомских молекула: а) теоријско израчунавање;
б) експериментална потврда

The main cluster is highlighted in the center, and the highlighted triatomic molecules have broken bonds in diatomic molecules. As a result, some triatomic molecules in the center have an excess negative charge, and others – a positive charge. In Fig. 6, these molecules are shown in different colors. The clusters are flat and interact with each other by cohesion, and the solid resembles a layer cake. The formation of clusters occurs by combining the molecules of the first and the second coordination layers (Gretchikhin, 2004) and (Gretchikhin, 2008). The energy from the heated gas is transferred to the spacecraft surface by the collision of air molecules with the solid clusters. Thermal random velocity of the heated air

$$v_T = \sqrt{\frac{8k_b T_a}{\pi m_a}}, \tag{8}$$

where k_b is the Boltzmann constant, T_a is the temperature of shock-compressed air, and m_a is the average weight of air molecules.

Only 1/6 of air molecules collide directly with the surface. The molecules collide with the clusters of the solid. In convective heat transfer, only the surface layer of cluster formations is excited. Clusters of aluminum are formed by triatomic molecules, producing a face-centered crystalline structure. Since there is a hollow in the center of a cluster, which does not receive the impacts of external particles, only 9/10 of the total flow of external particles acting on the surface of the

spacecraft is received. The second coordination layer of the cluster is destroyed before the melting temperature is reached, and the first coordination layer is destroyed after the melting temperature is reached. Near the boiling temperature, the number of molecules in a cluster is approx. 6 (Gretchikhin, 2008). When air molecules collide with clusters on the surface of a solid, the energy transfer ratio is (Gretchikhin, 2004)

$$\eta = \frac{4m_a m_S}{(m_a + m_S)^2}, \tag{9}$$

where m_b is the weight of a solid cluster and m_S is the average effective mass of air molecules in the atomic form equal to approx. 29/2.

Taking into account (8) and (9), the convective energy flux to the solid surface is

$$J_C = \frac{9}{120}\rho v_T^3 \eta, \tag{10}$$

where ρ is the density of the air behind the shock wave front.

Energy is transferred to the area of one molecule of a solid body

$$E_m = \frac{10}{9} J_C \pi r_m^2 \quad . \tag{11}$$

The radius of a triatomic molecule $r_m \approx 2.155 r_a$ and r_a is the radius of an atom of the solid, obtained by the radiographic method. At each altitude, an aluminum object loses its weight to a depth

$$dh = 2r_a \frac{E_m}{E_{св.}}, \tag{12}$$

where $E_{св.}$ is the molecular bond energy, determined by the boiling temperature. For aluminum, this value is $3.389 \cdot 10^{-20}$ *J*. The results of calculation of the depth of complete dissociation of the main clusters according to (12) are given in Table 1. It takes only ¾ of the total heat flux in convective heat transfer. The remaining part of the convective energy flux is absorbed by intercluster hollows preventing the noticeable destruction of the solid (see Fig. 6).

As a result of destruction, the total number of triatomic aluminum molecules is formed as negative ions

$$N_{Al}^{-} = 2\pi r^2 dh \frac{\rho_{Al}}{m_b}, \tag{13}$$

and the concentration of negative ions of triatomic aluminum molecules in the shock-compressed gas

$$n_{Al}^{-} = \frac{N_{Al}^{-}}{2\pi r^2 dh}. \tag{14}$$

The temperature of gas of triatomic aluminum molecules is equal to the boiling temperature, i.e. $T_{кип}$ = 2,743 K.

The total number of air molecules in the shock-compressed air behind the shock wave

$$N_a = 2\pi r^2 dh\rho / m_a, \tag{15}$$

and the molecules are at the temperature determined according to (7).

The average effective temperature will be

$$T_{эфф.} = \left(\frac{T_{кип.} N_{Al} + T_0 N_a}{N_{Al} + N_a} \right). \tag{16}$$

At this temperature, the following aluminum combustion reactions occurs:

$$Al_3^- + O \Leftrightarrow Al_2 + AlO + e + 1.134\ eV; \quad Al_2 + O \Leftrightarrow Al + AlO + 3.14\ eV$$
$$Al + O \Leftrightarrow AlO + 5.14\ eV. \tag{17}$$

The total energy released during the complete combustion of triatomic aluminum molecule is 9.414*eV*, and the energy of the electron gas corresponds to the effective temperature of the plasma determined according to (16). The electron gas ionizes negative ions of aluminum molecules by electron impact:

$$Al_3^- + e \Leftrightarrow Al_3 + 2e. \tag{18}$$

In this case, the temperature of the electron gas is (Gretchikhin & Kudrjashov, 1970)

$$T_e = 0.55 \cdot IA \cdot 11600 = 11388\ \text{K}. \tag{19}$$

The electron gas produced from the ionization of negative ions is nonequilibrium. Consequently, the plasma of the shock-compressed gas at such temperatures of the electron gas and a sufficiently high temperature of the atomic gas has a noticeable radiation capacity. In this case, radiative heat transfer must be considered.

Radiative heat transfer

For dense plasma, the radiation of individual atoms and molecules from the inner layers is intensely absorbed inside the plasma, and thermal radiation can be considered as black body radiation, taking into account the emissivity factor. For evaluations, let us assume that the emissivity factor κ = 0.5. Then

$$J_L = \kappa \sigma_S T_{эфф}^4, \quad (20)$$

where $\sigma_S = 5.67 \cdot 10^{-8} W \cdot m^{-2} K^{-4}$ is the Stefan constant.

The results of the obtained radiant energy fluxes at different altitudes are given in Table 1. The energy flux in radiative heat transfer penetrates through the solid to the skin layer depth. If the solid receives external radiation, then the thickness of the skin layer can be determined according to the formula (Gretchikhin, 2016):

$$\Delta r = \sqrt{\frac{\rho_Э}{\pi f \mu}}, \quad (21)$$

where f is the electromagnetic radiation frequency, μ is the magnetic permeability, and $\rho_Э$ is the electrical conductivity of the solid.

In formula (21), the frequency of thermal radiation f corresponds to the maximum of the radiation flux density distribution function per unit frequency interval according to the Planck formula. Therefore, the obtained specific values of the absorption thickness appeared to be much smaller than the thickness of the aluminum cluster. This means that all incident radiation is completely reflected from an aluminum surface with a close-packed structure (Fig. 6*b*). The absorption of the radiant flux takes place in the defects of the crystalline structure and in the centers of cluster formations. For an ideal surface, absorption occurs only by the centers of cluster formations and is approximately 1/12, and as the surface transits to the liquid state, the ratio of the absorbed radiant flux energy increases, and the radiant flux contributes to the destruction of both a metal and a dielectric moving object.

With the emission of molecules with electron affinity from the spacecraft surface, an electric double layer is formed. At some distance, negative ions are ionized, and the produced electrons, passing through the potential difference of the double electric layer, bombard the surface and additionally increase the energy flux to the spacecraft surface.

Electron impact energy flow

Negative ions from the aluminum surface are emitted in the form of triatomic molecules at the boiling temperature. Ionization of negative ions of aluminum molecules takes place due to the occurrence of reactions (17) and (18). Both reactions take place in the gas-vapor phase. As a result of the emission of negative ions from the aluminum surface, the electric double layer is formed. The potential difference in the electric double layer is determined by the molecular energy at the boiling temperature. For aluminum, the potential difference of the double layer is

$$\Delta U = \frac{k_b T_{кип.}}{e} V. \tag{22}$$

The flux of energy carried by electrons to the aluminum surface will be

$$J_e = n_{Al}^{-} v_e k_b T_{кип}, \tag{23}$$

and the total energy transferred to the surface by electron impact will be

$$\Delta E_2 = J_e 2\pi r^2 dh. \tag{24}$$

The resulting energy on the metal surface of the incoming solid is the sum of the convective and electronic heat transfer, i.e. $\Delta E = \Delta E_1 + \Delta E_2$.

The pressure that arises in the boundary layer is

$$P = \frac{\Delta E}{2\pi r^2 dl}. \tag{25}$$

The values of pressure arising in the boundary layer at different altitudes are given in Table 1. Such pressures occur during the explosion of explosives (Gretchikhin, 2008). The explosion in the boundary layer has such high intensity that the entire structure of the spacecraft breaks down into small parts. This process is shown in Fig. 7 and Fig. 8 (Gretchikhin, 2008).

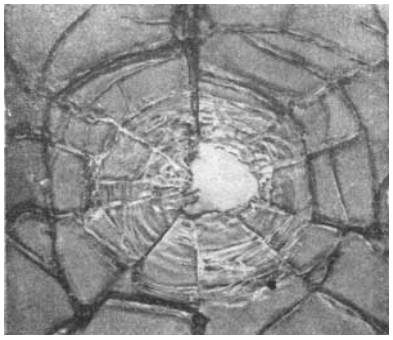


Figure 7 – Fracture pattern in a glass plate exposed to an explosion pressure of $2.8 \cdot 10^9$ Pa
Рис. 7 – Изображение разрушения стеклянной пластины под давлением взрыва $2.8 \cdot 10^9$ Pa
Слика 7 – Начин лома стаклене плоче изложене притиску експлозије од $2{,}8 \times 10^9$ Pa

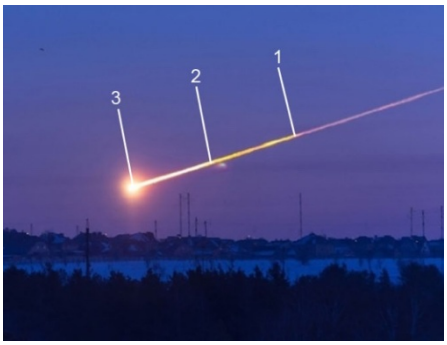


Figure 8 – Meteor flight path, Chelyabinsk, 2013:
1 – the 1st explosion – cracking;
2 – the 2nd explosion – breaking up into separate parts;
3 – the 3rd explosion – the most powerful explosion: the component parts are scattered over long distances from each other

Рис. 8 – Вхождение метеора под Челябинском, 2013:
1 – первый взрыв – растрескивание;
2 – второй взрыв – разделение на отдельные части;
3 – третий взрыв – наиболее мощный: составные части разбрасывает на большие расстояния друг от друга

Слика 8 – Путања лета метеора, Челъабинск, 2013:
1 – прва експлозија – пуцање;
2 – друга експлозија — распадање на делове;
3 – трећа, најснажнија експлозија – расејавање фрагмената на великим удаљеностима

A sublimation spot appears in the explosion center. An explosion on the surface of a solid causes not only sublimation, but also cracking of the entire array in the form of radial cracks, as well as formation of cylindrical and spherical cracks inside the solid. This stops the flow of energy to the surface. As a result, a sequence of explosions occurs, causing breakdown of solid monolith into separate small parts. The effective interaction surface between the solid and the shock-compressed air increases. Therefore, there are successive explosions with increasing intensity. The fire cloud of explosion also grows in size. Finally, small fragments of the spacecraft fall to the Earth. This was experimentally confirmed when the long-term orbital station MIR-1, with the main structure made of duralumin without a thermal-protective coating, entered dense atmospheric layers. The sequence of explosions occurred when a meteor fell near Chelyabinsk. There were three consecutive explosions, and the last explosion was the most powerful one.

Thus, in the exploration of outer space, humanity is at the initial stage. Only the first cosmic velocity has been overcome. The exploration of the Moon and the nearest planets of the solar system involves overcoming the second cosmic velocity. The "Apollo-11" returned from the Moon by mere chance. It is necessary to carefully study the entire dynamics of the flight and the nature of the interaction with the Earth's atmosphere. Until the entire dynamics of the flight with the second cosmic velocity is fully explained, it is still necessary to use only automatic machines.

Conclusions

Let us briefly formulate the obtained phenomena and the results in the exploration of the outer space:

1. For the descent trajectory of the spacecraft with the structure made of duralumin without a thermal-protective coating at the first and second cosmic velocities at altitudes of 80 to 40 km, data were obtained on the increase in density, pressure and temperature behind the shock front, as well as the backout of the shock wave from the surface of the descending spacecraft.

2. The effective temperature of the shock-compressed gas reaches its maximum value of 7,340 K for the first cosmic velocity and 15,602 K for the second cosmic velocity at an altitude of approx. 60 km. At an altitude of 80 km, it is 7.000 K and 15.500 K, respectively, and at an altitude of 40 km – 6.400 K and 14.700 K.

3. Calculations were made of the energy fluxes to the surface of the spacecraft for every 10 km in the altitude range of 40 to 80 km, for convective and radiative heat transfer, as well as for the impact of electrons produced due to ionization of negative ions. In this case, at the first cosmic velocity, the greatest energy flux is realized under the influence of an electron flux, and at the second cosmic velocity, radiative heat transfer appeared to be the most significant.

4. The increase in pressure in the boundary layer at the spacecraft surface at the first and second cosmic velocities was calculated taking into account the burning of negative ions of triatomic molecules of aluminum with the formation of AlO molecules. At all considered altitudes, the pressure rises instantly to a value of 10^9 to 10^{11} Pa and more, which is typical for explosions of various explosives. Each subsequent explosion produces shock waves in the surrounding atmosphere and compressive waves in the entire structure of the spacecraft. The descending spacecraft cracks, and its entire structure breaks down into parts. The area of interaction increases sharply, and each subsequent explosion is greater in intensity and size. After each explosion, the energy flux to the surface stops due to shielding for all types of heat transfer. After the dispersion of the explosion products, an intense flux of energy reappears on the surface of the descending spacecraft and a new explosion occurs. As a result, the last most intense explosion occurs at an altitude of approx. 40 km, after which individual fragments of the spacecraft fall to the Earth. All this was clearly visible during the descent of the long-term orbital station "MIR-1" and when a meteor entered near Chelyabinsk.

5. The situation is slightly better for spacecraft with thermal protection, but is still very dangerous. Descents must not be carried out at low g-forces. Even at the first cosmic velocity, the descent phase at an altitude of 80 to 40 km should be passed as quickly as possible.

6. When descending spacecraft and meteors enter the atmosphere at the second or greater cosmic velocity, the temperature of the shock-compressed gas reaches more than 15.000 K. At such temperatures, the power of the explosions increases by an order of magnitude. This results in falling of small debris and even individual dust particles to the Earth, which was observed when the Chelyabinsk meteor entered the Earth's atmosphere.

To summarize for meteors entering the Earth's atmosphere:

a) At an altitude of about 80 km, an explosion occurs due to the formation of shock waves and combustion of negative ions, which leads to the cracking of the entire monolith of the initial meteor.

b) After the second explosion, the monolith breaks up along cracks (into separate unconnected parts) and the area from which negative ions emit dramatically increases. The concentration of negative ions in the boundary layer sharply increases so that the power of the next explosion increases as well.

c) After the third very powerful explosion, individual pieces of the disintegrated meteor scatter in all directions (All three explosions with increasing power were witnessed when the Chelyabinsk meteor entered the Earth's atmosphere).

d) The individual parts of the meteor still perform supersonic motion, but at different speeds and with a chaotic distribution in space. Around each of them there are explosions, but with less power and not connected to each other in time. A hissing effect occurs, which was witnessed when the Tunguska meteor entered the Earth's atmosphere.

Meteors flying around the Sun in great numbers are very dangerous for the Earth. They are charged and therefore broke in the physical vacuum (Gretchikhin, 2018b), and may eventually fall to the Earth. For the planet, it could have disastrous consequences that might be more terrible than the consequences of an atomic bomb explosion.

The current state of the planet Mars is proof of this. It is believed that long time ago the explosion of Phaeton led to the formation of the asteroid belt. Consequently, the fall of asteroids on the planet Mars led to Phaeton's destruction. That is why today the surface of Mars is reminiscent of impact craters of the Moon and the deserts and polar ice caps of the Earth.

References

Babichev, A.P., Babushkina, N.A., Bratkovskij, A.M. et al. 1991. *Physical values: Handbook*. Moscow: Energoatomizdat (in Russian). ISBN: 5-283-04013-5 (In the original: Бабичев, А.П., Бабушкина, Н.А., Братковский, А.М. и др. 1991. *Физические величины. Справочник*. Москва: Энергоатомиздат. ISBN: 5-283-04013-5).

Elanskij, G.N. 1991. *Stroenie* i svojstva metallicheskih rasplavov. Moscow: Metallurgija (in Russian). ISBN: 5-229-00723-0 (In the original: Еланский, Г.Н. 1991. *Строение и свойства металлических расплавов*. Москва: Металлургия. ISBN: 5-229-00723-0)

Engebretson, M.J. & Hedin, A.E. 1986. DE-2 mass spectrometer observations relevant to the Shuttle glow. *Geophysical Research Letters,* 13(2), pp.109-112. Available at: https://doi.org/10.1029/GL013i002p00109.

Gretchikhin, L.I. 1986. *Neravnovesnoe opticheskoe izluchenie vozdushnyh i kosmicheskih letatel'nyh apparatov*. Ph.D. thesis. Minsk, Belarus: Belarusian Polytechnic Institute (in Russian). (In the original: Гречихин, Л.И. 1986. *Неравновесное оптическое излучение воздушных и космических летательных аппаратов.* Докторская диссертация. Минск, Беларусь: Белорусский политехнический институт).

Gretchikhin, L.I. 2003. Vzaimodejstvie tverdogo tela s okruzhajushhej sredoj v rezhime svobodnomolekuljarnogo obtekanija (jeffekt Gretchikhina). In *The First Belarusian Space Congress*, Minsk, Belarus, pp.31-33, October 28-30 (in Russian). (In th eoriginal: Гречихин, Л.И. 2003. Взаимодействие твердого тела с окружающей средой в режиме свободномолекулярного обтекания (эффект Гречихина). В: *Первый Белорусский космический конгресс*, г. Минск, Беларусь, с.31-33, 28-30 октября).

Gretchikhin, L.I. 2004. *Physics of nanoparticles and nanotechnologies. General foundations, mechanical, thermal and emission properties*. Minsk: Tekhnoprint (in Russian). (In the original: Гречихин, Л.И. 2004. *Физика наночастиц и нанотехнологий. Общие основы, механические, тепловые и эмиссионные свойства*. Минск: УП «Технопринт»).

Gretchikhin, L.I. 2008. *Nanochasticy i nanotehnologii*. Minsk, Belarus: Pravo i jekonomika (in Russian). (In the original: Гречихин, Л.И. 2008. *Наночастицы и нанотехнологии*. Минск, Беларусь: Право и экономика).

Gretchikhin, L.I. 2016. *Osnovy radiosvjazi*. Minsk, Belarus: National Library of Belarus (in Russian). (In the original: Гречихин, Л.И. 2016. *Основы радиосвязи*. Минск, Беларусь: Национальная библиотека Беларуси).

Gretchikhin, L.I. 2018a. Negative ions in space exploration. In: *The Eight World Congress "Aviation in the XXI-st century - Safety in Aviation and Space Technology"*, Kiev, Ukraine, pp.2.3.29-2.3.37, October 10-12 [online]. Available at: http://conference.nau.edu.ua/index.php/Congress/Congress2018/paper/viewFile/5471/4035 [Accessed: 28 April 2021].

Gretchikhin, L.I. 2018b. Complex charge and electron spin. *Aeronautics and Aerospace Open Access Journal*, 2(6), pp.424-428. Available at: https://doi.org/10.15406/aaoaj.2018.02.00074.

Gretchikhin, L.I. 2018c. Negative ions and their role in the development of science and technology. *Vojnotehnički glasnik/Military Technical Courier*, 66(4), pp.847-863. Available at: https://doi.org/10.5937/vojtehg66-17262.

Gretchikhin, L.I. 2019. Formation of negative ions an the surface of a solid body and their influence on the thermoelectronic and autoelectronic emission of free electrons. *American Journal of Applied Scientific Research*, 5(3), pp.47-55. Available at: https://doi.org/10.11648/j.ajasr.20190503.11.

Gretchikhin, L.I. & Kudrjashov, V.V. 1970. Srednejeffektivnaja temperatura jelektronnogo gaza, obrazovannogo pri udarnoj ionizacii. *Izvestiya vuzov. Fizika*, 9, pp.7-16 (in Russian) (In the original: Гречихин, Л.И, Кудряшов, В.В. 1970. Среднеэффективная температура электронного газа, образованного при ударной ионизации. *Известия вузов. Физика*, 9, с.7-16).

Gretchikhin, L.I., Laptsevich, A.A. & Kuts, N.G. 2012. *Ajerodinamika letatel'nyh apparatov*. Minsk, Belarus: Pravo i ekonimka (in Russian). (In the original: Гречихин, Л.И., Лапцевич, А.А., Куць, Н.Г. 2012. *Аэродинамика летательных аппаратов*. Минск, Беларусь: Право и экономика).

Gretchikhin, L.I., Latushkina, S.D., Komarovskaya, V.M. & Shmermbekk, Yu. 2015a. The cluster structure of silicon and its surface construction. *Strengthening technologies and coatings*, 9, pp.5-10 (in Russian) [online]. Available at: https://www.mashin.ru/files/2015/up_0915_01-48_min.pdf [Accessed: 28 April 2021] (In the original: Гречихин, Л.И., Латушкина, С.Д., Комаровская, В.М., Шмермбекк, Ю. 2015а. Кластерная структура кремния и конструкция его поверхности. *Упрочняющие технологии и покрытия*, 9, с.5-10 [онлайн]. Доступно на: https://www.mashin.ru/files/2015/up_0915_01-48_min.pdf [Дата обращения: 28 апреля 2021]).

Gretchikhin, L.I., Latushkina, S.D., Komarovskaya, V.M. & Shmermbekk, Yu. 2015b. Formation of a close-packed and cluster lattice structure of indium on a silicon surface. *Strengthening Technologies and Coatings*, 6, pp.3-12 (in Russian) [online]. Available at: http://www.mashin.ru/files/2015/up615_web1.pdf [Accessed: 20 September 2020]. (In the original: Гречихин, Л.И., Латушкина, С.Д., Комаровская, В.М., Шмермбекк, Ю. 2015b. Образование плотноупакованной и кластерной решеточной структуры индия на поверхности кремния. *Упрочняющие технологии и покрытия*, 6, с.3-12 [онлайн]. Доступно на: http://www.mashin.ru/files/2015/up615_web1.pdf [Дата посещения: 20 сентября 2020 г.]).

Johnson, C.J. & Keppner, J.P. 1956. Daytime measurement of positive and negative ion composition to 131 km by rocket-borne spectrometer. *Journal of Geophysical Research*, 61(3), p.575. Available at: https://doi.org/10.1029/JZ061i003p00575).

McMahon, W., Salter, R., Hills, R. & Delorey, D. 1983. Measured electron contribution to Shuttle plasma environment. In: *Shuttle Environment and Operations Meeting, AIAA 1983-2598,* Washington, DC, pp.52-58, October 31 - November 02. Available at: https://doi.org/10.2514/6.1983-2598.

Papadopoulos, K. 1983. The space shuttle environment as evidence of critical ionization phenomena. In: *Symposium Active Experiments in Space,* Alpbach, Austria, pp.227-244, May 24-28.

Prince, R.H. 1985. On spacecraft-induced optical emission: a proposed second surface luminescent continuum component. *Geophysical Research Letters*, 12(7), pp.453-456. Available at: https://doi.org/10.1029/GL012i007p00453.

Shmermbekk, Yu., Migas, D.B., Gutkovsky, A.I. & Grechikhin, L.I. 2020. Emission portrait of surface of reinforcing structural material. *Strengthening technologies and coatings,* 16(3), pp.136-143 [online]. Available at: https://www.elibrary.ru/item.asp?id=42573978 [Accessed: 28 April 2021].

Zeldovich, Y.B. & Raizer, Y.P. 1966. *Fizika udarnyh voln i vysokotemperaturnyh gidrodinamicheskih javlenij*. Moscow: Nauka (in Russian) (In the original: Зельдович, Я.Б., Райзер, Ю.П. 1966. Физика ударных волн и высокотемпературных гидродинамических явлений. Москва: «Наука»)

ПОЛОЖИТЕЛЬНАЯ И ОТРИЦАТЕЛЬНАЯ РОЛЬ ОТРИЦАТЕЛЬНЫХ ИОНОВ В ОСВОЕНИИ КОСМОСА

Леонид И. Гречихин

Белорусская государственная академия связи,
Минск, Республика Беларусь

РУБРИКА ГРНТИ: 55.00.00 МАШИНОСТРОЕНИЕ:
55.49.03 Аэродинамика ракет и космических аппаратов
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Ведение/цель: При спуске с орбиты полета космических аппаратов с первой и второй космических скоростях без теплозащиты с дюралюминиевой конструкцией на высотах полета от 80 км до 40 км получены данные по увеличению плотности, давления и температуры за фронтом ударной волны, а также отхода ударной волны от поверхности спускаемого аппарата.

Методы: Через каждые 10 км произведены расчеты потоков энергии на поверхности летательного аппарата при конвективном и лучистом теплообмене, а также при ударном воздействии электронами, которые получены при ионизации отрицательных ионов.

Результаты: При первой космической скорости наибольший поток энергии реализуется при воздействии электронного потока, а при второй космической скорости − лучистый теплообмен. В ударно сжатом газе на всех рассмотренных высотах полета давление повышается мгновенно до значения $10^9 \div 10^{11}$ Па, что приводит к последовательному взрыву с нарастающей мощностью и при этом возникают ударные волны в окружающей атмосфере и волны сжатия во всей конструкции летательного аппарата. Последний самый мощный взрыв возникает на высоте ~ 40 км.

Вывод: Спускаемый аппарат разрушается на отдельные мелкие части вплоть до мелких пылинок.

Ключевые слова: отрицательные ионы, космический аппарат, электризация, конвективный теплообмен, лучистый теплообмен, явление ионизации, ударные волны, взрыв.

ПОЗИТИВНА И НЕГАТИВНА УЛОГА НЕГАТИВНИХ ЈОНА У СВЕМИРСКИМ ИСТРАЖИВАЊИМА

Леонид И. Гречихин

Белоруска државна академија за комуникације,
Минск, Република Белорусија

ОБЛАСТ: машинство
ВРСТА ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: За свемирску летелицу од дуралуминијума без заштитне превлаке отпорне на топлоту, која се спушта из орбиталне путање првом и другом космичком брзином, на висини од 80 до 40 км, добијени су подаци о повећању густине, притиска и температуре иза ударног таласа, као и о одбијању ударног таласа од површине свемирске летелице на силазној трајекторији.

Методе: Израчунате су вредности флукса енергије ка површини летелице на сваких 10 км, за пренос топлоте конвекцијом и радијацијом, као и за утицај електрона насталих јонизацијом негативних јона.

Резултати: При првој космичкој брзини највећи флукс енергије настаје под утицајем флукса електрона, а при другој космичкој брзини долази до преноса топлоте радијацијом. У гасу компресованом услед удара, на свим разматраним висинама долази до тренутног пораста притиска до вредности 109 ÷ 1011 Ра, што проузрокује ланчане експлозије све веће јачине, као и ударне таласе у околној атмосфери праћене компресивним таласима у целокупној структури летелице. До последње, најснажније експлозије долази на висини од око 40 км.

Закључак: Свемирска летелица се при слетању распада на делове величине честица праха.

Кључне речи: негативни јони, свемирска летелица, напајање, пренос топлоте конвекцијом, пренос топлоте радијацијом, јонизација, ударни таласи, експлозија.

Paper received on / Дата получения работы / Датум пријема чланка: 01.05.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 22.06.2021.
Paper accepted for publishingon / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 24.06.2021.

ON NEW MILITARY TECHNOLOGIES AND CONCEPTS EXPLORED FROM THE SYRIAN CONFLICT EXPERIENCE

Nebojša V. Nikolić
University of Defense in Belgrade, Strategic Research Institute, Defense Studies Section, Belgrade, Republic of Serbia,
e-mail: nebojsa.nikolic11@mod.gov.rs,
ORCID iD: https://orcid.org/0000-0003-4875-3418

DOI: 10.5937/vojtehg69-31659; https://doi.org/10.5937/vojtehg69-31659

FIELD: Military applications, Military technologies, Modern warfare
ARTICLE TYPE: Original scientific paper

Abstract:

Introduction/purpose: The purpose of this paper is to presents some tendencies stemming from the experiences from the ongoing Syrian conflict towards the development of new military concepts and technologies. The manner, scope and dynamics of exploitation of the combat experience from the Syrian conflict is a good example how great powers improve the capabilities of their defense systems.

Methods: An extensive content analysis of selected reference sources has been applied. The system approach was used for a structural and balanced presentation of the available information. The comparative analysis has confirmed some similarities in the behavior of the great powers in terms of deploying and testing complex combat systems of strategic importance in local wars. Inductive thinking has contributed to the synthesis of appropriate conclusions.

Results: Among the presence of several great and regional powers heavily involved in this conflict, Russia's is considered to be the most dominant and as such is the main subject of investigation in this paper. Field testing of new military equipment is known to be important but of extreme importance is its testing under real combat conditions. In parallel with intensive testing of a wide range of military technologies, there are indicators of developing new concepts, doctrines, and organizational upgrades on the basis of the Syrian combat experiences.

ACKNOWLEDGMENT: This work was partially supported by the Ministry of Education and Science of the Republic of Serbia under Interdisciplinary Project No.III-47029 (title: "Cost Effective Selection of New Technologies and Concepts of Defense Through Social Reforms and Strategic Orientations of Serbia in 21st Century).

Conclusion: From the standpoint of military technology and concept development, the Russian endeavor in Syria has become an example of a comprehensive and systematic aproach to learning, training, innovations, and implementations of the most relevant factors in the development of a modern military organization as a response to challenges of contemporary armed conflicts.

Key words: military technology, innovation and testing, military concepts, combat experience, Syrian conflict.

Introduction

All military organizations focus on preparing themselves for future warfare in the best possible way. It is highly beneficial to conduct all available analyses of experiences from current conflicts. The main goal of this paper is to review the available lessons learned from the Russian engagement in the current conflict in Syria. This conflict has more different aspects, to mention the most important ones: international, political, humanitarian, demographic, strategic, economic, social, military, and technological. Additionally, all these implications are not exclusively related to Syria and Russia, nor to the other powers involved, like Turkey, the USA, Israel, Iran, and some Western states, but to a wider set of other states: all neighbor states, regional states, South-European states, and organizations like the EU and NATO. Due to its space limit and its purpose, this paper will treat only the military-technical aspect with consequential inclusion of some organizational, doctrinal, and personnel aspects for a military organization.

Co-relations among military technologies (and other civilian but military applicable technologies), military concepts (including tactical, operational, and strategic levels as well as organizational issues), and the character and nature of contemporary and future warfare / conflicts are permanent subjects of various research studies. Of particular importance is perceiving trends and changes in military technology in some future period, a decade or two, for example (O'Hanlon, 2019). A good review of contemporary trends in military technology development has been offered by O'Hanlon (2019), together with an estimate of their impacts through the three-level scale (moderate, high, and revolutionary impact). O'Hanlon (2019) has grouped various technologies into four general groups as follows: sensors; computers and communications; projectiles, propulsion, and platforms; and other weapons and technologies (O'Hanlon, 2019). It is interesting that this O'Hanlon's forecast has assigned the highest impact ("revolutionary") mainly to the second general group ("computer and communication") and only to the

"robotics and autonomous systems" component from the third general group ("projectiles, propulsion and platforms"). Therefore, these are as follows (O'Hanlon, 2019): "computer hardware; computer software; offensive cyber operations; system of systems; and artificial intelligence and big data".

Besides availability of modern military technology, at least equal importance has an organizational propensity of a military organization to explore, test, and implement technological novelties and, if necessary, to adapt its organization, concepts, and doctrines to the best use of new technologies. So, both issues are needed: firstly, military technology development, innovations, and patents; and secondly, "military technology diffusion" (Schimd, 2018).

In rare cases, it is possible to monitor the application and use of a wide set of new military technologies in an ongoing armed conflict. Some great powers frequently have such opportunities to test and check their novel military equipment and improve its performance through real combat testing. It is exactly the case of the Syrian conflict where many great powers and regional states have been involved for almost the whole second decade of the 21st century. Therefore, the Syrian warfare theater has become "an incubator of learning, training, and innovation" (Adamsky, 2018).

Among the most interesting cases is the Russian military experience due to a wide engagement scope, but also due to a high level of exploitation of overall experience and improved "culture of military innovations" (Adamsky, 2020). In the context of mutual relations between military technologies and military concepts, it should be always kept in mind that "technology shapes warfare, not war" (Roland, 2009). That means that technology may have tremendous influence on warfare (a way in which a war is conducted) and on the means and materials engaged and used in a war. However, the war is a more general category; it relates to the state in which one society or state may be found due to decisions of its top ruling elites. On the other hand, warfare is a way in which a war is conducted and that heavily depends on war material and military technical factors.

According to some official statements, it is considered that more than 600 pieces of military equipment and various weapon systems were field-tested and thanks to that many monitored defects were resolved (Thomas, 2020), some of which are presented in the third chapter. The following chapter presents some doctrinal and organizational issues which are consequent implications of the warfare conditions and applications of new technologies. The concept of network-centric warfare

is one of them (McDermott, 2020). The concluding chapter summarizes the main implications for a military organization based on the experience from the Syrian operations.

General context of the Russian engagement in Syria

Among other great and regional powers interested and engaged in the Syrian conflict, Russia is the only one officially called to enter the Syrian territory by a call issued from the legal Syrian government. Consequently, the Russian military engagement is the most dominant comparing to others. The Russian engagement in Syria started in late September 2015 immediately after a large military exercise, "Tsentr-2015" (Blank, 2019), and has many dimensions and implications, many of which are significant and a subject of research in various fields (Jones, 2020).

Russia conducted a diplomatic campaign and a military campaign in support of the Syrian government as well as a peace-enforcement and peace-keeping campaign with Turkey, together with air operations and air control, military coordination with the forces of the Syrian government, Turkey, the USA, Israel, Iran, and various local and regional militias. The international and strategic consequences of the Syrian conflict have been widely considered at many political instances, and have been a subject of many research studies, but also explored in the media.

Unlike its former engagement in Afghanistan, Russia's dominant form in Syria was distance operations with the engagement of the Russian Air Forces. Intensive engagement of air forces against an asymmetric opponent is not a new model - it has been applied many times by the Western states. The modes of deployment of air forces in achieving operational and strategic goals are a very interesting topic in general and particularly for great powers engagement in various hybrid wars in terms of considering possibilities to reach the main strategic goals by air forces only (Waller, 2020). Nevertheless, there are also important consequences from the Syrian campaign for land forces (the Army), particularly in the context of modernization of the already existing (older) weapon systems in artillery (International Institute for Strategic Studies, 2021).

Military-technology testing on the Syrian battlefield

"Military research and development (R&D) is the most expensive and basic phase in the creation of a new weapon platform", (Hagelin, 004). During several past decades, interference and overlapping

between military R&D and civilian R&D have been established in many fields of technology and science. However, even if some civilian technology is found appropriate for use in some military domain, it still has to be tested and checked according to specific military standards. Furthermore, some military technological entities, such as various combat platforms (tanks, fighters, submarines, artillery), do not have any civilian counterpart, so they have to be invented, designed, produced, and tested through military research and development. In any case, the above statement by Hagelin (2004) will be still accurate in the near future.

The main question could be formulated here: what kind of military platforms, weapons and equipment, with which performances, should be created by military R&D? The answer to this question leads us to military battlefields (current or imagined future ones), and to the military operational art, strategic thinking, and tactical expertize. In order to strengthen the link between military R&D and battlefield expertize, smart armies use various approaches. For example, the US Army has created "a US Army Science Officer position for liaison in order to bring operational experience quickly to the laboratories and help implement new technology requirements", (Hagelin, 2004). In other cases, engineers and researchers are temporary assigned to military formations in order to be close enough to see, perceive, recognize, and record the relevant parameters of the platforms and equipment under study as well as the operational conditions and requirements in the environment where their weapon platform or equipment operates. The Russian performance in the Syrian conflict shows a very high level of this cooperation between the representatives from industrial and military R&D and the world of operational art in contemporary warfare such as the Syrian conflict.

Field testing of armament and combat equipment

Real combat environment is the best place for testing real values and applicability of new weapons and equipment. Official media statements confirm that over 600 items of different weapon systems and equipment have been tested with engagement of 1,200 engineers from 57 defense companies, and with a very high level of elimination of defects on the tested equipment (Thomas, 2020). We are presenting here some of those weapon systems, platforms, and equipment which were used in field testing during the Syrian conflict.

Combat aircraft. A Russian government official stated that various combat aircraft were tested in the Syrian theater: the Su-35S and Su-30SM fighters; Su-34 and Su-24M (fighter-bombers and frontline

bombers); Su-25SM attack aircraft; Tu-22MZ and Tu95MS long-range aircraft. A particular attention was dedicated to electronic devices, software, compatibility, and interoperability among various equipment and platforms (Thomas, 2020). A fast operational tempo of air forces combat engagement induced opportunities for testing and improvement of servicing and maintenance procedures. Some estimations suggest that there were between 20 to 50 various combat aircraft and from 16 to 40 attack and transport helicopters (Jones, 2020).

Combat helicopters. Some helicopters were field tested in Syria as follows: Ka-52, Mi-24, Mi-35, and Mi-28. Multirole helicopters, like Mi-28N and Mi-35, are capable of various missions, and they were also used, for so-called "free hunting" of terrorists, including demanding night missions (night vision systems could detect a vehicle at 15 kilometers (Mi-28N), and up to 7 km for Mi-35 (Thomas, 2020)). Some anti-tank guided missiles mounted on the Mi-28NE were tested and replaced due to field test results (Khrizantema-VM 9M123M was involved instead of Ataka anti-tank guided missile).

Anti-radiation (anti-radar) missile. There are some indices that the tactical anti-radiation missile Kh-25ML was tested as well. It is a modernized version of an older missile which intended use is against surface-to-air missile platforms of adversary's air-defense systems. Its range is about 20 kilometers and speed is 850 meters per second (Thomas, 2020).

Tanks. From rare statements of some Russian officials, it could be concluded that even the Armata T-14, a future main battle tank, was field tested in the Syrian combat environment (Pronk, 2020). Also, continued field-trial testing will be provided with a number of these tanks to be delivered to the Russian Army units at the field. The tank factory managers hope that this "combat-proven" marking will help Armata's trade position on the international armament market.

Armored reconnaissance vehicle BRDM-2 modernization. This vehicle had a third wave of modernization in 2017 and field testing in Syria. A closed turret with a machine gun was installed, while the gunner is protected from enemy projectiles (Thomas, 2020).

Artillery systems. There are indices that some new howitzer types were deployed in Syria, i.e. the 2Sm19M1 Msta and its novel version, the 2S19M2 (Thomas, 2020).

Anti-tank grenade launcher, the SPG-9 Kopye. The Kopye is an accurate anti-tank grenade launcher for close combat, with a high rate of fire of up to six rounds per minute, with a maximum range of one kilometer and low production cost (Thomas, 2020).

Heavy flamethrower, the Solntcepek TOS-1A. This rocket launcher was used in Hama and Idlib provinces and has proved its effectiveness in countering terrorists in urban structures and mountain hiding-places. This system uses thermo-baric mixtures which produce an effect of a fuel-air explosion with high temperatures (Thomas, 2020).

Pontoon bridge. Russian forces deployed the PP-2005M pontoon bridge (carrying capacity of 120 tones, and with about 1 hour erection time), across the Euphrates in support of a Syrian army combat mission (Thomas, 2020).

Individual reconnaissance system, the Glaz. The Glaz is equipped with a high resolution camera and is intended for hand-held rocket launching at 300 meters into the air in order to monitor and send live recordings of the enemy positions behind some barriers, buildings or uneven terrain. Its field of view covers about one half of a square kilometer and is landed by a parachute (Thomas, 2020).

Individual protection system. It is observed that a new generation of armor suits for individual protection is used for field testing in the Syrian combat environment (special Kevlar, aramid fiber material). According to some information, it is five times stronger than steel (Thomas, 2020).

Field-testing of new Command and Control systems

Command & Control systems. Probably the most beneficial impact from the engagement in the Syrian conflict, inside military framework, has been found in the development, implementation, testing, and improvement of the complex system of military command and control which had to be established for expeditionary forces deployed far from the Russian territory. Also, this engagement in Syria has been an excellent experiment for a tactical command and control system known as ESU TZ, which is in its essence a modern C4 system (Command, Control, Communications, and Computers). It supports successfully inter-service communications between army units and air forces. This C4 system also integrates target data gathered by UAVs and processed further towards air force striking units or to artillery units for fire support (Thomas, 2020).

In general, the modernization of command and control systems in the Russian military is a part of practical implementation of an older Russian concept known under the terms “reconnaissance-strike” (term for the strategic-operational level) and “reconnaissance-fire” (name for the operational-tactical level), Adamsky (2018). In the essence of both concepts there is an idea about the shortest possible reaction time of the

military capability of connecting the reconnaissance process for target determination, processing the data, making a decision, and engaging the target. Similar to this concept are some other well-known concepts such as: the OODA cycle (Observe-Orient-Decide-Act), Lawson's C2 model, and the HEAT model (Nikolić, 2016), (Nikolic, 2017).

The Russian command and control system with regard to operations in Syria has been organized in three general levels (Adamsky, 2018). At the top level, there is the Group of Combat Management – an integral part of the National Defense Management Center in the Moscow region. This Group is responsible for the communication and coordination with high commands of other foreign countries and organizations present in Syria (the US, Turkey, Israel, UN). At the middle level, there is the Command Post of the Grouping of Forces, located at the Khmeimim base in Syria. The second level conducts the communication and coordination activities with all other allied high commands in Syria such as the Syrian Army, Iran, and a number of pro-regime militias. It also exchanges information with local operational commands of the US, Turkey, and Israel in order to avoid confusion and forces collisions. At the third level, there are Operational Groups of Advisors. They are deployed widely and attached to selected operational-tactical command posts of the Syrian Army and other allied forces in the Syrian theater (Adamsky, 2018).

Emerge of UAV use and recognition of drone importance

UAVs – Unmanned Aerial Vehicles (popular term is Drones; or, UAS – Unmanned Aerial Systems in the Russian terminology). The Russian forces have clearly realized potential of unmanned aerial vehicles in their different roles. In 2016, Russian Army had about 2,000 drones, while 70 of that number were deployed in Syria at that time (Center for Analysis of Strategies and Techniques, 2020). That number increased in the following years with a respectable number of drones engaged on a daily basis (Adamsky, 2018). By 2018, there were more than 23,000 sorties of various drones which made about 140,000 hours in aerial operations (surveillance, reconnaissance, and target acquisitions), and those numbers confirm greater engagement of drones than that of manned aircraft. The prevailing type of drones used by the Russian forces has been the Orlan-10, a reconnaissance drone (reconnoitering targets for airstrikes; spotting artillery engagements; and assessing results of strikes and fires) with the following characteristics: it carries up to 5kg (cameras, electronics, transmitters); operational autonomy 120 kilometers, up to 5,000 meters altitude and up to 14 hours

in a single flight; launched by catapult, landing by parachute, no runway needed (Center for Analysis of Strategies and Techniques, 2020). A complete set of the Orlan-10 consists of the following items: 2 UAVs, the ground control station, the payload, the additional accessories, and a light vehicle. The price of the whole set is nearly 600,000$.

Threats from UAV attacks were recognized and some measures were taken. The air defense system for close combat, the Tor-M2, has been noticed at the Khmenimim airport base in Syria. It is supposed that this system will contribute to defense from drone attacks. This system is able to detect, track and engage targets in the zone up to 15 kilometers in radius and 10 kilometers in height, while servicing up to four targets simultaneously. It is worth to point out that for many militaries across Europe, drone defense is still an open question.

Strategic technology testing and/or demonstration of power

Cruise Missiles. In the Syrian theater, two types of cruise missiles were used for targets located deep in Syria: Kh-555 (range of 2,000 km), and a more modern Kh-101 (4,000 km of range). But the main motive to use these sophisticated missiles against terrorist groups was not only combat need nor weapons testing (which is always welcomed), but rather a demonstration of technical and operational capabilities for a long-range strike, as well as strategic willingness to put in use such weapons if it is needed (Pronk, 2020). However, Russia is not alone in this kind of reasoning - principally the same logic was applied by the USA in NATO bombing of Yugoslavia in 1999, when strategic stealth bombers B-2 were used flying long way from their base in Missouri to the Balkans in Europe (Lambeth, 2001). According to Lambeth (2001, p.89), six B-2 strategic bombers performed 49 combat sorties form Whiteman base, Missouri, which is only about 0.5% of all combat sorties conducted during the war in 1999, but they were much more effective – even 11% of all dropped bombs came from the B-2. Furthermore, one third of all smart bombs was dropped from the B-2 (Lambeth, 2001). In that way, the following goals were achieved: demonstration of capability for a global strike (from the USA mainland to the Southeast Europe); demonstration of the penetration capability against air-defense (due to the stealth capability of the B-2); precision bombing of up to 16 different targets in one sortie; check of crew's capability to conduct combat missions of long duration (28 to 32 hours per one round-trip combat mission); multiple refueling capability for long distance missions, etc. (Lambeth, 2001). All of the above seen in 1999 has similar counterparts in ongoing experimentations

of great powers involved in the Syrian conflict (long-range bombers Tu-22M3, see - launched cruise missiles Kalibr, etc. Thomas, 2020).

Engineering and logistics

New robotic mine clearing devices. Russian engineering units and teams have successfully cleared large areas of minefields (thousands of hectares, and tens of thousands of buildings), and many roads while destroying more than a hundred thousand of explosive devices (Thomas, 2020). For these tasks, they used some new robotized engineering equipment (multifunctional mine clearing robotic system - the Uran-6; ground-penetrating radars - the OKO-2; remote-controlled mine clearing vehicle equipped with an electromagnetic pulse generator - the Listva). Besides that high engineering performance, they established a mine clearing training center and had trained more than 600 Syrian soldiers by 2018 (Thomas, 2020).

Logistics. Due to long distances from the Russian territory and drastically different climate conditions and heavy terrain, as well as due to challenging security environment at all levels, logistics support of the Russian forces in Syria has been and still is a huge challenge. Health support for personnel and good living conditions, together with very improved quartermaster, food, and sanitary conditions, are much better than in some former times, i.e. accommodation tents replaced with solid block modules; food prepared by only Russian cooks instead of locals; strict control over food stocks and water supply; special uniforms for high temperature climate, etc. Combat items supplies (ammunition and fuel) were well managed and sustained at appropriate level with the goal to sustain demands for a high consumption rate caused by intensive air operations, ground patrolling, as well as for combat support of operations of the Syrian allies (Thomas, 2020). To illustrate the level of logistics efforts, during the five months in 2015 (the beginning of engagement), Russian logistics deployed more than 200,000 tons of material from Russia to the deployed forces in Syria (Clark, 2021).

Military management lesson learned

The Russian armed forces conducted two main reforms during the last few decades. The first one was induced after the war in Georgia in 2008 while the second one started with personal changes at the highest ministerial level (with the then-new Minister of Defense Sergei Shoigy), and at the level of the new Chief of General Staff (General Valery Gerasimov), in 2012.

A strong reform momentum to the Russian military modernization and improvement occurred at the beginning of wider Russian engagement in Syria in 2015. That momentum brought changes and improvement in many aspects: strategic, doctrinal, operational, tactical, logistical, and military-technical upgrading with new weapons and military systems. Some of them will be presented here.

Military personnel upgrade with combat experience

Engagement in the Syrian conflict has been a unique opportunity for gaining combat experience, and it has been performed in a well-organized manner. Some estimations (Ramm, 2019), suggest that by the middle of 2018, more than 63,000 military personnel (including 434 generals and 25,738 officers) were deployed in Russian bases in Syria on a rotating basis, usually a 3-month deployment, while for senior officers it was six to nine months (Jones, 2020). The estimates for the personnel contingent go between 3,000 to 5,000 troops with periodical peaks of about 6,000 troops (Jones, 2020). A large part of deployed personnel consisted of officers (about 40%) selected from across all units and districts in Russia so that their experience as well as burden sharing could be distributed throughout all parts of the armed forces. It is interesting that almost two thirds of Russian Air Force personnel had gained deployment experience in Syria by 2018 (Jones, 2020).

Similarly to the situation in Western armies, combat experiences gained from deployment in combat zones have become a valuable factor for successful professional careers of Russian officers. The Russian military has recognized indispensable value of combat experience and has started to consider that as a precondition for promotions and appointments for higher professional positions in military organizations.

Contemporary warfare enriches military professionals with additional types of experiences such as: facing with several categories of conflict participants; field-testing of new weapons and equipment; application of old procedures in new environment and testing new operational procedures and doctrinal guidelines; performing joint forces coordination and operations; conducting cooperation with different allies, local population, units, and commands of other powers present in Syria, etc.

Adjustment of concepts, procedures, and doctrines

Perception of dominance of urban operations. It has been realized that terrorists and insurgents mostly use populated areas for their activities (operations, sustainment, supply, recruitment, and protection). Some lessons learned from urban operations in Syria show

some similarities with urban operations in Grozny (Chechen wars) and even with some cases during WWII. In Syria, the following tactic was usually used: attacks on fortified terrorist bases in urban environment usually start after extensive situation monitoring followed by encircling the enemy location but not completely - instead, one small corridor is left uncovered as an offer to defenders to retreat including all those from civilian population who want to leave the location; it is then followed by artillery and direct fire engagement on focused parts of the urban location; after the artillery action, what follows are actions by specially composed maneuverable assault teams, with optional tank support behind assault teams if needed (Thomas, 2020). Sometimes, instead of artillery and tanks, helicopters delivered precision-guided weapons, while robotized platforms were used for reconnaissance and mine-clearing.

Defense from UAVs. The Russian forces in Syria experienced several drone attacks. In spite of media attractiveness of such events, it should not be a surprise as it was foreseen in some earlier studies (Bunker, 2015), and every army (and not only the military, but also commercial sector) should expect that in future conflicts. Efficient and effective “drone defense” is an open question (Bendett, 2019) for many militaries around the world due to a great potential of drone engagement (Yaacoub et al, 2020). Anti-drone combat could be successful with good air-defense systems and highly trained personnel. For example, in rebels’ UAV attacks on the Russian forces in Tartus and Khmeimim bases in January 2018, seven of 13 attacking drones were destroyed by the air-defense system Pantcir while the rest of them were landed by Russian electronic warfare units capturing the control over them (Urcosta, 2020). On the other hand, when poor servicing of air-defense system is present, attacking drones are very efficient and an effective combat tool due to their much lower price than those of targets which they attack. This new way of warfare generates many possibilities and subjects for research studies at higher levels of military education (Nikolic, 2018).

Conclusion

The military lessons learned from the engagement in the Syrian conflict are numerous. However, the main beneficiary can be probably found in the domain of command and control process and corresponding technical systems, with the main output in shortening the decision-making cycle, networking of forces, and superior situation awareness. From the purely technical side of military technology, combat environment is almost indispensable for developing and testing new

weapons and equipment, and that fact has been used intensively. The importance and applicability of robotized platforms and unmanned aerial vehicles was recognized and will fuel development of future similar systems as well as appropriate counter measures.

Gathering combat experience through periodical force rotation was applied and then used and disseminated through the whole force structure by appropriate promotions, advancements and posting combat-experienced personnel to the key positions across the military hierarchy. The analyses of the deployment and combat experience serve as a pivot for creating new procedures, manuals, and military doctrines.

This work should be taken not as a final review of a contemporary conflict's impact on military technology development but rather as an initial step for further research and deeper insight into particular topics. Future research should unavoidably include other contemporary conflicts such as the Caucasian war in the fall of 2020 which was far less asymmetric than the Syrian conflict and as such could be of interest for many small countries.

References

Adamsky, D. 2018. Moscow's Syria Campaign: Russian Lessons for the Art of Strategy. *Russie.Nei.Visions*, 109, July [online]. Available at: https://www.ifri.org/en/publications/notes-de-lifri/russieneivisions/moscows-syria-campaign-russian-lessons-art-strategy [Accessed: 1 April 2021]. ISBN: 978-2-36567-890-2.

Adamsky, D. 2020. *Russian Lessons from the Syrian Operation and the Culture of Military Innovation*. Garmisch-Partenkirchen: European Center for Security Studies „George C. Marshall", Security Insight report No.047.

Bendett, S. 2019. The Rise of Russia's Hi-Tech Military. *Fletcher Security Review*, 6(1), Summer, pp.6-14 [online]. Available at: https://www.fletchersecurity.org/summer-2019-military-technologies [Accessed: 1 April 2021].

Blank, S.J. 2019. *The Russian Military in Contemorary Perspective. Strategic Studies Institute*. Carlisle, PA: U.S. Army War College Press.

Bunker, R.J. 2015. *Terrorist and Insurgent Unmanned Aerial Vehicles: Use, Potentials, and Military Implications*. Carlisle, PA: Strategic Studies Institute, U.S. Army War College [online]. Available at: https://scholarship.claremont.edu/cgu_facbooks/50/ [Accessed: 1 April 2021].

-Center for Analysis of Strategies and Techniques (CAST). 2020. *Russian UAV in Syria* [online]. Available at: http://cast.ru/eng/products/articles/russian-uavs-in-syria.html/ [Accessed: 1 April 2021].

Clark, M. 2021. *The Russian Military's Lessons Learned In Syria*. Washington, DC: Institute for the Study of War [online]. Available at: http://www.understandingwar.org/report/russian-military%E2%80%99s-lessons-learned-syria [Accessed: 1 April 2021].

Hagelin, B. 2004. *Science- and technology-based military innovation: the United States and Eur*ope. Solna, Sweden: SIPRI Yearbook 2004: Armaments, Disarmament and International Security, pp.285-304.

-International Institute for Strategic Studies (IISS). 2021. *The Military Balance 2021.* London, UK: Routledge & CRC Press. ISBN: 9781032012278.

Jones, S.G. 2020. *Moscow's War in Syria*. Washington, DC: Center for Strategic & International Studies and Lanham, MD: Rowman & Littlefield [online]. Available at: https://www.csis.org/analysis/moscows-war-syria [Accessed: 1 April 2021]. ISBN: 978-1-5381-4015-4 (pb); 978-1-5381-4016-1 (eBook).

Lambeth, B.S. 2001. *NATO's Air War for Kosovo: A Strategic and Operational Assessment*. Santa Monica, CA: RAND Corporation. Available at: https://doi.org/10.7249/MR1365.

McDermott, R. 2020. Tracing Russia's Path to Network-Centric Military Capability. *Jamestown Foundation*, Programm: Russia's Path to the High-Tech Battlespace, 4 December [online]. Available at: https://jamestown.org/program/tracing-russias-path-to-network-centric-military-capability/ [Accessed: 1 April 2021].

Nikolic, N. 2017. Tandem Queueing Concept in Improving Command & Control Process in Hybrid Environment. In: *XLIV International Symposium on Operational Research "SYM-OP-IS-2017"*, Zlatibor, Serbia, pp.675-680, September 25-28 [online]. Available at: http://symopis.vggs.rs/razno/Zbornik_radova_SYM-OP-IS_2017.pdf [Accessed: 1 April 2021]. ISBN: 978-86-7488-135-4.

Nikolic, N. 2018. Strengthening defense research as part of higher military education for future security challenges. *Security and Defense Quarterly,* 21(4), pp.58-72. Available at: https://doi.org/10.5604/01.3001.0012.5181.

Nikolić, N. 2016. Conceptualizing Simulation for Lawson's Model of Command and Control Processes. In: *7th International Scientific Conference on Defensive Technologies OTEH*, Belgrade, pp.446-450, October 6-7.

O'Hanlon, M. 2019. *Forecasting Change in Military Technology*, *2020-2040*. Washington, DC: The Brookings Institution [e-book]. Available at: https://www.worldpittsburgh.org/wp-content/uploads/2019/01/Forecasting-change-in-military-technology-2020-2040-Brookings-2018.pdf [Accessed: 1 April 2021].

Pronk, D. 2020. Lessons Learned in the Levant: Russia's Arms in the Syrian Conflict. *Clingendael Magazine,* May [online]. Available at: https://www.clingendael.org/publication/russias-arms-syrian-conflict [Accessed: 1 April 2021].

Ramm, A. 2019. The Russian Army: Operations and Modernizations. *CNA Analysis Solutions*, October [online]. Available at: https://www.cna.org/CNA_files/PDF/IOP-2019-U-021801-Final.pdf [Accessed: 1 April 2021].

Roland, A. 2009. War and Technology. Program on Teaching Innovation. *Foreign policy research institute*, 27 February [online]. Available at: https://www.fpri.org/article/2009/02/war-and-technology/ [Accessed: 1 April 2021].

Schimd, J. 2018. *The Determinants of Military Technology Innovation and diffusion*. Ph.D. thesis. Atlanta, GA: Georgia Institute of Technology [online]. Available at: https://smartech.gatech.edu/handle/1853/59877 [Accessed: 1 April 2021].

Thomas, T. 2020. Russian Lessons Learned in Syria: An Assessment. *MITRE Center for Technology and National Security*, June [online]. Available at: https://www.mitre.org/sites/default/files/publications/pr-19-3483-russian-lessons-learned-in-syria.pdf [Accessed: 1 April 2021].

Urcosta, R.B. 2020. The Revolution in Drone Warfare: The Lessons from the Idlib De-Escalation Zone. *Journal of European, Middle Eastern, & African Affairs*, August 31 [online]. Available at: https://www.airuniversity.af.edu/JEMEAA/Display/Article/2329510/the-revolution-in-drone-warfare-the-lessons-from-the-idlib-de-escalation-zone/ [Accessed: 1 April 2021].

Yaacoub, J-P., Noura, H., Saman, O. & Chehab, A. 2020. Security analysis of drone systems: Attacks, limitations, and recommendations. *Internet of Things*, 11(art.number:100218). Available at: https://doi.org/10.1016/j.iot.2020.100218.

Waller, J.K. 2020. *Airpower Theory And Hybrid Warfare: Warden's Five Rings*. Masters thesis. Baltimore, Maryland: Johns Hopkins University [online]. Available at: https://jscholarship.library.jhu.edu/handle/1774.2/62790 [Accessed: 1 April 2021].

НОВЫЕ ВОЕННЫЕ ТЕХНОЛОГИИ И КОНЦЕПЦИИ,
ОСНОВАННЫЕ НА ОПЫТЕ СИРИЙСКОГО КОНФЛИКТА

Небойша В. Николич

Университет обороны в г. Белград, Институт стратегических исследований, г. Белград, Республика Сербия

РУБРИКА ГРНТИ: 78.00.00 ВОЕННОЕ ДЕЛО:
78.25.00 Вооружение и военная техника;
78.25.23 Новейшие разрабатываемые средства вооруженной борьбы и защиты от них
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Целью данной статьи является описание некоторых тенденций, вытекающих из опыта актуального сирийского конфликта, в направлении разработки новых военных концепций и технологий. Способ, масштабы и динамика использования боевого опыта в сирийском конфликте являются хорошим примером того, как великие державы улучшают возможности своих систем обороны.

Методы: В статье был применен обширный контент-анализ избранных информационных источников. В использовании доступной информации был применен системный подход для ее структурного и сбалансированного изучения. Сравнительный анализ подтвердил некоторое сходство в поведении великих держав в плане развертывания и тестирования сложных боевых систем, имеющих стратегическое значение в локальных войнах. Индуктивное мышление способствовало обобщению соответствующих выводов.

Результаты: Среди участия нескольких великих и региональных держав, активно вовлеченных в этот конфликт, Россия считается доминирующей, и она как таковая является основным предметом исследования данной статьи. Всем известно насколько важны испытания новой военной техники и, что ее испытания в реальных боевых условиях являются важнейшим показателем. Наряду с интенсивным тестированием широкого спектра военных технологий в условиях войны, также выявляются главные индикаторы разработки новых концепций, доктрин и организационных совершенствований вооруженных сил, основанных на опыте сирийского конфликта.

Выводы: Вмешательство России в вооруженный конфликт в Сирии с точки зрения военной технологии и разработки концепции стало примером комплексного и систематического подхода в изучении, учениях, инновациях и во внедрении наиболее важных факторов в развитие современной военной организации в качестве ответной меры на вызовы современных вооруженных конфликтов.

Ключевые слова: военные технологии, инновации и испытания, военные концепции, боевой опыт, сирийский конфликт

НОВЕ ВОЈНЕ ТЕХНОЛОГИЈЕ И КОНЦЕПТИ НАСТАЛИ НАКОН ИСКУСТАВА ИЗ СИРИЈСКОГ СУКОБА

Небојша В. Николић

Универзитет одбране у Београду, Институт за стратегијска истраживања, Београд, Република Србија

ОБЛАСТ: војне примене, војне технологије, савремени рат
ВРСТА ЧЛАНКА: оригинални нуачни рад

Сажетак:

Увод/циљ: У раду су приказане одређене тенденције развоја нових војних технологија и концепата проистекле из искустава из текућег оружаног сукоба у Сирији. Начин, обим и динамика коришћења борбених искустава из овог сукоба представљају добар пример како велике силе побољшавају своје способности и спроводе реформе сопственог система одбране.

Методе: У раду је примењена анализа садржаја обимног материјала из одабраних референтних извора информација. Системски приступ је примењен за структурирани и балансирани приказ расположивих информација. Упоредна анализа потврдила је сличности у понашању великих сила при употреби и провери сложених борбених система стратегијског значаја у локалним сукобима. Индуктивно мишљење допринело је синтетизовању одговрајућих закључака.

Резултати: Поред више великих и регионалних сила које у великој мери учествују у овом сукобу, руско присуство се сматра најдоминантнијим. Улога и важност тестирања нове војне опреме и технологије је позната, а посебну вредност имају тестирања у реалним борбеним условима. Истовремено са интензивним тестирањима широког скупа војних технологија у ратним условима, евидентни су и показатељи развоја нових концепата, процедура и доктрина, као и усавршавања организационих форми војних снага заснованих на борбеним искуствима из рата у Сирији.

Закључак: Руски подухват у Сирији, са аспекта развоја војних технологија и нових концепата, постаје пример свеобухватног и систематског приступа у изучавању, обуци, иновацијама и имплементацијама најрелевантнијих фактора у развоју модерне војне организације, што представља одговор на изазове савремених оружаних сукоба.

Кључне речи: војне технологије, иновације и тестирање, војни концепти, борбено искуство, сиријски сукоб.

Paper received on / Дата получения работы / Датум пријема чланка: 04.04.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 31.05.2021.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 02.06.2021.

VOJNOTEHNIČKI GLASNIK / MILITARY TECHNICAL COURIER, 2021, Vol. 69, Issue 3

ПРЕГЛЕДНИ РАДОВИ

ОБЗОРНЫЕ СТАТЬИ

REVIEW PAPERS

QUANTUM ELECTRODYNAMICS DIVERGENCIES

Nicola Fabiano

University of Belgrade, Vinča Institute of Nuclear Sciences - National Institute of the Republic of Serbia, Belgrade, Republic of Serbia,
e-mail: nicola.fabiano@gmail.com,
ORCID iD: https://orcid.org/0000-0003-1645-2071

DOI: 10.5937/vojtehg69-30366; https://doi.org/10.5937/vojtehg69-30366

FIELD: Mathematical physics
ARTICLE TYPE: Review paper

Abstract:

Introduction/purpose: The problem of divergencies in Quantum Electrodynamics (QED) is discussed.

Methods: The renormalisation group method is employed for dealing with infinities in QED.

Results: The integrals in QED giving physical observables are finite.

Conclusions: The divergencies in QED can be treated in a consistent way providing mathematical rigorous results.

Key words: Quantum Electrodynamics, Quantum Field Theory, Renormalisation Group.

Renormalisation group

The quantum field brings together two fundamental notions of classical and non-relativistic quantum physics: particles and fields. For instance, the quantum electromagnetic field can be reduced to particles called photons, or to a wave process described by a classical field. The same is true for the quantum Dirac field, for electrons.

Quantum field theory, QFT for short, as the theory of interacting quantum fields, includes the remarkable phenomenon of virtual particles related to virtual transitions in quantum mechanics. For example, a photon propagating through empty space, the classical vacuum, undergoes a virtual transition into an electron–positron pair. Usually, this pair undergoes the

reverse transformation: annihilation back into a photon. This sequence of two transitions is known as the process of vacuum polarisation. Hence the vacuum in QFT is not an empty space, rather it is filled by virtual particle–antiparticle pairs.

Another example is the electromagnetic interaction between two electric charges, e.g. between two electrons. In QFT, rather than a Coulomb force described by a potential, the interaction corresponds to an exchange of virtual photons, which, in turn, propagate in spacetime accompanied by virtual electron–positron pairs.

QFT calculation usually results in a series of terms, each of which represents the contribution of different vacuum polarisation mechanisms. Unfortunately, most of these terms turn out to be infinite.

The puzzle was resolved in the late 1940s, mainly by Bethe (Bethe, 1947), Feynman (Feynman, 1949a), Schwinger (Schwinger, 1948), Tomonaga (Tomonaga, 1946) and Dyson (Dyson, 1949). These famous theoreticians were able to show that all infinite contributions can be grouped into a few mathematical combinations that correspond to a change of normalisation of quantum fields, ultimately resulting in a redefinition, i.e. "renormalisation" of masses and coupling constants. Physically, this effect is a close analogue of a classical "dressing process" for a particle interacting with a surrounding medium.

The most important feature of renormalisation is that the calculation of physical quantities gives finite functions of new "renormalised" couplings, such as electron charge and masses, all infinities being swallowed by the factors of the renormalisation redefinition. The "bare" values of mass and electric charge do not appear in the physical expression. At the same time, the renormalised parameters should be related to the physical ones, measured experimentally.

Dealing with infinities

Infinities are disturbing. In Nature infinities seldom happen. There are "only" about 10^{80} atoms in the Universe. The Universe itself had a beginning, but (as of 2021) it will expand forever to a state of thermodynamically no free energy. Mathematics itself started using infinite numbers only in 17^{th} century, and division by zero is invalid even in hyperreal numbers.

Yet in physics we have to deal with infinities even from classical electromagnetism. Consider a static electrical field generated by a single particle,

say an electron e. Then we have

$$\operatorname{div} \vec{\mathcal{E}} = \delta(\mathbf{r}) \, . \tag{1}$$

By symmetry arguments, we immediately obtain the electrical field $\vec{\mathcal{E}}$, that is

$$\vec{\mathcal{E}} = \frac{e}{4\pi \mathbf{r}^2} \tag{2}$$

and computing the total energy of the field, proportional to its electromagnetic mass m_{em},

$$E = \frac{1}{2} \int \mathrm{d}V \vec{\mathcal{E}}^2 = \frac{1}{2} \int_{r_e}^{\infty} \mathrm{d}r \left(\frac{e}{4\pi r^2} \right)^2 4\pi r^2 = \frac{e^2}{8\pi r_e} \tag{3}$$

one sees that becomes infinite as the electron radius r_e goes to 0. In late 19^{th} century, that meant that an electron needed infinite energy to be accelerated.

When quantising the electromagnetic field, we are faced with another divergence problem. Writing down the Hamiltonian of harmonic oscillators for each radiation mode identified by $(\mathbf{k}, r)$

$$H = \sum_{\mathbf{k}} \sum_{r} \hbar \omega_{\mathbf{k}} \left(a_r^{\dagger}(\mathbf{k}) a_r(\mathbf{k}) + \frac{1}{2} \right) \tag{4}$$

we see that the energy of vacuum state $|0\rangle$ equals to $\frac{1}{2} \sum_{\mathbf{k}} \sum_r \hbar \omega_{\mathbf{k}}$, which is an infinite constant $(\omega_{\mathbf{k}} = c|\mathrm{k}|)$. This problem is usually dealt with by shifting the Hamiltonian by this infinite value, as one has the freedom to redefine the zero of energy scale.

During the development of quantum electrodynamics (QED) it was discovered that many integrals were divergent (Dirac, 1927), (Dirac, 1934), (Heisenberg, 1934). Those were present in perturbative calculations involving Feynman diagrams (Feynman, 1949a), (Feynman, 1949b) containing closed loops. Particles circulating in closed loops are called *virtual particles* because they are off–shell, that is $p^2 \neq m^2$. In a loop, their momentum and energy are not determined and thus they have to be integrated over all values allowed by the whole 4–momentum conservation. Such integrals are divergent, i.e. give infinite results. Divergencies that are troublesome in quantum field theory are almost always due to large energy and momenta i.e. *ultraviolet divergencies* – (UV), or conversely short distance behaviour.

It is possible to give perfectly meaningful and rigorous results to this divergent integrals in an ample class of theories, as we will see.

QED divergencies

We will now treat the divergencies given by loops present in quantum electrodynamics. Recall that the Lagrangian is given by

$$\mathcal{L} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \overline{\psi}\left[i\gamma_\mu(\partial^\mu - ieA^\mu) - m\right]\psi \tag{5}$$

where $F^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu$, ψ is a 4 component Dirac spinor and e the electric charge. Recall that under a gauge transformation $\mathcal{L}$ is invariant for $\psi \to e^{i\alpha}\psi$ and $A_\mu \to A_\mu + \partial_\mu\alpha$.

In order to perform the calculation, we will make use of the so–called *dimensional regularisation* (Bollini, 1972), (Hooft, 1972). This technique was introduced during investigation of the renormalisation of non Abelian gauge fields. It consists of writing Euclidean Feynman integrals obtained by means of a Wick rotation (Wick, 1954) $x_0 \to ix_0$ (i.e. with positive defined metric $x_0^2 + x_1^2 + x_3^2 + x_3^2$) in a space with generic dimension D, and making an analytic continuation in D itself which assumes non–integer values. Recalling that the volume of a D dimensional sphere S_D is

$$\int_{S_D} \mathrm{d}^D x = \int_0^R \mathrm{d}r\,\mathrm{d}\Omega_D\, r^{D-1} = R^D\,\frac{\pi^{D/2}}{\Gamma\left(\frac{D}{2}+1\right)} \tag{6}$$

i.e. $\Omega_D = \pi^{D/2}/\Gamma(D/2+1)$, one could infer that all possible divergencies stem only from the Gamma function term. Eventually, we will get rid of those infinities obtaining meaningful results.

As we are going to do our calculations in D dimensions, a few observations on the Lagrangian (5) are in order. One half spin spinors ψ have the dimension $(1-D)/2$, while vector fields A_μ have the dimension $(2-D)/2$. Clifford algebra of γ matrices retains the usual form

$$\{\gamma_\mu, \gamma_\nu\} = 2g_{\mu\nu} \tag{7}$$

while $g_{\mu\nu} = \mathrm{diag}(+1, -1, -1, \ldots -1)$. The coupling constant e is replaced by

$$e \to e\mu^{(4-D)/2} \tag{8}$$

μ being a mass parameter of dimensional regularisation. In Euclidean space photon propagator becomes simply $\delta_{\mu\nu}/p^2$, while the fermion pro-

Fabiano, N., Quantum electrodynamics divergencies, pp.656–675

pagator is $-i/(\not{p}+m)$. The vertex of two fermions and a vector becomes $-ie\mu^{(4-D)/2}\gamma_\rho$.

Vacuum polarisation

The first loop diagram of QED we consider is the so–called vacuum polarisation diagram, i.e. the correction to the photon line, shown in Fig. 1.

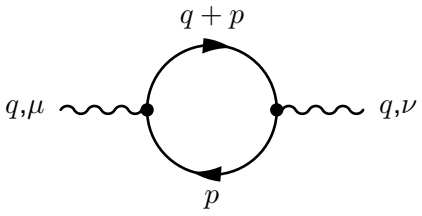


Figure 1 – Vacuum polarisation diagram
Рис. 1 − Диаграмма поляризации вакуума
Слика 1 – Дијаграм поларизације вакуума

The expression for the loop is given by

$$\Pi_{\mu\nu}(q) = -(e\mu^{(4-D)/2})^2 \int \frac{\mathrm{d}^D p}{(2\pi)^D}\ \mathrm{Tr}\left[\gamma_\mu \frac{1}{\not{p}+\not{q}+m}\gamma_\nu \frac{1}{\not{p}+m}\right] \tag{9}$$

where the minus sign comes because of the fermion loop, the trace is calculated over γ matrices. This will be rewritten in a more suitable form for calculations

$$\Pi_{\mu\nu}(q) = -(e\mu^{(4-D)/2})^2 \int \frac{\mathrm{d}^D p}{(2\pi)^D}\ \frac{\mathrm{Tr}[\gamma_\mu(\not{p}+\not{q}-m)\gamma_\nu(\not{p}-m)]}{[(p+q)^2+m^2][p^2+m^2]}\ . \tag{10}$$

From eq. (9), it is readily apparent that in $D=4$ the integral is quadratically divergent, with a sub-leading logarithmic divergent term. In fact, for large p we have

$$\int^\Lambda \frac{\mathrm{d}^D p}{(2\pi)^D}\ \frac{1}{\not{p}+\not{q}+m}\frac{1}{\not{p}+m} \sim \int^\Lambda \mathrm{d}p\ p^{D-1}\frac{1}{p^2} \sim \Lambda^{D-2}\ . \tag{11}$$

Let us introduce a trick due to Feynman for writing denominators, using

$$\frac{1}{AB} = \int_0^1 \frac{\mathrm{d}x}{[(1-x)A+xB]^2}\ . \tag{12}$$

We will now shift the integration variable with the Feynman parameter x

$$p' = p + qx. \tag{13}$$

Plugging it back into eq. (10), we obtain

$$\Pi_{\mu\nu}(q) = -(e\mu^{(4-D)/2})^2 \times$$
$$\int_0^1 \mathrm{d}x \int \frac{\mathrm{d}^D p'}{(2\pi)^D} \frac{\mathrm{Tr}[\gamma_\mu(\not{p}' + \not{q}(1-x) - m)\gamma_\nu(\not{p}' - \not{q}x - m)]}{[p'^2 + m^2 + q^2 x(1-x)]^2} \,. \tag{14}$$

By symmetry considerations, that is $p' \to -p'$, terms odd in p' do not contribute to the integral. For the trace in D dimensions of γ matrices, we have the following formulæ:

$$\mathrm{Tr}(\gamma_\mu \gamma_\nu) = -2^{D/2}\delta_{\mu\nu} \tag{15}$$

and

$$\mathrm{Tr}(\gamma_\mu\gamma_\nu\gamma_\rho\gamma_\sigma) = 2^{D/2}[\delta_{\mu\nu}\delta_{\rho\sigma} + \delta_{\mu\sigma}\delta_{\nu\rho} - \delta_{\mu\rho}\delta_{\nu\sigma}] \,. \tag{16}$$

Using these expressions, we will rewrite the trace of eq. (14) as follows

$$[p'_\rho p'_\sigma - q_\rho q_\sigma x(1-x)]\mathrm{Tr}(\gamma_\mu\gamma_\nu\gamma_\rho\gamma_\sigma) + m^2\mathrm{Tr}(\gamma_\mu\gamma_\nu) \,, \tag{17}$$

remembering that the trace of an odd number of gamma matrices is zero.

Using eqs. (15) and (16), we arrive at the following expression

$$2^{D/2}\{2p'_\mu p'_\nu - 2x(1-x)(q_\mu q_\nu - \delta_{\mu\nu}q^2) - \delta_{\mu\nu}[(p'^2 + m^2 + q^2x(1-x)]\} \,, \tag{18}$$

after having added and subtracted $\delta_{\mu\nu}q^2x(1-x)$. We end up with the following integral, after dropping the prime for simplicity

$$\Pi_{\mu\nu}(q) =$$
$$-(e\mu^{(4-D)/2})^2 2^{D/2} \int_0^1 \mathrm{d}x \int \frac{\mathrm{d}^D p}{(2\pi)^D} \left\{ \frac{2p_\mu p_\nu}{[p^2 + m^2 + q^2x(1-x)]^2} - \right.$$
$$\left. \frac{2\delta_{\mu\nu}}{[p^2 + m^2 + q^2x(1-x)]} - \frac{2x(1-x)[q_\mu q_\nu - \delta_{\mu\nu}q^2]}{[p^2 + m^2 + q^2x(1-x)]^2} \right\} \,. \tag{19}$$

Integrating over the loop with the aid of eqs. (67) and (69) shows that the first two terms cancel out. Defining $\varepsilon = (4-D)/2$, the integral reads

$$\Pi_{\mu\nu}(q) = \frac{e^2}{2\pi^2}\Gamma(\varepsilon)(q_\mu q_\nu - \delta_{\mu\nu}q^2)\int_0^1 \mathrm{d}x\; x(1-x)\left[\frac{m^2+q^2x(1-x)}{2\pi\mu^2}\right]^{-\varepsilon} . \tag{20}$$

As D approaches 4, we can expand eq. (20) in powers of ε. Noticing that a small power is indistinguishable from a logarithm, namely,

$$x^{-\varepsilon} = 1 - \varepsilon\log(x) + \mathcal{O}(\varepsilon^2) \tag{21}$$

and using the properties of the Gamma function illustrated in the appendix , we can see that eq. (20) becomes

$$\Pi_{\mu\nu}(q) = \frac{e^2}{2\pi^2}(q_\mu q_\nu - \delta_{\mu\nu}q^2)\left\{\frac{1}{6\varepsilon} - \frac{1}{6}\gamma - \right.$$
$$\left.\int_0^1 \mathrm{d}x\; x(1-x)\log\left[\frac{m^2+q^2x(1-x)}{2\pi\mu^2}\right]\right\} + \mathcal{O}(\varepsilon) , \tag{22}$$

where we have used the result of

$$\int_0^1 \mathrm{d}x\; x(1-x) = \frac{1}{6} . \tag{23}$$

Properties of vacuum polarisation

A few remarks on formula (22) are in order. First of all, we have actually checked out that thanks to dimensional regularisation and because of the Gamma function properties of its singularities, the loop integral has only a divergence given by a simple pole for $D \to 4$, all other terms being finite. The technique used when D approaches 4 is known by the name *"epsilon expansion"* (Wilson and Kogut, 1974), very often employed in Statistical Mechanics as well.

If just the finite part is considered, eq. (22) could be rewritten as

$$\Pi_{\mu\nu}(q) = (q_\mu q_\nu - \delta_{\mu\nu}q^2)\pi(q^2) \tag{24}$$

where at one-loop order $\pi(q^2)$ is given by

$$\pi(q^2) = -\frac{e^2}{2\pi^2}\int_0^1 \mathrm{d}x\; x(1-x)\log\left[\frac{m^2+q^2x(1-x)}{2\pi\mu^2}\right] . \tag{25}$$

The form of eq. (24) shows that vacuum polarisation $\Pi_{\mu\nu}(q^2)$ obtained is also a Lorentz invariant as it should be, since all its parts are Lorentz

invariant. It can be shown that this statement holds true to any order of perturbation theory. It also obeys to the equation

$$q^{\mu}\Pi_{\mu\nu}(q^2) = 0 \tag{26}$$

known as Ward–Takahashi identity (Ward, 1950), (Takahashi, 1957). In QED, this means that non–transverse photon polarisation can be consistently ignored: a photon cannot acquire mass.

Observe also that vacuum polarisation depends upon a mass parameter μ, that is an energy scale.

Fermion propagator

Continue now to the computation to the correction of the fermion line shown in Fig. 2

Figure 2 – Fermion propagator diagram
Рис. 2 − Диаграмма пропагатора фермионов
Слика 2 – Дијаграм пропагатора фермиона

This diagram is usually denoted by $\Sigma(p)$. As for the vacuum polarisation graph, we will proceed with dimensional regularisation in Euclidean space, for which

$$\Sigma(p) = -(e\mu^{(4-D)/2})^2 \int \frac{\mathrm{d}^D k}{(2\pi)^D}\, \gamma_\mu \frac{(-i)}{\not p - \not k + m} \gamma_\nu \frac{\delta_{\mu\nu}}{k^2}\ . \tag{27}$$

For Euclidean space, the Clifford algebra of gamma matrices has the form

$$\{\gamma_\mu, \gamma_\nu\} = -2\delta_{\mu\nu}\ , \tag{28}$$

and rewrite the fermion propagator as

$$\frac{(-i)}{\not p + m} = i\frac{\not p - m}{p^2 + m^2}\ . \tag{29}$$

Introducing the Feynman parameter integration as seen before , we have

$$\Sigma(p) = -i(e\mu^{(4-D)/2})^2 \times$$
$$\int_0^1 \mathrm{d}x \int \frac{\mathrm{d}^D k}{(2\pi)^D} \frac{\gamma_\mu(\not{p} - \not{k} - m)\gamma_\mu}{[k^2(1-x) + (p-k)^2 x + m^2 x]^2} . \tag{30}$$

Shift the integration variable as

$$k' = k - px \tag{31}$$

and plug it back into (30) obtaining

$$\Sigma(p) = -ie^2\mu^{4-D} \int_0^1 \mathrm{d}x \int \frac{\mathrm{d}^D k'}{(2\pi)^D} \frac{\gamma_\mu(\not{p}(1-x) - \not{k}' - m)\gamma_\mu}{[k'^2 + m^2 x + p^2 x(1-x)]^2} . \tag{32}$$

Because of symmetry, the terms linear in k' vanish. The remaining terms give

$$\Sigma(p) = -ie^2\mu^{4-D} \times$$
$$\int_0^1 \mathrm{d}x \, \gamma_\mu[\not{p}(1-x) - m]\gamma_\mu \frac{\Gamma\left(\frac{4-D}{2}\right)}{(4\pi)^{D/2}} [p^2 x(1-x) + m^2 x]^{(D-4)/2} \tag{33}$$

because of eq. (67).

Before expanding in $\varepsilon = (4-D)/2$, we have to make use of gamma matrices relations

$$\gamma_\mu\gamma_\mu = -D \tag{34}$$

and

$$\gamma_\mu\gamma_\rho\gamma_\mu = (2 - (4-D))\gamma_\rho . \tag{35}$$

In terms of ε, eq. (33) becomes

$$\Sigma(p) = -2i\frac{e^2}{16\pi^2}\Gamma(\varepsilon) \int_0^1 \mathrm{d}x \left[\frac{p^2 x(1-x) + m^2 x}{4\pi\mu^2}\right]^{-\varepsilon} \times$$
$$[\not{p}(1-x) + 2m - \varepsilon(\not{p}(1-x) + m)] . \tag{36}$$

Expanding around $\varepsilon = 0$ furnishes us with the result

$$\Sigma(p) = \frac{-i}{\varepsilon}\frac{e^2}{16\pi^2}(\not{p} + 4m) + i\frac{e^2}{8\pi^2}\left[\frac{1}{2}\not{p}(1+\gamma) + m(1+2\gamma) + \right.$$
$$\left. \int_0^1 \mathrm{d}x \, [\not{p}(1-x) + 2m] \log\left(\frac{p^2 x(1-x) + m^2 x}{4\pi\mu^2}\right)\right] + \mathcal{O}(\varepsilon) . \tag{37}$$

Vertex correction

Last one–loop QED correction is the vertex correction shown in Fig. 3.

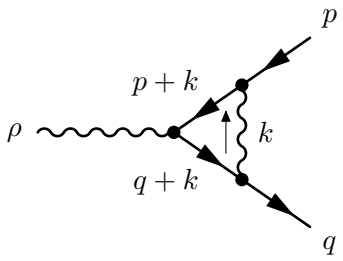


Figure 3 – Vertex correction diagram
Рис. 3 − Диаграмма коррекции вершин
Слика 3 – Дијаграм корекције вертекса

$$\Gamma_\rho(p,q) = -i(e\mu^{(4-D)/2})^3 \times$$
$$\int \frac{\mathrm{d}^D k}{(2\pi)^D}\, \gamma_\mu \frac{1}{\not{p}+\not{k}+m}\gamma_\rho \frac{1}{\not{q}+\not{k}+m}\gamma_\nu \frac{\delta_{\mu\nu}}{k^2}\,. \tag{38}$$

This time, unlike in the previous cases, we have to deal with three propagators inside the loop, so this case is more complicated. It is necessary to introduce two Feynman parameters, x and y, make use of the relation

$$\frac{1}{ABC} = 2\int_0^1 \mathrm{d}x \int_0^{1-x} \mathrm{d}y\, \frac{1}{[Ay + B(x-y) + C(1-x)]^3} \tag{39}$$

and rewrite eq. (38) as

$$\Gamma_\rho(p,q) = -2i(e\mu^{(4-D)/2})^3 \int_0^1 \mathrm{d}x \int_0^{1-x} \mathrm{d}y \int \frac{\mathrm{d}^D k}{(2\pi)^D}$$
$$\frac{\gamma_\nu(\not{p}+\not{k}-m)\gamma_\rho(\not{q}+\not{k}-m)\gamma_\nu}{[k^2 + m^2(x+y) + 2k\cdot(px+qy) + p^2 x + q^2 y]^3}\,. \tag{40}$$

Shifting the integration variable as follows

$$k' = k + px + qy \tag{41}$$

and plugging it back in the integral, eq. (40) becomes

$$\Gamma_\rho(p,q) = -2i(e\mu^{(4-D)/2})^3 \int_0^1 \mathrm{d}x \int_0^{1-x} \mathrm{d}y \int \frac{\mathrm{d}^D k}{(2\pi)^D}$$

$$\frac{\gamma_\nu(\not{k}-\not{q}y+\not{p}(1-x)-m)\gamma_\rho(\not{k}-\not{p}x+\not{q}(1-y)-m)\gamma_\nu}{[k^2+m^2(x+y)+p^2x(1-x)+q^2y(1-y)-2p\cdot qxy]^3}\,. \tag{42}$$

By inspection of eq. (42), the denominator goes like $1/k^6$ for large k and the numerator as k^2, thus (42) behaves like

$$\int^\Lambda \frac{\mathrm{d}^D k}{(2\pi)^D}\,\frac{k^2}{k^6}\sim\Lambda^{D-4}\,, \tag{43}$$

and in $D\to 4$ only the piece quadratic in k is problematic. Writing

$$\Gamma_\rho(p,q)=\Gamma^{(1)}_\rho(p,q)+\Gamma^{(2)}_\rho(p,q) \tag{44}$$

where $\Gamma^{(1)}_\rho(p,q)$ contains only the quadratic part in k, we find using eq. (67)

$$\Gamma_\rho(p,q)=-i\frac{(e\mu^{(4-D)/2})^3}{2(4\pi)^{D/2}}\Gamma\left(\frac{4-D}{2}\right)\int_0^1\mathrm{d}x\int_0^{1-x}\mathrm{d}y \\ \frac{\gamma_\nu\gamma_\sigma\gamma_\rho\gamma_\sigma\gamma_\nu}{[m^2(x+y)+p^2x(1-x)+q^2y(1-y)-2p\cdot qxy]^{(4-D)/2}} \tag{45}$$

for the divergent part and for the convergent part using eq. (69)

$$\Gamma_\rho(p,q)=-i\frac{(e\mu^{(6-D)/2})^3}{2(4\pi)^{D/2}}\Gamma\left(\frac{6-D}{2}\right)\int_0^1\mathrm{d}x\int_0^{1-x}\mathrm{d}y \\ \frac{\gamma_\nu[\not{p}(1-x)-\not{q}y-m]\gamma_\rho[\not{q}(1-y)-\not{p}x-m]\gamma_\nu}{[m^2(x+y)+p^2x(1-x)+q^2y(1-y)-2p\cdot qxy]^{(6-D)/2}}\,. \tag{46}$$

As eq. (46) is convergent, we are allowed to put directly $D=4$ obtaining

$$\Gamma_\rho(p,q)=-i((e\mu^{(6-D)/2})^3)\frac{e^2}{16\pi^2}\int_0^1\mathrm{d}x\int_0^{1-x}\mathrm{d}y \\ \frac{\gamma_\nu[\not{p}(1-x)-\not{q}y-m]\gamma_\rho[\not{q}(1-y)-\not{p}x-m]\gamma_\nu}{[m^2(x+y)+p^2x(1-x)+q^2y(1-y)-2p\cdot qxy]}\,. \tag{47}$$

For the divergent part, using the identity

$$\gamma_\sigma\gamma_\mu\gamma_\rho\gamma_\nu\gamma_\sigma=2\gamma_\nu\gamma_\rho\gamma_\mu-(D-4)\gamma_\mu\gamma_\rho\gamma_\nu \tag{48}$$

together with eq. (35) allows us to rewrite eq. (45) in the form

$$\Gamma_\rho(p,q)=-ie\mu^\varepsilon\gamma_\rho\frac{e^2}{8\pi^2}\Gamma(\varepsilon)(1-\varepsilon)^2\int_0^1\mathrm{d}x\int_0^{1-x}\mathrm{d}y$$

$$\left[\frac{m^2(x+y)+p^2x(1-x)+q^2y(1-y)-2p\cdot qxy}{4\pi\mu^2}\right]^{-\varepsilon}\ , \tag{49}$$

that is

$$\Gamma_\rho(p,q) = -ie\mu^\varepsilon\gamma_\rho\frac{e^2}{16\pi^2}\left\{\frac{1}{\varepsilon}-\gamma-1-2\int_0^1 \mathrm{d}x\int_0^{1-x}\mathrm{d}y\right.$$
$$\left.\log\left[\frac{m^2(x+y)+p^2x(1-x)+q^2y(1-y)-2p\cdot qxy}{4\pi\mu^2}\right]\right\}\ . \tag{50}$$

Other one–loop diagrams

At the one-loop level for QED, we have to consider also diagrams with an internal fermionic loop and an odd number of external photons, as shown in Figs. 4 and 5, and one with four external photons as in Fig. 6.

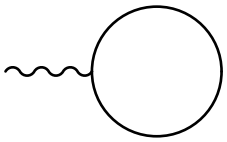


Figure 4 – One external photon
Рис. 4 − Один внешний фотон
Слика 4 – Један спољашњи фотон

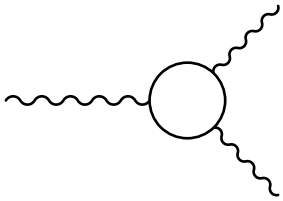


Figure 5 – Three external photons
Рис. 5 − Три внешних фотона
Слика 5 – Три спољашња фотона

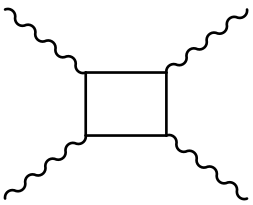


Figure 6 – Feynman diagram for photon scattering
Рис. 6 − Диаграмма Фейнмана для рассеяния фотонов
Слика 6 – Фејнманов дијаграм расејања фотона

Fermion loops with an odd number of external photon lines vanish because of symmetry reasons. Consider such a diagram G_n with n points

that can be written as

$$G_n = \mathrm{Tr}[\gamma_{\mu(1)} S_F(x_1, x_n)\gamma_{\mu(n)} S_F(x_n, x_{n-1})\gamma_{\mu(n-1)} \dots \gamma_{\mu(2)} S_F(x_2, x_1)] \quad (51)$$

where $S_F(x_i, x_j)$ is the fermion propagator that connects points x_i and x_j, where photon lines insert. From gamma matrices algebra, we recall the existence of a matrix $C = i\gamma^2\gamma^0$ such that transposes each gamma matrix:

$$C\gamma_\mu C^{-1} = -\gamma_\mu^T \, . \quad (52)$$

Therefore, this relation holds true for the fermionic propagator as well

$$CS_F(x, y)C^{-1} = S_F(y, x)^T \, , \quad (53)$$

where the inversion of coordinates in the propagator should be noticed. Insert now the term CC^{-1} between the propagators in eq. (51) and rewrite

$$\begin{gathered} G_n = (-1)^n \mathrm{Tr}[\gamma_{\mu(1)}^T S_F^T(x_n, x_1)\gamma_{\mu(n)}^T S_F^T(x_{n-1}, x_n)\gamma_{\mu(n-1)}^T \dots \\ \gamma_{\mu(2)}^T S_F^T(x_1, x_2)] = \\ (-1)^n \mathrm{Tr}[\gamma_{\mu(1)} S_F(x_1, x_n)\gamma_{\mu(n)} S_F(x_n, x_{n-1})\gamma_{\mu(n-1)} \dots \\ \gamma_{\mu(2)} S_F(x_2, x_1)] \, . \end{gathered} \quad (54)$$

For odd n, therefore, $G_n = -G_n$ so it implies $G_n = 0$. This proves the statement, known as Furry's theorem (Furry, 1937).

About the box diagram with four external photons depicted in Fig. 6, often referred to as a light–light scattering diagram, the internal loop is made out of four fermions; therefore, for $D = 4$, it is expected to diverge like

$$\int^\Lambda \mathrm{d}^4 p \, \frac{1}{\not{p}^4} \sim \log \Lambda \, . \quad (55)$$

Luckily, this diagram is actually convergent after an explicit calculation.

Suppose that the box diagram was actually divergent. This would mean that we are faced with new interactions among four photons, $A_\mu A_\nu A_\rho A_\sigma$, not present in the original Lagrangian (5). Because of gauge invariance, this new term should be proportional to $(F_{\mu\nu})^4$, implying a kinetic term with more than two derivatives, possibly spoiling causality.

Appendix

Gaussian and Feynman integrals

$$\int_{-\infty}^{+\infty} \mathrm{d}x\ e^{-ax^2} = \sqrt{\frac{\pi}{a}} \tag{56}$$

$$\int_{-\infty}^{+\infty} \mathrm{d}x\ e^{-ax^2+bx} = \sqrt{\frac{\pi}{a}}\, e^{\frac{b^2}{4a}} \tag{57}$$

Momenta:

$$\int_{-\infty}^{+\infty} \mathrm{d}x\ x^{2n} e^{-ax^2} =$$

$$\left(\frac{d}{db}\right)^{2n} \int_{-\infty}^{+\infty} \mathrm{d}x\ e^{-ax^2+bx}\bigg|_{b=0} = \sqrt{\frac{\pi}{a}}\,\frac{1}{a^n}\,(2n-1)!! \tag{58}$$

odd momenta are zero by symmetry.

In Euclidean D dimensions, we have:

$$\int \mathrm{d}^D x\ \exp(-\alpha x^2 + \beta\cdot x) = \left(\frac{\pi}{\alpha}\right)^{D/2} \exp\left(\frac{\beta^2}{4\alpha}\right)\ . \tag{59}$$

For the operators A and J, where $\mathbf{x}\cdot A\cdot\mathbf{x} = x_i A_{ij} x_j$ and $J\cdot\mathbf{x} = J_{ij}x_j$, with repeated indices summed over:

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\cdots\int_{-\infty}^{\infty}\prod_{i=1}^{N}\mathrm{d}x_i\ e^{-\frac{1}{2}\mathbf{x}\cdot A\cdot\mathbf{x}+J\cdot\mathbf{x}} = \left[\frac{(2\pi)^N}{\det(A)}\right]^{\frac{1}{2}} e^{\frac{1}{2}J\cdot A^{-1}\cdot J}\ . \tag{60}$$

An almost trivial yet very useful expression is the following:

$$\frac{1}{A^n} = \frac{1}{\Gamma(n)}\int_0^{+\infty}\mathrm{d}\alpha\ \alpha^{n-1}\exp(-\alpha A) \tag{61}$$

that allows us to combine propagators and Gaussian integrals.

Applying eqs. (59) and (61) to the propagators written in Euclidean space (i.e. $k^2 = k_0^2 + \mathbf{k}^2$), one obtains:

$$\frac{1}{k^2+m^2} = \int_0^{+\infty}\mathrm{d}\alpha\ \exp[-\alpha(k^2+m^2)] \tag{62}$$

$$\int \mathrm{d}^D k\ \frac{1}{(k^2+m^2)} = \int_0^{+\infty}\mathrm{d}\alpha\ \int \mathrm{d}^D k\ \exp[-\alpha(k^2+m^2)] =$$

$$\pi^{D/2}\int_0^{+\infty}\mathrm{d}\alpha\;\alpha^{-D/2}\exp(-\alpha m^2)=\pi^{D/2}\Gamma\left(1-\frac{D}{2}\right)m^{(D-2)} \tag{63}$$

$$\int\mathrm{d}^Dk\;\frac{1}{(k^2+m^2)^2}=$$
$$\pi^{D/2}\int_0^{+\infty}\mathrm{d}\alpha\;\alpha^{-D/2-1}\exp(-\alpha m^2)=\pi^{D/2}\Gamma\left(2-\frac{D}{2}\right)m^{(D-4)} \tag{64}$$

$$\int\mathrm{d}^Dk\;\frac{1}{(k^2+m^2)^3}=\frac{1}{2}\pi^{D/2}\Gamma\left(3-\frac{D}{2}\right)m^{(D-6)}\;. \tag{65}$$

By induction, one obtains the formula for a generic power of a propagator:

$$\int\mathrm{d}^Dk\;\frac{1}{(k^2+m^2)^n}=\pi^{D/2}\frac{\Gamma\left(n-\frac{D}{2}\right)}{\Gamma(n)}m^{(D-2n)}\;. \tag{66}$$

Let us now shift the integration variable $k=k'+p$ and insert it back into eq. (66), obtaining

$$\int\mathrm{d}^Dk\;\frac{1}{(k^2+2p\cdot k+(m^2+p^2))^n}=\pi^{D/2}\frac{\Gamma\left(n-\frac{D}{2}\right)}{\Gamma(n)}m^{(D-2n)}\;. \tag{67}$$

By repeated differentation of eq. (67) $\partial/\partial p_\mu$ we obtain the expressions

$$\int\mathrm{d}^Dk\;\frac{k_\mu}{(k^2+2p\cdot k+(m^2+p^2))^n}=\pi^{D/2}\frac{\Gamma\left(n-\frac{D}{2}\right)}{\Gamma(n)}m^{(D-2n)}(-p_\mu)\;. \tag{68}$$

and

$$\int\mathrm{d}^Dk\;\frac{k_\mu k_\nu}{(k^2+2p\cdot k+(m^2+p^2))^n}=$$
$$\frac{\pi^{D/2}}{\Gamma(n)}m^{(D-2n)}\left[\Gamma\left(n-\frac{D}{2}\right)p_\mu p_\nu+\frac{1}{2}\delta_{\mu\nu}\Gamma\left(n-1-\frac{D}{2}\right)m^2\right] \tag{69}$$

Riemann's Gamma function

Riemann's Gamma function is defined by the integral

$$\Gamma(z) = \int_0^\infty \mathrm{d}t\; t^{z-1} e^{-t}\;, \tag{70}$$

for $\Re(z) > 0$, which satisfies the recursive relation $\Gamma(z+1) = z\Gamma(z)$, thus having the property that for integer values $\Gamma(n) = (n-1)!$ since $\Gamma(1) = 1$.

Originally, the function was defined by Weierstrass as an infinite product by the relation

$$\frac{1}{\Gamma(z)} = z e^{\gamma z} \prod_{n=1}^{\infty} \left[\left(1 + \frac{z}{n}\right) e^{-\frac{z}{n}} \right] \tag{71}$$

γ being the Euler–Mascheroni's constant, $\gamma \approx 0.57721$. From (71), it is readily apparent that $\Gamma(z)$ is analytic except for negative integers $z = 0, -1, -2, \ldots$ where it has simple poles. It is also possible to obtain the reflection formula

$$\Gamma(z)\Gamma(1-z) = \frac{\pi}{\sin \pi z} \tag{72}$$

that allows us to obtain the value $\left\{\Gamma(\frac{1}{2})\right\}^2 = \pi$. Defining the function $\psi(z)$ (or digamma) as the logarithmic derivative of $\Gamma(z)$, i.e.

$$\psi(z) = \frac{\Gamma(z)'}{\Gamma(z)} \tag{73}$$

from the reflection formula it has the property that $\psi(1-z) - \psi(z) = \pi \cot \pi z$.

Subsequent derivatives are defined by the functions

$$\psi^{(n)}(z) = \left(\frac{d}{dz}\right)^{(n+1)} \log(\Gamma(z)) \tag{74}$$

that allows us to express the Gamma function near the simple poles $z = -n$:

$$\Gamma(z) = \frac{(-1)^n}{n!(z+n)} + \frac{(-1)^n \psi(n+1)}{n!} + \mathcal{O}(z+n) \tag{75}$$

For integers n

$$\psi(n+1) = -\gamma + \sum_{k=1}^{n} \frac{1}{k} = -\gamma + H_n \tag{76}$$

where H_n is a harmonic number, defined as seen above from the sum of the reciprocal of integers, having the property that $H_n \sim \log n + \gamma + 1/(2n) + \mathcal{O}(1/n^2)$ for large n.

Another relevant formula related to the Gamma function is the asymptotic expansion, known as Stirling's series:

$$\Gamma(z+1) = \sqrt{2\pi z}\left(\frac{z}{e}\right)^z \left[1 + \frac{1}{12z} + \frac{1}{288z^2} - \frac{139}{51840z^3} - \frac{571}{2488320z^4} + \mathcal{O}\left(\frac{1}{z^5}\right)\right] \tag{77}$$

that can be computed from a saddle approximation of the Gamma function.

References

Bethe, H.A. 1947. The Electromagnetic Shift of Energy Levels. *Physical Review*, 72(4), pp.339-341. Available at: https://doi.org/10.1103/PhysRev.72.339.

Bollini, C.G. & Giambiagi, J.J. 1972. Dimensional Renormalization: The Number of Dimensions as a Regularizing Parameter. *Il Nuovo Cimento B*, 12(1), pp.20-26. Available at: https://doi.org/10.1007/BF02895558.

Dirac, P.A.M. 1927. The Quantum Theory of the Emission and Absorption of Radiation. *Proceedings of the Royal Society of London A*, 114(767), pp.243-65. Available at: https://doi.org/10.1098/rspa.1927.0039.

Dirac, P.A.M. 1934. Discussion of the infinite distribution of electrons in the theory of the positron. *Mathematical Proceedings of the Cambridge Philosophical Society*, 30(2), pp.150-163. Available at: https://doi.org/10.1017/S03050041000 1656X.

Dyson, F.J. 1949. The Radiation Theories of Tomonaga, Schwinger, and Feynman. *Physical Review*, 75(3), pp.486-502. Available at: https://doi.org/10.1103/Ph ysRev.75.486.

Feynman, R.P. 1949a. Space–Time Approach to Quantum Electrodynamics. *Physical Review*, 76(6), pp.769-89. Available at: https://doi.org/10.1103/PhysRe v.76.769.

Feynman, R.P. 1949b. The Theory of Positrons. *Physical Review*, 76(6), pp.749-759. Available at: https://doi.org/10.1103/PhysRev.76.749.

Furry, W.H. 1937. A Symmetry Theorem in the Positron Theory. *Physical Review*, 51(2), pp.125-129. Available at: https://doi.org/10.1103/PhysRev.51.125.

Heisenberg, W. 1934. Bemerkungen zur Diracschen Theorie des Positrons. *Zeitschrift für Physik*, 90(3-4), pp.209-231. Available at: https://doi.org/10.1007/ BF01333516 (in German).

Hooft, G.'t. & Veltman, M. 1972. Regularization and renormalization of gauge fields. *Nuclear Physics B*, 44(1), pp.189-213. Available at: https://doi.org/10.1016/ 0550-3213(72)90279-9.

Schwinger, J. 1948. On Quantum–Electrodynamics and the Magnetic Moment of the Electron. *Physical Review*, 73(4), pp.416-17. Available at: https://doi.org/10.1103/PhysRev.73.416.

Takahashi, Y. 1957. On the generalized ward identity. *Il Nuovo Cimento*, 6(2), pp.371-375. Available at: https://doi.org/10.1007/BF02832514.

Tomonaga, S. 1946. On a Relativistically Invariant Formulation of the Quantum Theory of Wave Fields. *Progress of Theoretical Physics*, 1(2), pp.27-42. Available at: https://doi.org/10.1143/PTP.1.27.

Ward, J.C. 1950. An Identity in Quantum Electrodynamics. *Physical Review*, 78(2), pp.182. Available at: https://doi.org/10.1103/PhysRev.78.182.

Wick, G.C. 1954. Properties of Bethe-Salpeter Wave Functions. *Physical Review*, 96(4), pp.1124-1134. Available at: https://doi.org/10.1103/PhysRev.96.1124.

Wilson, K.G. & Kogut, J. 1974. The renormalization group and the epsilon expansion. *Physics Reports*, 12(2), pp.75-199. Available at: https://doi.org/10.1016/0370-1573(74)90023-4.

КВАНТОВЫЕ ЭЛЕКТРОДИНАМИЧЕСКИЕ РАСХОДИМОСТИ

Никола Фабиано

Белградский университет, Институт ядерных исследований «Винча» - Национальный институт Республики Сербия, г. Белград, Республика Сербия

РУБРИКА ГРНТИ: 27.35.00 Математические модели естественных наук и технических наук. Уравнения математической физики
27.35.57 Математические модели квантовой физики
27.35.59 Методы теории возмущений
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: В данной статье обсуждается проблема расходимостей в квантовой электродинамике (QED).

Методы: В статье применялся метод ренормализационной группы в работе с бесконечностями в QED.

Результаты: Интегралы в QED, дающие физические наблюдаемые величины, конечны.

Выводы: Расхождения в QED можно рассматривать последовательным образом, обеспечивая строгие математические результаты.

Ключевые слова: квантовая электродинамика, квантовая теория поля, ренормализационная группа.

КВАНТНЕ ЕЛЕКТРОДИНАМИЧКЕ ДИВЕРГЕНЦИЈЕ

Никола Фабиано
Универзитет у Београду, Институт за нуклеарне науке „Винча“ - Национални институт Републике Србије, Београд, Република Србија

ОБЛАСТ: математика, физика
ВРСТА ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: У раду се разматра проблем дивергенција у квантној електродинамици (QED).

Методе: Метода ренормализационе групе користи се за решавање бесконачности у QED.

Резултати: Интегрални у QED који дају физичке опсервабилности јесу коначнии.

Закључак: Разлике у QED могу се третирати на доследан начин пружајући строге математичке резултате.

Кључне речи: квантна електродинамика, квантна теорија поља, ренормализациона група.

Paper received on / Дата получения работы / Датум пријема чланка: 16.01.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 18.05.2021.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 20.05.2021.

JAVA GUI APLICATION FOR COMPARING THE LEVELS OF BIOMETRIC SECURITY - FINGERPRINT VS. IRIS

Komlen G. Lalović[a], *Mitko* Z. Bogdanoski[b]

[a] Educons University, Faculty of Project and Innovation Management, Belgrade, Republic of Serbia,
e-mail: komlen.lalovic@pmc.edu.rs, **corresponding author**,
ORCID iD: http://orcid.org/0000-0002-4590-2185

[b] Military Academy "General Mihailo Apostoloski", Skopje, Republic of North Macedonia,
e-mail: mitko.bogdanoski@ugd.edu.mk,
ORCID iD: https://orcid.org/0000-0002-8098-1421

DOI: 10.5937/vojtehg69-32007; https://doi.org/10.5937/vojtehg69-32007

FIELD: IT
ARTICLE TYPE: Review paper

Abstract:

Introduction/purpose: The main purpose of this paper is to present a novel Java GUI – based software application for a comparative analysis of fingerprint and iris biometrics.

Methods: The first part of this work is realized in Java Programming language. in the GUI framework named swing while the rest of the paper shows in detail the advantages and disadvantages of both systems and gives scientific data on when fingerorint and iris recognition can be used to enable top level security. The main method here is a well known comparative analysis.

Results: The results were obtained for both fingerprint and iris biometrics, showing the difference between the two.

Conclusion: Different types of biometrics, based on body parts formed at different age, are given as well as the comparison of their security levels.

Keywords: programming, Java, GUI, biometrics, fingerprint, iris, patent.

Introduction

Java is one of the oldest object-oriented programming languages based on all OOP concepts. Its framework, or, better to say, the swing set of libraries is one of the oldest and most stable ones for creating GUI (GUI – Graphical User Interface) applications. Biometrics is a scientific discipline and technology that measures and analyzes biological

characteristics of people. It is a part of advanced security systems widely used in today's modern society and protection systems.

The highest persistence in biometrics and the lowest possibility of interrupting data are found in fingerprints and their minutiae; therefore, this work and this patent device focus on this kind of biometrics.

The main difference between fingerprints and the iris in humans is their forming period: fingerprints are formed in the prenatal period, before a baby is born, and the iris with its pigmentation is formed from year two to year four in children. This is crucial for understanding security systems that can be created and used based on these two biometrics types.

Technology overview

A well-known OOP programming language which runs on over 3.5 billion devices worldwide is Java. It is a very strong and stable programming language providing all OOP aspects of software development. In developing this application, the authors used the swing framework in Java.

All known tech devices based on fingerprint scanners use different algorithms and SDK in their scan process to determine a person's identity. Search through the national patent base of the Republic of Serbia has shown that devices with this purpose, similar to the one presented in this paper, have not been found, namely, not one of these patents deals with this idea and a solution presented here, with this dual fingerprint biometric scanner with its own lighting and battery supply. (Dahlen & Caplice, 2014), (Lalović et al, 2017), (Lalović et al, 2016b)

Today, all devices scan only one or more fingers of only **one** person; there are no fingerprint scanners that can scan fingers of two different people at the same time using only one device, which is unique to our idea. What is more, there are no devices which generate a unique reference ID while scanning is performed, and that unique ID can be connected with the record of fingerprint scanned and stored data. (Lalović et al, 2015)

If we look at the issued patent confirmation no. П-2009/0253, of International classification such as G-07-D7/12 (2008.04), a device called "Hand mobile device for checking travel and personal documents, reading biometric data and face recognition of persons which carry those documents" has been described as one function of the device that scan the finger of one person at just that moment, unlike ours. (Lalović et al, 2016b), (Moore et al, 2015), (Wing, 2014).

Discusion

One issued patent with no. confirmation 13848069.4 of April 2/2013, with remark W-O-2014059761 and classification no. G–06 F21/00 is a classic scanner named “Fingerprint Identification Device”, described as a device which has a scanning function and provides all data about the fingerprint of a person (extractor for fingerprint *minutiae*[1]). (Lalović et al, 2019), (Jain et al, 2008)

Our device has two separate fields for simultaneous scanning of fingers from two different persons, which, at the same time, generates a unique constant ID reference with an additional guarantee of a person's identity and provides a guarantee of the motherhood for every newborn baby in maternity wards. (Lalović et al, 2016a), (Maček et al, 2015)

Java GUI application

It is well known that Java is one of the oldest and most stable object-oriented programming languages established around 1995, with strong OOP principles when creating all kinds of applications. A good knowledge of this language prompted us to create a GUI application in Java swing framework (set of libraries) in order to provide a quality overview in real time. As far as the design is concerned, the GUI app builder in *NetBeans* IDE 8.2 was used while for the source code we overrode methods OnClick in JButton object, showing the result set in two panels at a same time. For the main frame, we used JFrame Java class and its methods on the object created with the next source code and the constructor class method:

JFrame mainWindow = new JFrame(“Main Window”);

A Java swing GUI is an older and stable Java framework for designing and developing good graphical applications based on classes and top level containers such as JFrame and its methods.

Figure 1 shows a GUI builder in NetBeans 8.2 version for the development of a Java GUI application. (Lalović, 2020)

[1] Minutiae – fingerprint specific points visible on a finger image

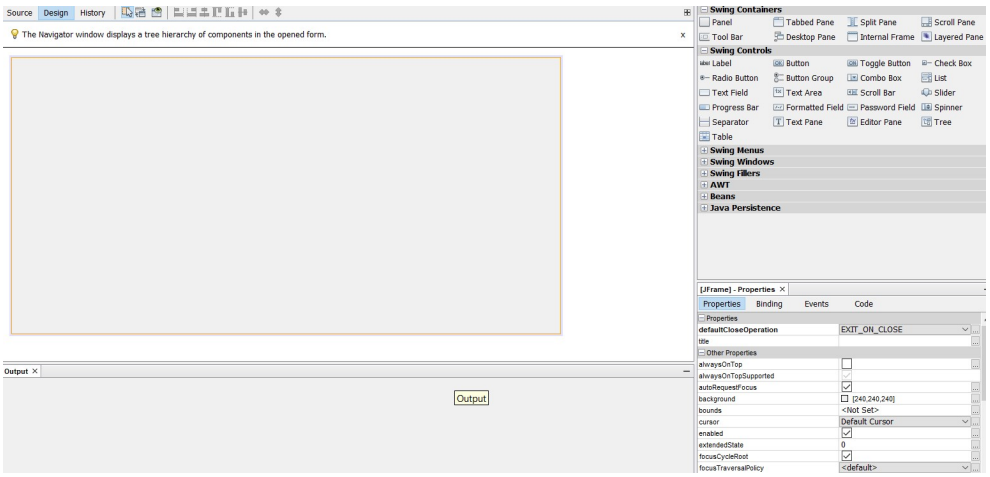


Figure 1 – GUI Builder NetBeans 8.2 IDE
Рис. 1 – Графическое окружение для развития приложения NetBeans 8.2 IDE
Слика 1 – Графичко окружење за развој апликација NetBeans 8.2 IDE

Essence of two biometrics

A scientific fact in biometrics, used as a part of advanced security systems such as informatics and computers, is that fingerprints are formed during the prenatal period of every newborn baby, i.e. during the fetal period, and they remain constant in the same shape of minutiae during the whole life of a person. (Lalović et al, 2019), (Jain et al, 2008), (Lalović et al, 2016a)

Many research studies discuss fingerprints of the fetus and ultra-wave and biometrics scans show that the minutiae on every finger are formed until the end of 7th month of pregnancy, prenatally. This important fact is needed to be mention here, since babies born before their regular time of birth, during 8th, and especially by the end of 7th month of pregnancy, already have fingerprints formed on every finger and toe. (Lalović et al, 2019)

This information is essential because the fingerprint minutiae (ridges and valleys) are the only biometrics formed prenatally and can be used for the purpose of guaranteeing identity. The idea of this patent and innovation is based on this very scientific fact confirmed by both biometrics and gynecology, i.e. midwifery as a branch of healthcare protection system. (Lalović et al, 2016a), (Maček et al, 2015), (Lalović, 2018)

Other types of biometry such as iris recognition are not reliable in this, period at the moment of birth, because until the age of four the pigmentation in the child's eye is changeable and can become very different. Thus, since both the shape and the color change, this makes it impossible to be used for this purpose and for this idea.

Also, the head, the hand, and the body shape and size rapidly change since they normally grow, so it is obvious why they cannot be used here. The scientific fact is that the fetus fingerprint is formed prenatally, by the end of 7^{th} month in the uterus of a pregnant woman and stays constant with the same construction and shape of minutiae. (Lalović et al, 2019)

There are a large number of various fears during the birth process, both of mothers and also of people in medical health care systems in maternity wards. A study done in Australia and New Zealand from 2009 to 2011 based on 17 workshops with the participation of over 700 midwives shows that this device can now dispel one of the biggest fears - dealing with unknown. (Dahlen & Caplice, 2014)

Data is gathered during the process of fingerprint scans of a mother and her baby, with an ID unique reference that is also encrypted and stored at the device, its memory or at the server in an encrypted form. The device is not to be left opened or available to unauthorized personnel, but only to authorized nurses, doctors, and midwives who have contact with the device in maternity wards.

After the process of scanning, motherhood is confirmed for each mother – baby pair by the authorized person - representative of a maternity ward and the mother who enter PIN2 code that only they have for the data. (Jain et al, 2008), (Lalović et al, 2017)

A change of the stored data is disabled and the identity of each newborn baby is guaranteed 100% in practical terms and there is no possibility of making a human mistake during the process thanks to the device.

It is possible to check any mother-baby pair in maternity wards worldwide, at any time.

The Information stored on the device or the server with a backup copy is always in a completely encrypted form and there is no possibility of corrupting the data. A possibility of archiving data is enabled only after the confirmation of the mother that everything has been done right and after this mother – baby pair has left the hospital. That is the moment

[2] PIN – Personal Identification Number - code

when proving the guarantee of motherhood is no longer necessary in a hospital. (Dahlen & Caplice, 2014)

It is very important to prevent any possible theft of baby's identity or babies getting switched at birth, which has unfortunately probably happened at some places and parts of the whole world, including the Balkans. At the moment when it is implemented, the device will guarantee, prove, and serve as evidence of motherhood for every newborn baby.

The application itself of the device is universal, on every continent and in every country; there are no restrictions on the use of it. It requires only basic IT equipment for implementation, such as a PC, a server and this patent device which is a dual-biometric fingerprint scanner. The device will be affordable to be installed in every maternity ward in any health care system in any country in the world.

Research

Figure 2 shows a fingerprint of a human finger with all minutiae on it.

As it can be seen clearly, ridges and valleys are scanned on one of the existing fingerprint scanners. There are various scanners such as: optical, capacitive, thermal, pressure, etc. All of them possess advantages and disadvantages, depending on the purpose and the fingers scanned. (Tot et al, 2021)

Figure 2 – Fingerprint minutiae (Anthony, 2019)
Рис. 2 – Детали отпечатка пальца (Anthony, 2019)
Слика 2 – Минуције отиска прста (Anthony, 2019)

The main difference between these two kinds of biometrics is that fingerprints are formed in the prenatal period and can be acquired at the very moment of birth, while the iris is formed between the second and the fourth year in children, at the early period of childhood, because iris pigmentation is then formed, so iris biometrics can be acquired subsequently, from the age of five.

Figure 3 – Iris recognition in biometrics (Burt, 2020)
Рис. 3 – Биометрическое распознавание по радужной оболочке глаза (Burt, 2020)
Слика 3 – Ирис препознавање у биометрији (Burt, 2020)

It can be seen that both systems provide a high level of protection, depending on the purpose and the age of humans.

Further development

Both of these biometric types, iris and fingerprint recognition, have a big potential in the future. They are part on many known security systems being used today. At the moment, we can say that it will be a future of security systems and biometry development. Each of them has both advantages and disadvantages and Java programming language can be used for many possible applications.

Conclusion

It is well known in research circles that the main purpose, besides identity guarantee and nonrepudiation, each biometrics is eager to provide is minimization of FAR[3] and also of FRR[4] in order to become more accurate and secure. Our results with this device and GUI app are also within this mainstream.

The main difference here is that fingerprints are formed at a moment of birth and the iris is formed after the age of four.

Also, each biometric system has a large potential of making good security systems, which is possible and existing nowadays. We can freely say, now for sure, that fingerprint and iris recognition will be the future of security systems and biometrics development. Java as OOP programming language can be used for each application for biometric measurements either of the iris or the fingerprint, creating good user experience at the same time.

References

Anthony, A. 2019. *8+ Biometrics APIs At Your Fingertips* [online]. https://nordicapis.com/8-biometrics-apis-at-your-fingertips/ [Accessed: 20 February 2021].

Burt, C. 2020. *New terminal brings contactless iris biometrics to UnionCommunity's UBio line* [online]. Available at: https://www.biometricupdate.com/202005/new-terminal-brings-contactless-iris-biometrics-to-unioncommunitys-ubio-line [Accessed: 20 February 2021].

Dahlen, H.G. & Caplice, S. 2014. What do midwives fear? *Women and Birth,* 27(4), pp.266-270. Available at: https://doi.org/10.1016/j.wombi.2014.06.008.

Jain, A.K., Flynn, P. & Ross, A.A. 2008. *Handbook of Biometrics.* Boston, MA: Springer. Available at: https://doi.org/10.1007/978-0-387-71041-9. ISBN: 978-0-387-71041-9.

Lalović, K. 2018. Patent overview: Device for fingerprint identity guarantee. *Vojnotehnički* glasnik/Military Technical Courier, 66(2), pp.366-379. Available at: https://doi.org/10.5937/vojtehg66-15868.

Lalović, K. 2020. *Osnove Java programiranja*. Belgrade: Golden Mind (in Serbian). ISBN: 978-86-902148-0-8.

[3] FAR – False Accept Rate
[4] FRR – False Reject Rate

Lalović, K., Anđelić, S. & Tot, I. 2017. How to guarantee baby identity based on fingerprint biometry. In: *The Ninth International Conference on Business Information Security (BISEC-2017)*, Belgrade, pp.1-4, October 18 [online]. Available at: http://bisec.rs/files/2017/16-k-lalovic-s-andjelic-i-tot-bisec-2017.pdf [Accessed: 20 February 2021].

Lalović, K., Maček, N., Milosavljević, M., Veinović, M., Franc, I., Lalović, J. & Tot, I. 2016a. Biometric Verification of Maternity and Identity Switch Prevention in Maternity Wards. *Acta Polytechnica Hungarica*, 13(5), pp.65-81. Available at: https://doi.org/10.12700/APH.13.5.2016.5.4.

Lalović, K., Milosavljević, M., Tot, I. & Maček, N. 2015. Device for biometric verification of maternity. *Serbian Journal of Electrical Engineering*, 12(3), pp. 293-302. Available at: https://doi.org/10.2298/SJEE1503293L.

Lalović, K., Nikolić, J., Tot, I. & Lalović, Ž. 2016b. Software algorithm of device for biometric identification of parenthood. In: *The Eighth International Conference on Business Information Security (BISEC-2016)*, Belgrade, pp.66-71, October 15 [online]. Available at: https://www.metropolitan.ac.rs/files/2016/10/BISEC2016_Conference-Proceedings.pdf#page=67 [Accessed: 20 February 2021].

Lalović, K., Tot, I., Arsić, A. & Škarić, M. 2019. Security Information System, Based on Fingerprint Biometrics. *Acta Polytechnica Hungarica*, 16(5), pp.87-100. Available at: https://doi.org/10.12700/APH.16.5.2019.5.6.

Maček, N., Đorđević, B., Gavrilović, J. & Lalović, K. 2015. An Approach to Robust Biometric Key Generation System Design. *Acta Polytechnica Hungarica*, 12(8), pp.43-60. Available at: https://doi.org/10.12700/APH.12.8.2015.8.3.

Moore, K., Persaud, T.V.N. & Torchia, M. 2015. *Before We Are Born, 9th Editio*n. Philadelphia, PA: Saunders. ISBN: 9780323313445.

Tot, I., Trikoš, M., Bajčetić, J., Lalović, K. & Bogićević, D. 2021. Software Platform for Learning about Brain Wave Acquisition and Analysis. *Acta Polytechnica Hungarica*, 18(3), pp.147-162. Available at: https://doi.org/10.12700/APH.18.3.2021.3.8.

Wing, B. 2014. NIST publishes compression guidance for fingerprint. *IT Professional*, 16(2), pp.38-44. Available at: https://doi.org/10.1109/MITP.2013.89.

ПРИЛОЖЕНИЕ JAVA GUI ДЛЯ СРАВНЕНИЯ УРОВНЕЙ БИОМЕТРИЧЕСКОЙ БЕЗОПАСНОСТИ – РАДУЖНАЯ ОБОЛОЧКА ГЛАЗА ПО СРАВНЕНИЮ С ОТПЕЧАТКАМИ ПАЛЬЦЕВ

Комлен Г. Лалович[а], *Митко* З. Богданоски[б]

[а] Университет «Educons», факультет проектирования и инновационного менеджмента, г. Белград, Республика Сербия, **корреспондент**

[б] Военная академия «Генерал Михаило Апостолоски», г. Скопье, Республика Северная Македония

РУБРИКА ГРНТИ: 50.00.00 АВТОМАТИКА. ВЫЧИСЛИТЕЛЬНАЯ ТЕХНИКА:
50.41.00 Программное обеспечение вычислительных машин, комплексов и сетей
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: Основная цель данной статьи заключается в представлении нового программного приложения, основанного на графическом приложении Java для сравнительного анализа биометрических данных отпечатков пальцев и радужной оболочки глаза.

Методы: Первая часть работы реализована на языке программирования Java, в графическом окружении swing, в то время как в продолжении статьи подробно описаны преимущества и недостатки обеих систем и приведен ряд значимых научных данных о том, в каких случаях распознавание отпечатков пальцев и радужной оболочки глаза может использоваться для обеспечения безопасности на высшем уровне. В исследовании применялся сравнительный анализ.

Результаты: В статье приведены результаты исследования обеих систем как отпечатков пальцев, так и радужной оболочки глаза, а также описаны выявленные разницы между ними.

Выводы: Различные виды биометрического распознования формируются в зависимости от возраста людей без учета сравнения уровня безопасности.

Ключевые слова: программирование, Java, графическое окружение, биометрия, отпечаток пальца, радужная оболочка глаза, патент.

ГРАФИЧКА АПЛИКАЦИЈА ЈАВА ЗА ПОРЕЂЕЊЕ НИВОА БИОМЕТРИЈСКЕ СИГУРНОСТИ ИРИСА ПРЕМА ОТИСКУ ПРСТА

Комлен Г. Лаловић[а], *Митко* З. Богданоски[б]

[а] Educons Универзитет, Факултет за пројектни и иновациони менаџмент, Београд, Република Србија, **аутор за преписку**

[б] Војна академија „Генерал Михаило Апостолоски”, Скопље, Република Северна Македонија

ОБЛАСТ: информационе технологије
ВРСТА ЧЛАНКА: прегледни чланак

Сажетак:

Увод/циљ: Главни циљ рада јесте да прикаже нову софтверску апликацију за компаративну анализу између отиска прста и ириса у биометрији, формирану код људи кроз графичку апликацију јава.

Методе: Први део рада реализован је у програмском језику јава, графичком окружењу званом свинг, а остатак детаљно приказује предности и недостатке оба ова система и научно обезбеђује све релевантне податке када могу бити коришћени и узети да би обезбедили врхунску сигурност. Главни метод представља компаративна анализа.

Резултати: Резултати садрже оба система – и отисак прста и ирис, а приказана је и разлика.

Закључак: Врсте биометрије различито се формирају, а зависе од година старости, без поређења нивоа сигурности.

Кључне речи: програмирање, Јава, графичко окружење, биометрија, отисак прста, ирис, патент.

Paper received on / Дата получения работы / Датум пријема чланка: 26.04.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 18.06.2021.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 20.06.2021.

DESCRIPTION OF THE TETRA 1 TECHNOLOGY AND STANDARD FOR MODERN DIGITAL TRUNKING SYSTEMS OF FUNCTIONAL MOBILE RADIO COMMUNICATIONS

Slađan M. Svrzić[a], *Petar* Jovanoski[b]

[a] Tesla Systems Ltd, Belgrade, Republic of Serbia,
e-mail: milosavljevic_svrzic@hotmail.com, **corresponding author**,
ORCID iD: https://orcid.org/0000-0003-4525-9844

[b] EVN Macedonia, Skopje, Republic of North Macedonia,
e-mail: jovanoski55@yahoo.com

DOI: 10.5937/vojtehg69-30858; https://doi.org/10.5937/vojtehg69-30858

FIELD: Telecommunications
ARTICLE TYPE: Review paper

Abstract:

Introduction/purpose: Since the end of 1995, when TETRA MoU promoted the new TETRA Standard within ETSI, tentatively called TETRA 1, it quickly began to be used, almost exclusively, for the construction of Functional UHF digital trunking systems for mobile radio communications.

Methods: A description of the relevant issues from the TETRA 1 technology standards and an analysis of existing specifications, with a more detailed presentation of the radio interface.

Results: This article highlights the numerous advantages that radio systems based on the TETRA Standard have in relation to the Functional systems of analog trunking of mobile radio communications, and gives an overview of the basic package of Specifications for system implementation based on the TETRA Standard 1. It describes the interfaces used in the system with a special reference to the description of the radio interface, organized by TDMA, and the method of integration of voice and data transmission. The organization and the basic elements of the TETRA network infrastructure are presented as well as those of the final user's equipment, followed by the analysis of possible practical architectures of mobile radio communication networks based on that standard.

Conclusion: After the general descriptions of technology, organization, and architecture, the following are presented: the basic concept of the organization of TETRA 1 network use, the general principle of organization of mobile participants' connections and the basic elements of the TETRA network as well as the architecture and topology of the TETRA 1 network construction.

Key words: Mobile radio communications-MR, Professional Mobile Radio Communication System-PMR, analog trunking, digital trunking, TDMA, Radio-Air interface, Digital Trunking System of Mobile Radio Communications-TETRA, ETSI.

Introduction

The beginnings of TETRA (*TErrestrial Trunked RAdio*) date back to 1989, when four leading European companies for the production of mobile radio equipment (Ericsson, Motorola Solutions, Nokia, and Philips) began work on developing a system of mobile digital trunking radio communications for integrated speech and data transmission, called the MDTRS (*Mobile Digital Trunked Radio System*). During the same year, work began in North America on the development of a new, accompanying Standard for Interoperable Digital Mobile Radio Communications for Voice Transmission, today known as P25 (*Project 25*). While the development of the P25 Standard was the responsibility of the *North American Public-Safety Community* (NAPsC), TETRA was developed under the auspices of the *European Telecommunications Standards Institute* (ETSI), supported by many manufacturers and equipment vendors, system users and regulators (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002a, 2002b), (Swan, 2015), (Svrzić, 2021).

As the interest of manufacturers of equipment of Functional Mobile Radio Communications Systems-PMR (*Professional Mobile Radio*) for the new standard progressed by providing significant support during 1993, the way was paved for the emergence of a strong and solidary association of manufacturers and sellers of such equipment. Therefore, in December 1994, under the auspices of ETSI, the TETRA MoU Association (*TETRA Memorandum of Understanding*) was formed and started working, uniting the world's most important manufacturers and sellers of PMR equipment at the time. As such, the TETRA MoU association has played a very important role from the very beginning (until today), not only for the permanent development of TETRA but also for maintaining interoperability, creating new market opportunities, and fighting against fierce competition (Ovchinnikov et al, 2000), (Swan, 2015), (Svrzić, 2021). By the end of May 1999, the TETRA MoU Association already consisted of 58 different organizations from 18 countries around the world (out of which: 23 equipment manufacturers, 12 system and operator owners, 3 regulatory bodies, etc.) (Dunlop et al, 1999).

In August 1995, ETSI adopted and approved the *Specification ETS 300 391* (*Part 1, 2 and 3*), within which the general settings for the

security architecture of the UPT system (*Universal Personal Telecommunication*) were defined, the ICS proforma (*Implementation Conformance Statement proformas*) was given as well as certain CTSs (*Conformance Test Specifications*) (ETSI, 1995). Subsequently, in December of the same year, ETSI adopted and approved the new TETRA Radio Interface-TAI (*TETRA Air Interface*), as the full *European Telecommunications Standard* (ETS) *EN 300 392-Part 2*, although TETRA was already aiming ambitiously not only at the European, but also at the the complete world market (ETSI, 1996). The new standard, tentatively named TETRA 1, was not related to the then existing *Public Access Mobile Radio Access System* (PAMR), nor was the PAMR part of TETRA, as TETRA proved to be an adaptable standard for *Functional Mobile Radio Communication Systems*. Namely, the infrastructure of the TETRA system is formed from switching elements, a certain number of base and many mobile radio stations, and, being a highly redundant and flexible system for all requirements, it seems ideal both for regular business and functional mobile radio communications and for mobile radio communications in critical situations for general public safety. The TETRA 1 standard is a set of necessary *Specifications* (recommendations) for integrated voice and data transmission-TETRA V+D (*TETRA Voice + Data*) and within that for group, broadband, and emergency calls, then for fast access to the system (which is usually shorter than 300 ms), for TMO (*Trunking Mode Operation*) and DMO type of work (*Direct Mode Operation*), for different levels of application of system access protection through authentication and information encryption, for telephony with network participants functional PABX and participants of public PSTN (including full duplex), to support the smooth operation of control points (*Control and Dispatch Centers*), and circuit-switched data transmission, as well as for independent packet data transmission by TETRA PDO (*TETRA Packet Data Optimized*). (Ovchinnikov et al, 2000), (Swan, 2015), (Svrzić, 2021)

Although at the time of the creation of the *TETRA 1 Standard*, the data transfer rate (*Data*) in it was relatively low and comparable to the data transfer rate of other technologies, it should be noted that even at that time the *TETRA 1 Standard* offered a powerful system of *Status Messages*-SM and short written messages-SDM (*Status and Short Data Messaging*), as well as a special data package directly related to the execution of special tasks in the field. However, fewer than five years passed since its inception when members of the *ETSI TETRA project*, which includes both users and equipment manufacturers, within the *TETRA Technical Committee* (TC) and the *TETRA Association* (TA), in

1999, recognized the need for necessary improvements of the first generation of the existing standard, tentatively called the *TETRA 1 Standard*, in several different areas. Although the number of these areas was initially wide, significant developments in the telecommunications industry (combined with changes in market needs) led to ETSI deciding in September 2000 to start activities to improve the existing standard towards *second-generation TETRA* (Swan, 2015), (Svrzić, 2021). As a result of these activities, at the end of 2005, a document was published defining the areas, services and characteristics of the *TETRA 1 Standard*, which were envisaged for treatment and improvements through the planned new TETRA 2 Standard, as follows:

- Increase connection range in the TMO mode.
- Use of a multi-purpose adaptive *voice codec*- AMR (*Adaptive Multiple Rate*).
- Use of mixed excitation, with line prediction, excited *voice codec* - MELPe (*Mix Exitation Line Prediction*).
- Introduction of an improved part of the standard for fast data transfer, called TEDS (*TETRA Enhanced Data Service*) (Swan, 2015), (Nouri, 2016), (Svrzić, 2021).

In particular, it should be noted that the development of high-speed data transfer according to the *TETRA 2 Standard*, i.e. the introduction of part of the standard for high-speed data transmission according to TEDS, had its prehistory since at the beginning there were two different ways of its development:

1.- *TETRA Advancet Packet Service* - TAPS, which was based on the evolution of the GRPS / EDGE standard, and was thus focused mainly on the PAMR market, i.e. for public mobile communications.

2.- *TETRA Enhanced Data Service* - TEDS, which implied a slightly different appearance of the standard in terms of data transfer speed, and was aimed at the entire TETRA market (in all sectors). In addition, it envisaged full compatibility with TETRA 1 V + D and easy migration of equipment from TETRA 1 V + D to TEDS, as well as flexible use of the existing frequency spectrum allocated for use in PMR of different holders.

At the end of that "race", and after the consensus reached at the working group WG4 EPT on 04.07.2002, the concept of TEDS won as a direction preferred by a group of the world's 5 largest manufacturers of TETRA equipment (with six different technologies) and most of the functional users of PMR. However, due to the painstaking debate over the choice of only one, since then initially offered technology options,

there were many failed attempts to reach a consensus on this issue as well. The most important thing is that after 4 years of controversy, the decision was finally made, so the amended *TETRA 2 Standard* was finally made public in 2006. Since then, until today, several significant improvements have been made within the new *TETRA 2 Standard*, including the previously mentioned: *High Speed Data* (HSD) and the selection and standardization of additional *voice codecs* for speech digitization. In addition, the following were realized: the evolution of the TETRA SIM card, achieving interoperability (even "*roaming*"), between TETRA 2 and public GSM, as well as the transition from 2.5G to 3G network, while maintaining wide compatibility with the first generation of *TETRA 1 devices* and full integration of their features into the new generation of *TETRA 2 devices*. (Swan, 2015), (Nouri, 2016), (Svrzić, 2021)

When it comes to the availability and harmonization of the frequency spectrum, i.e. spectral efficiency, it should be pointed out that these were the key moments for the worldwide success of the *TETRA Standard*. Namely, an open MR (*Mobile Radio*) standard, which means that equipment from different manufacturers can be used in a single radio network, must offer the system owner (on the one hand) sufficient spectral efficiency, with the possibility of choosing equipment from different manufacturers, and at the same time it must enable the manufacturer (on the other hand) to achieve reasonable economy on the existing scale, in order to maintain itself in the widely competitive world market of sellers. Thanks to the work of the *European Radio-communications Office* (ERO) from the *Community European Conferences of Postal and Telecommunications Administrations* (CEPT), and consultations with NATO and their substantial cooperation (as well as the cooperation of some other users of the radio spectrum in Europe), for the needs of the *TETRA system* in Europe, subbands of frequencies have been defined:

- 380-385 and 390-395MHz, which is 200 communication radio channels with a width of 25kHz (strictly for the needs of public security and safety services and the army),
- 410-430 and 450-470 MHz, which is additional 800 communication radio channels 25kHz wide (intended for the needs of commercial services: services, transport, etc.), and
- 870-876 and 915-921 MHz, which is more additional 240 communication radio channels with a width of 25kHz (also intended for the needs of commercial services: services, transport, etc.).

Also, the mentioned 380-400 MHz and 410-430 MHz parts of the spectrum, otherwise designated as basic subbands, together with the newly assigned auxiliary subband 806-870 MHz, are also widely available for use by TETRA in other regions of the world (meaning those outside Europe: in America, Asia, Australia, etc.). (Ovchinnikov et al, 2000), (Swan, 2015), (Svrzić & Ćosović, 2002a, 2002b), (Svrzić, 2021)

Initially, there were concerns about whether this radio spectrum width would be sufficient for the frequency plan, as well as whether it would allow the required density of *TETRA network elements*, necessary for good radio coverage and adjusted capacity of communication radio channels, to be implemented. However, the improved technical RF (*Radio Frequency*) characteristics in the standard have allowed the third generation mobile *TETRA terminals* to operate successfully on the combined broadband configuration of both basic subbands, i.e. in the continuity of 380 to 430 MHz. This made it possible, by combining the basic spectral subbands of 380-400 MHz and 410-430 MHz, to provide additional radio coverage and increased capacity of communication radio channels wherever necessary (of course, if the user has that spectrum width available). That is why TETRA has already unequivocally proved its pronounced spectral efficiency in that respect, since from the very beginning it has enabled a large number of today's operating national networks to be able to function simultaneously and successfully only in the basic part of the spectrum from 380 to 400 MHz, i.e. without the use of additional sub-bands of the radio spectrum. (Swan, 2015), (Svrzić, 2021)

Advantages of digital standards and technologies for PMR trunking systems

Mobile radio communication trunking systems, both analog and digital, are in fact UHF (*Ultra High Frequency*) mobile radio communication systems that automatically switch the available *communication radio channels* of *Base Radio Stations* (BRSt) for the interconnection of mobile participants as well as for the connection of mobile participants with other participants. One of these *communication radio channels* must be used as a *Control Channel*. Through this channel, calls are registered by mobile and other participants, status messages are transmitted and the order of connection requests is assigned. Namely, as soon as the request for establishing a connection arrives, one of free communication radio channels (channels from the capacity of the respective BRSt, in whose service zone the participant

who sent the connection request is assigned) is assigned to the participants for exclusive use to occupy that channel for communication with each other. In cases when, during the established connection, new calls for establishing connections via the same BRSt arrive on the system, they are assigned the remaining ones and not the occupied *communication radio channels* for the connection, until the full utilization of the *communication radio channels* on the respective BRSt. If all channels are busy, a queue is formed for new connection requests (these requests are queued). As soon as one of the busy *communication radio channels* is vacated, the system assigns it to the first participant from the formed waiting list. This means that in the *trunking system of mobile radio communications*, the call for connection is sent only once because, in case of impossibility for current connection, the call will be placed on the waiting list and will be processed later in the order and priority that the participant has (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2000), (Svrzić & Ćosović, 2002b). An important difference in the functioning of conventional from *trunking systems of mobile radio communications* is plastically shown in Figure 1.

Trunking Mobile radio communication systems belong to the class of *mobile radio communication systems* primarily oriented towards the formation of various functional and corporate radio networks which provide for the active application of mobile users in separate speech groups, formed for a permanent or temporary task. Such systems are used mainly by the police, specialized social security and protection services, companies engaged in land and air transport, large producers and distributors of all types of energy (oil, gas, electricity, etc.) in different countries, as well as by the military in order to provide functional connections between: mobile radio participants with each other, mobile radio participants and stationary radio participants, as well as between mobile radio participants and participants of *Public telephone networks*-PSTN and ISDN, and *Functional telephone networks*-PABX. For *Public* and *Functional trunking systems of mobile radio communications*, there are a number of different standards differing from each other in: applied methods for transmission of voice signals (analog and digital); types of network access: FDMA (*Frequency Division Multiplex Access*), TDMA (*Time Division Multiplex Access*) and CDMA (*Code Division Multiplex Access*); the manner of allocating and determining the *communication radio channel*: with decentralized and centralized management; the type of *Control-Management Channel*: separated and distributed; and in other characteristics.

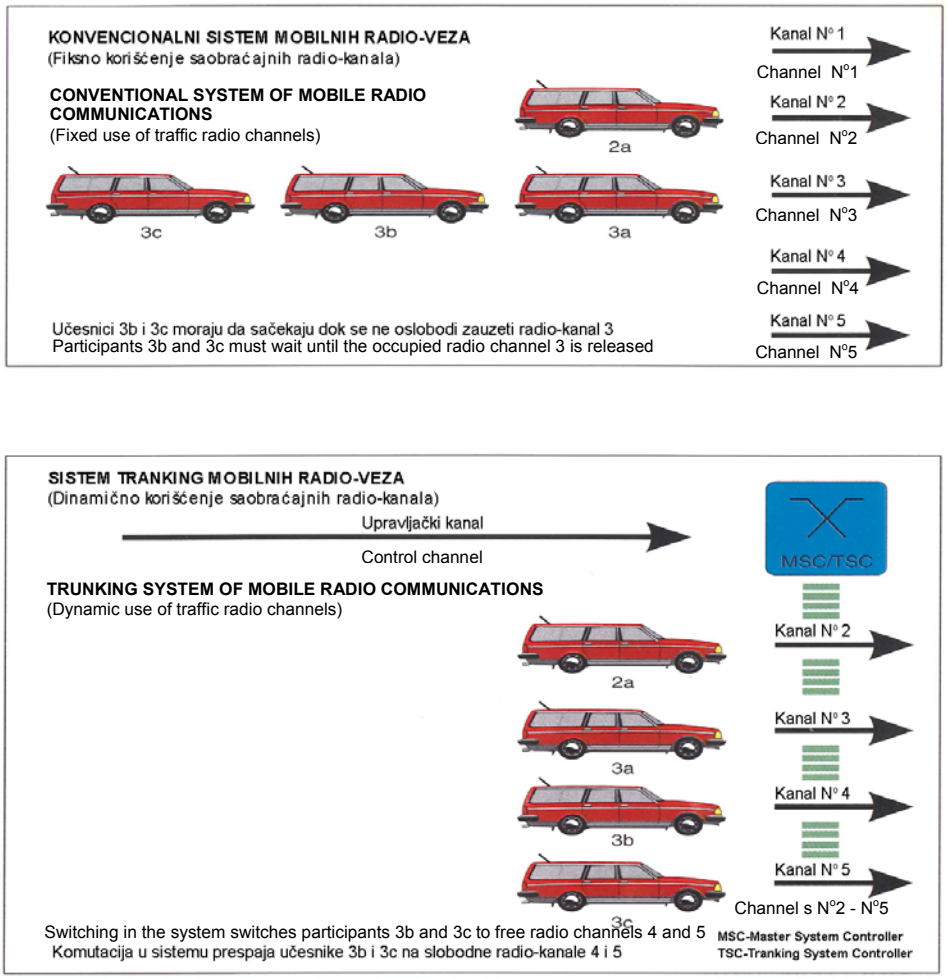


Figure 1 – Use of channels in conventional and trunking systems of mobile radio communications (Rohde & Schwartz, 1994)
Рис. 1 – Использование каналов в обычных и транкинговых системах мобильной радиосвязи (Rohde & Schwartz, 1994)
Слика 1 – Коришћење канала код конвенционалних и транкинг система мобилних радио-комуникација (Rohde & Schwartz, 1994)

Until about 20 years ago, some previously produced *Analogue trunking systems of mobile radio communications* were still relatively widespread in the world, such as: *SMART TRUNK*, then systems with the standard MPT-1327 (*ACCESSNET*, *ACTIONET*, *EURONET-46-3*, *STANILITE*, *JRC*, *SELECTACOM MX* and others), systems

manufactured by Motorola (*STARTSITE*, *SMARTNET*, *SMARTZONE*), systems with distributed *Control and management channel* (*LTR* and *MULTI-NET* manufactured by FFJohnson Co and *ESAS* manufactured by Uniden). The technology of some of these systems, until that time, was used by the public security and security services of different countries, through their built *Functional networks of analog trunking of mobile radio communications*. (Svrzić & Ćosović, 2000), (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002b)

However, since about 15 years ago, the standards for *digital mobile radio communications* has been much more widespread in the world, and therefore the circle of users of *Digital trunking systems for mobile radio communications* has been constantly expanding, which is explained by a number of their systemic advantages over analog trunking systems, such as:

• better spectral efficiency due to the application of complex procedures in signal modulation and low speed algorithms for conversion and digitization of speech signals,

• increased capacity and quality of connections in the system, with a reduction in noise levels, and

• equalization of the quality of voice signal transmission in all BRSt service zones, at the expense of the application of digital signals in combination with coding, which is very resistant to interference.

Compared to analog systems, *Digital trunking systems of mobile radio connections*, besides systemic advantages, provide a number of operational advantages due to:

• a successful implementation of the requirements for high operability and security of connections,

• the provision of wide possibilities for data signal transmission,

• a wider range of liaison services (including special services related to the realization of special needs of public safety and security services), and

• a successful realization of connections between participants from different networks.

The requirement for high connection operability, first of all, means the minimum possible time for establishing a connection channel (*access time <300 ms*) for different types of connections (individual, group, with participants in telephone networks, etc.). With conventional mobile radio systems, it takes significantly longer than with analog trunking systems to establish a *communication channel* through which digital information is

transmitted due to the time required to establish synchronization between transmitter and receiver. However, in *mobile radio trunking systems*, where the exchange of information is mainly done via BRSt, the connection channel establishment time (*access time*) in digital systems is commensurate with the access time in analogue systems. This is due to the fact that in both *digital* and *analog trunking systems of mobile radio communications*, as a rule, the *Control Channel* is realized on the principle of digital signals. In addition, in *Digital trunking systems of mobile radio communications*, it is much easier to implement different connection modes, which significantly contribute to the operability of the system, such as:

- *direct connection mode*-DMO between mobile participants (without using BRSt),
- *open channel mode* (allocation and reservation of frequency network resources for the needs of a certain group of users, so that they can further conduct conversations without any prescribed procedure, and in that sense without delay),
- *emergency call mode*,
- *priority call mode*,
- etc. (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002a, 2002b)

The requirement to provide wide possibilities for data signal transmission implies that Digital trunking systems of mobile radio communications are much better prepared for different modes of data signal transmission, which gives digital network owners much greater possibilities: for operational introduction of reductions from centralized databases, for transmission of necessary information including image transmission, and for the organization of centralized dispatch centers from the vehicle location system, realized on the basis of satellite radio navigation. Also, this means that in digital trunking systems, compared to analog ones, data signals (Data) are transmitted at significantly higher speeds (even several tens of times higher) (Nouri, 2016). In most digital trunking systems of mobile radio communications integrated with data transmission, the services of transmission of short messages and status messages, individual radio calls, facsimile connections, as well as access to fixed networks of data transmission connections, which work on the basis of TCP / IP, are the realized types of protocols. (Swan, 2015), (Svrzić, 2021)

The request for protection of connections includes the need to ensure the confidentiality of cvonversations (excluding the possibility that anyone other than the authentic user can extract information from the

connection channel), as well as protection against unauthorized access to the system (excluding the possibility of entering the management system, attempts to disrupt the regularity of the system in any way, protection from "duplicates", and so on). As a rule, the basic mechanisms of connection protection are the application of encryption of transmitted information as well as the identification and authentication of users. It is quite natural that in Digital trunking systems of mobile radio communications it is much easier to achieve protection of connections than in the case of analog trunking systems. Even without the application of special measures for "locking" information, the Digital trunking system of mobile radio communications provides a certain degree of protection for conversations (analog radio receivers with search are completely unsuitable for listening to conversations in digital radio). In addition, some standards of digital trunking radio communications provide for the possibility of transit encryption of information, which allows the use of original (i.e. developed by the equipment manufacturers themselves) algorithms for encrypting speech and data. Also, *Digital trunking systems of mobile radio connections* provide the possibility of using different mechanisms for *identification* and *authentication of users*: different *identification keys* and *SIM cards*, complex *authentication algorithms* that use *encryption*, etc.

The requirement for *a wide range of communication services* implies that *Digital trunking systems of mobile radio communications* realize a modern level of service of participants in the radio network, which represents: *possibility of automatic registration of participants*, *roaming*, *data signal protocol management*, *different priority call modes*, *call forwarding,* and so on. Also, in accordance with standard network service functions, based on the specifications of public security and protection services, standard digital trunking radio links often include requirements for the existence of specific connection services: *call mode that can be realized only with the permission of the system dispatcher*; *mode of dynamic modification of user groups*, *remote radio mode for remote listening*, etc.

The requirement for *the possibility of interconnection* implies that *Digital trunking systems of mobile radio communications*, which have a flexible structure of addressing users, provide ample opportunities for creating different *Virtual Networks* within the same system, and for organizing connections between participants of different networks when necessary. For public security and protection services, the request for providing *the possibility of organizing connections of joint action* of different specific units of services is especially relevant, in order to

coordinate actions in emergency situations: various disasters, accident situations, terrorist acts, and the like.

Based on such requirements, in the past, international meritorious organizations and some world-famous manufacturers of telecommunications equipment have developed a number of different standards for the construction of *Digital trunking systems for mobile radio communications*. Some popular standards of digital trunking of mobile radio connections, which, in addition to TETRA, have gained international significance and on the basis of which *Digital trunking systems of mobile radio communications* have been built in several countries, are:

- *EDACS*, developed by Ericsson from Sweden,
- *APCO-25*, developed by the *International Association of Official Representatives of General Security and Protection Services* (APCOI),
- *TETRAPOL*, developed by the French manufacturer MatraCommunications,
- *iDEN*, developed by Motorola from the USA. (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002a, 2002b)

All these standards generally met (some less, some more) modern requirements for *Digital trunking systems of mobile radio communications*, as they allow to build networks of digital mobile radio communications of different configurations: from the simplest-*single-zone networks of local importance* to very complex *multi-zone networks at the regional* or *national level*. Mobile radio communication systems built on the basis of these standards provide different modes of digital transmission and switching of voice signal (*individual call*, *group call*, *diffuse call*, etc.) and data signal transmission (*packet switching*, *circuit switching*, *short message transmission*, etc.), as well as the possibility of organizing connections with other different communication systems via standardized interfaces (with the *Digital Network of Integrated Services*-ISDN, with the *Public Telephone Network*-PSTN, with the *Functional Home ATC*-PABX and others). Such *Systems of digital trunking of mobile radio communications* use the most modern forms for conversion and processing of analog speech signals, which then coincide with really effective methods for encoding information, used to protect against various types of interference (*protective coding*). All systems of the stated standards allow their users the possibility of using *duplex radio connection*. Also, manufacturers of radio equipment for these systems ensure their compliance with the *MIL STD 810 standard* for various climatic and mechanical influences. (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002a, 2002b)

However, it turned out that of all these standards, the *TETRA* (*TErrestrial Trunked RAdio*) *Standard* is the most promising, as over time it has been widely accepted by many global equipment manufacturers and users on all continents, with chances to (of course, in the field of *functional mobile radio connection*) possibly get closer to the success of the *Global System for Mobile Communications*. Although many analysts predicted that, due to the significantly faster development and implementation of public digital cellular mobile telephony via GSM compared to functional telephony via the *Digital Mobile Radio Communications Trunking System* (DMRTS), there will be more mass migration of connection system owners from their existing *Functional Trunking system* on the Public GSM, this did not happen en masse for several reasons:

- DMRTS are intended for professional use by special groups of users (closed, e.g. police, military or business systems) while GSM is a public system for personal communication.
- With DMRTS, system owners have supervision and control of the system operation at all times and in each of its parts.
- DMRTS offers more reliable communications in all conditions (especially in crisis situations), much faster connection and a large number of services.
- DMRTS can work with a larger number of radio channels and in more frequency bands than GSM.
- Although DMRTS is more expensive than GSM systems (*radio terminals* are especially expensive), it can also cover areas that GSM does not cover (for example: locations of transformer stations, thermal and hydro power plants, transmission lines, surface mines, construction sites of new roads and tunnels, wells, gas pipelines, oil pipelines, military training grounds, and other facilities).
- DMRTS has a powerful dispatching system and a specially organized subsystem of automatic communication for connection with PABX as well as an output to PSTN and ISDN.
- With DMRTS, user terminals are much more robust and resistant to field work in all weather conditions, and even in natural disasters (higher "*IP protection*").
- DMRTS provide much better opportunities for data transfer and the organization of SCADA (*Supervisory Control And Data Acquisition*).
- DMRTS are designed for a strictly defined number of users, and as such, they have significant reserves of capacity for switching, transmission and management, both in terms of increased bandwidth

and in terms of redundancy. This guarantees that the system is reliable and that there can be no overload in it.

To conclude, even if the *TETRA Standard* is developed on the basis of general technical solutions and recommendations of the *GSM Standard*, it differs greatly from it, as it is oriented towards the construction of such radio communication systems that efficiently and economically support the sharing of mobile radio networks of different groups of users, with a special emphasis on quality assurance of secrecy and protection of transmitted information, as well as towards work in regular and critical conditions of use. In that sense, special attention in the standard is paid to the interests of public safety and security services which often operate in accident and critical situations, and therefore have a number of special requirements. It i also important that TETRA must be an open standard, ie. that equipment from different manufacturers can be used together in one radio network (although, in practice, this is mainly limited to the use of *mobile radio devices*, and not different *base radio stations*). (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002a, 2002b), (123seminarsonly, 2004), (Swan, 2015)

Overview of the TETRA 1 specification package

According to the first-basic package of *specifications*, the *TETRA 1 standard* consists of two parts:

a) TETRA V + D (*TETRA Voice + Data*) - i.e. part of the standard for integrated speech and data transmission, and

b) TETRA PDO (*TETRA Packet Data Optimized*) - i.e. part of the standard that describes a special variant of the trunking system, oriented (only) to optimized data transmission. (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002b), (123seminarsonly, 2004), (Swan, 2015), (Svrzić, 2021)

The *TETRA 1 standard* includes: Radio interface specifications, Interface specifications between TETRA network and *Integrated Services Digital Network*-ISDN, Interface specifications according to *Public Telephone Networks*-PSTN, Interface specifications according to *Data Networks*-PDN, Interface specifications for working with Telephone exchanges/networks of functional users-PABX, etc. Also, the *TETRA 1 standard* contains *specifications* for the description of *basic* and *additional services*, offered by mobile digital radio communication networks according to TETRA V + D or TETRA PDO, and the Interfaces of local and centralized (*external*) radio network management are specified.

The first document from the basic package of standards related to the *TETRA 1 system* was adopted by ETSI in August 1995 under the name *ETS 300 391-Part 1,2,3* **(**Part 1:"*Universal Personal* Telecommunication (UPT)-Specification of the security architecture for UPT phase1"; Part 2:"Implementation Conformance Statement (ICS) proforms"; Part 3: "Conformance Test Specifications (CTS)".) (ETSI, 1995), and at the beginning of the following year other parts of the basic package of standards were published (ETSI, 1996). Most of the specification documents from that package were supplemented at the end of 1997, although (over time) those specifications were modified and supplemented several times (newer versions). The most important parts of the TETRA 1 standard have been translated into the following specifications:

- ETR 300 391 *TETRA V + D Design Guide* (five parts, 1997/98);
- ETS 300 392 *TETRA V + D* (sixteen parts, 1996-2000);
- ETS 300 393 *TETRA PDO* (eleven parts, 1996-2000);
- ETS 300 394 *TETRA Conformance Testing* (two parts, 1996-2000);
- ETS 300 395 *TETRA Codec* (four parts, 1996-2000);
- ETS 300 396 *TETRA DMO* (five parts, 1996-2000). (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002b)

The contents of the system *Specifications of the TETRA 1 standard*, from ETS 300 392 to ETS 300 396, are shown in the following Tables 1, 2, 3, 4 and 5.

Table 1
Таблица 1
Табела 1

Part	The content
Part 1	General network design
Part 2	Air Interface (AI)
Part 3	Inter-working at the ISI
Part 4	Gateways basic operation
Part 5	Terminal equipment interface (TEI)
Part 6	Line connected stations
Part 7	Security
Part 8	Network management services
Part 9	General requirements for supplementary servicess

Part	The content
Part 10	Supplementary services stage 1
Part 11	Supplementary services stage 2
Part 12	Supplementary services stage 3
Part 13	SDL model of the Air Interface (AI)
Part 14	PICS Proforma specification
Part 15	Interworking-extended operations
Part 16	Gateways for supplementsry services

Note: This specification has a variation of the radio interface (AI, Release 2), which was published on 01.08.2016 within ETSI EN 300 392, Part 2, as version V3.8.1, and which is supplemented with ETSI TS100 392-18 - “Air interface optimized applications”. Within this edition, the specifications also include parts: TS100 392-15- “TETRA frequency bands, duplex spacings and shannel numbering”, TS100 392-16- “Network Performance Metrics” and TS100 392-17- “TETRA V+D and DMO specifications”.

One of the newer variations of this crucial specification was released in January 2019 for the TETRA 2-TEDS radio interface, under the designation ETSI TS 100 392-2 v3.9.1 Technical Specification, Part 2- “Air Interface (AI)” (ETSI, 2019).

Table 2
Таблица 2
Табела 2

Part	The content
Part 1	General network design
Part 2	Air Interface
Part 3	Inter-working
Part 4	Gateways
Part 5	Terminal equipment interface
Part 6	Line connected stations
Part 7	Security
Part 8	Network management services
Part 9	Performance objectives
Part 10	SDL model for air interface
Part 11	PICS Proforma

Table 3
Таблица 3
Табела 3

Part	The content
Part 1	Radio conformance testing
Part 2	Protocol conformance testing-voice+data

Table 4
Таблица 4
Табела 4

Part	The content
Part 1	General description of speech functions
Part 2	Codec
Part 3	Cpecific operational features
Part 4	Codec conformance testing

Table 5
Таблица 5
Табела 5

Part	The content
Part 1	General network design
Part 2	Direct MS-MS air interface
Part 3	Repeater
Part 4	Gateway
Part 5	Security

It should be noted that the Specifications of the TETRA 1 standard underwent the greatest changes in 2006, which was conditioned by the newly adopted Standard TETRA 2-TEDS (TETRA Enhanced Data Service), when there were significant changes in the organization of the radio interface for fast transmission data-HSD (High Speed Data) and in the selection and standardization of additional "voice codecs" for speech digitization. In addition, these specifications subsequently underwent partial changes when they were implemented: the evolution of the TETRA SIM card, achieving interoperability (even "roaming") between TETRA 2 and public GSM, and the transition from 2.5G to 3G network. What was important for all holders of hitherto realized systems according to the TETRA 1 standard is that the wide compatibility with the first generation of TETRA 1 devices and the full integration of their characteristics into the new generation of TETRA 2 devices is maintained. (Duncan, 2015), (Nouri, 2016), (Svrzić, 2021)

Existing interfaces within the TETRA 1 framework

The presented *Specifications of the TETRA 1 standard* do not set limits for the architecture of the mobile radio communication network, so, thanks to the modular principle of construction, different configurations of such radio networks can be realized, with different areas of geographical coverage by quality radio signals. In this sense, the radio networks of *the TETRA 1 standard offer* a distributed infrastructure for management and switching-SwMI (*Swiching Menager Infrastructure*), which provides fast call transfer and preservation of the system's ability to work locally, and in case of failure of certain network infrastructure elements.

The basic elements that make up each of the TETRA 1 networks are: Base transceiver radio stations (BRSt), Mobile handheld radio stations (RRSt), Mobile transport radio stations (PRSt), Fixed radio stations (FRSt), Devices for base station management (UBRSt), Switching base station radios (KBRSt), Dispatch desks (DP), and Maintenance and operation terminals (TTOE).

The functions of operational network service of participants and their intersystem coordinated work with participants in other TETRA networks, public and functional telephony networks as well as the functions of local-dispatching and central network management are determined by specified interfaces, clearly shown in Figure 2.

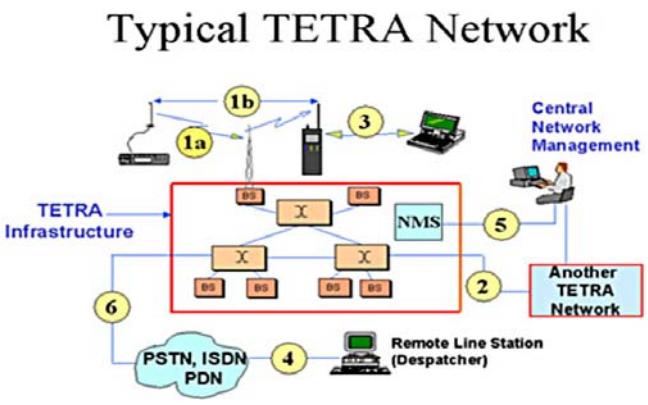


Figure 2 – Overview of different Interfaces in the TETRA standard (123seminarsonly, 2004)
Рис. 2 – Обзор различных интерфейсов в рамках стандарта TETRA (123seminarsonly, 2004)
Слика 2 – Приказ различитих интерфејса у стандарду TETRA (123seminarsonly, 2004)

The following specified interfaces can be seen in the figure:

• (1a) Radio interface for radio trunking work of BRSt (BS-Base Station) with participating mobile radio stations: RRSt and PRSt, and also with participating fixed radio stations (FRSt);

• (1b) Radio interface for direct connection between two participating mobile RSt, without participation of infrastructure network, (Direct Mode Radio Air Interface);

• (2) Inter System Interface (ISI) for the organization of connections between KBRSt (BSC-Base Station Controller) of different TETRA networks - or for connection to other TETRA networks;

• (3) Interface for connection between data transmission terminal and mobile RSt (sometimes for direct connection of local DP) -TEI (Terminal Equipment Interface);

• (4) Wired Line Interface (LSI), which connects the isolated DP to the BRSt Controller (BSC), via PSTN, ISDN or PDN;

• (5) Network Management Interface-NMI which serves to directly connect the workstation to the Central Network Management System - NMS;

• (6) Interface for connection to PABX, PSTN, ISDN (Gateways to PABX, PSTN, ISDN) and to the Package Data Network (PDN) (Gateways to PDN). (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002b), (123seminarsonly, 2004)

Figure 3 presents the role and location of the following open interfaces: *Radio-interface*-AIR IF (for TMO interaction) and *Radio-interface DMO* (for direct connection), and *Inter-system interface*-ISI and *Interface for connecting data transmission terminals* -TEI, and within the demonstrated infrastructure of two independent TETRA networks, which basically (each of them) consist of BRSt, devices with independent switching, and KBRSt with integrated switching (*Base Station*, *Switch*, *Base Station Controller*).

In order to, in some special cases, increase the BRSt service area (i.e. increase the range of the connection) in the *TETRA 1 standard*, the possibility of using the *participating mobile radio stations* as *a Retranslator* is also provided. This is realized with the application of *Direct Mode Operation* (DMO), as shown in the figure. By the way, during TMO (*Trunking Mode Operation*) TETRA supports the *semi-duplex mode* by default, but when communicating with participants from PABX, PSTN or ISDN, it works in *full time duplex*-TDD (*Time Division Duplex*).

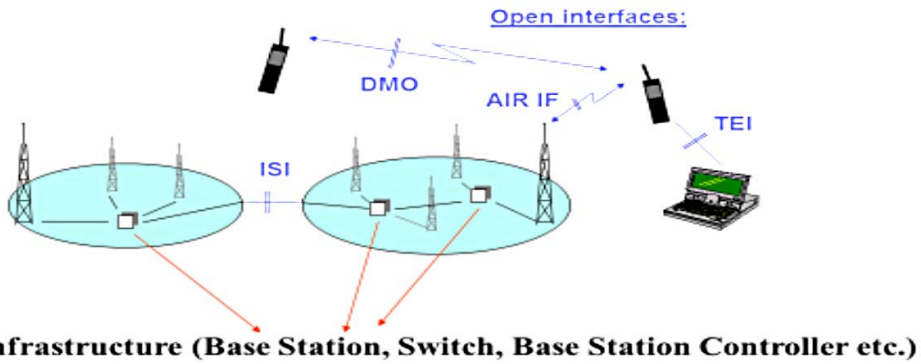


Figure 3 – Overview of the role and location of different interfaces on the TETRA network infrastructure (123seminarsonly, 2004)
Рис. 3 – Обзор роли и расположения различных интерфейсов в сетевой инфраструктуре TETRA (123seminarsonly, 2004)
Слика 3 – Приказ улоге и места различитих интерфејса на инфраструктури мреже TETRA (123seminarsonly, 2004)

Namely, due to the high speed of change of the transmission and *reception cycle by time multiplex*, it seems that the *semi-duplex* mobile RSt enabled *duplex communication* with the participants of the mentioned telephone networks. In doing so, the *TETRA 1 system* supports a complex level of protection of transmitted information by *encrypting speech*, *signaling, and user identification*. In doing so, security and protection are *integrated into the system* and through multiple levels of *identification* and *authentication*: *users by radio terminals*, *radio terminals by a network*, *one network by another network,* and a *user by another user.* (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002b), (123seminarsonly, 2004)

Description of the radio interface according to the TETRA 1 standard

The radio interface, defined in the *TETRA standard 1* via *ETS 300 392-Part 2*, is the basic interface in the system that provides for operation in a conventional frequency network with a *radio channel spacing of 25 kHz*. In this case, there is a necessary, minimum *duplex distance* between the transmitting and receiving frequency of 10 MHz in *the radio channel*. In principle, a *complete frequency range* of 150 to 900 MHz can

be used for *TETRA standard systems*, being clearly defined for use in European countries with *the subbands 380-385/390-395 MHz* (for public safety and security services) and *410-430/450-470 MHz* (for service services and commercial organizations). The remaining *subbands* used are: 870-876 MHz, used to receive base radio stations (*up-link*), and 915-921 MHz, used to transmit base radio stations (*down-link*).

Because it was rightly expected that a large number of owners and users of *Functional conventional PMR systems* will directly switch to the *TETRA system*, i.e. to bypass the technology of *Analog trunking systems of mobile radio communications* (meaning PMR *Standard MPT1327* and others), the use of the *time division multiple access* (TDMA) *technique* was adopted. The adopted TDMA contains *four user time slots*, organized on *each of the 25 kHz spaced radio carriers*. So, on *one pair of physical radio frequencies* BRSt, (for reception- "*up-link*" and for transmission- "*dow-nlink*") spaced 10 MHz, *4 independent time communication radio channels* (information channels) can be organized (Figure 4).

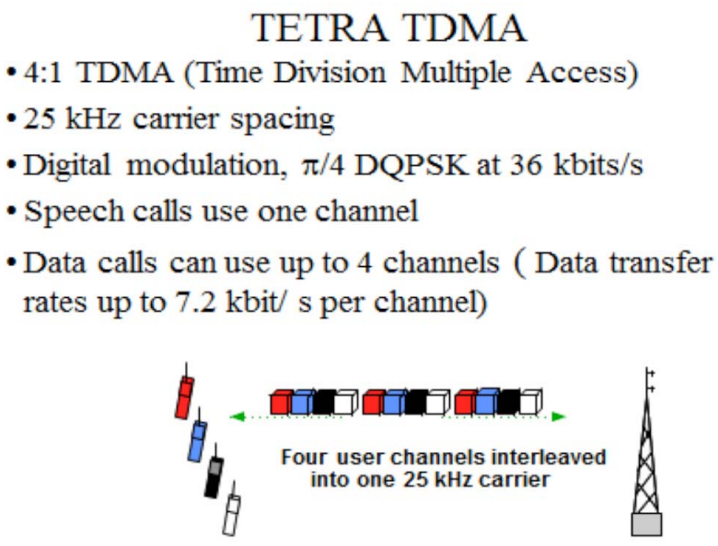


Figure 4 – Representation of TDMA, parameters and spectral efficiency in the TETRA Standard 1 (123seminarsonly, 2004)
Рис. 4 – Представление TDMA, параметров и спектральной эффективности в рамках стандарта TETRA 1 (123seminarsonly, 2004)
Слика 4 – Приказ TDMA, параметара и спектралне ефикасности код стандарда TETRA 1 (123seminarsonly, 2004)

This way of organization maintains the same *radio channel width of 25 kHz*, about one *radio frequency carrier*, as with conventional PMR systems, but the *spectral efficiency* is quadrupled in relation to them, while in relation to analog trunking systems PMR (with *the MPT1327 standard*, where the *channel spacing* is 12.5 kHz) it doubles. Compared to GSM, *four times better spectral efficiency* is also achieved, since in this system only 8 *communication radio channels* are organized at a width of 200 kHz, while at TETRA at a width of 200 kHz 8 *radio frequency carriers* are organized (with a radio-channel width of 25 kHz) and *4 communication radio channels* on each. In addition to *spectral efficiency*, TETRA also provides savings in BRSt equipment, as only *one transceiver radio unit* is required for all four user "*time slots*", i.e. for *four communication radio channels*.

In the *TETRA 1 standard*, according to the hierarchy, it is defined that announcements are submitted in *TDM multiframes*, with a duration of 1.02 s. By grouping 60 *TDM multi frames*, one *TDM hyperframe* is obtained. Each *TDM multi-frame* contains 18 *TDM primary frames*, of which the 18th is *the Control Frame*, i.e. the SACCH (*Slow Associated Control Channel*), through which signaling is always transmitted, even if all other channels occupied as working channels.

Each *TDM primary frame* has a duration of 56.67 ms and contains *4 time intervals* of 14.167 ms. In each of these *time intervals*, the information of one time (*communication*) channel is transmitted, within its duration of 14.167 ms, by placing in the channel a *channel packet* of a total length of 510 bits, out of which 432 are *information* while the rest are "*official bits*". This means that within 1s, 35,999.152 bits are transmitted for all *4 communication-traffic channels*, i.e. that the *channel speed* of the signal in one *communication radio channel* = 9 kb/s (Figure 5). (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002b), (123seminarsonly, 2004), (Svrzić 2021)

At the beginning of *each channel packet*, in a "*time slot*" of the *communication radio channel*, an *official PA block* (*Power Amplifier*) of 36 bits in length is handed over, intended for regulating the radiant power of the mobile radio station. It is followed by the *first information block*, 210 bits long, and then the *SYNCA synchronization block* 36 bits long, after which the *second information block* 216 bits long is passed. At the end of such *a channel packet*, a 6-bit *protection block* is passed. This *protective block* of bits excludes the possibility of overlapping (overflow) of information from adjacent *communication radio channels*.

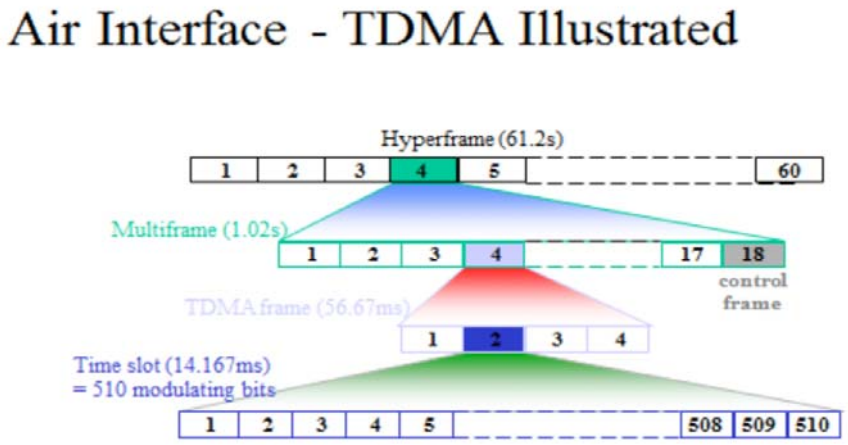


Figure 5 – Overview of the hierarchy of time structures in the TETRA system (123seminarsonly, 2004)

Рис. 5 – Обзор иерархии временных структур в системе TETRA (123seminarsonly, 2004)

Слика 5 – Приказ хијерархије временских структура у систему TETRA (123seminarsonly, 2004)

The connection between the "time slots" in the TDM primary frame and the user communication radio channels is as follows: each time slot represents a certain period of time associated with one communication radio channel (Figure 6).

It can be seen from the figure that the communication radio channel is actually a sequence of equally numbered “time slots” from continuous-successive TDM primary frames.

The receiver is synchronized to a specific time slot in which it can receive and reconstruct only those messages that belong to the communication channel it is currently using (which is assigned to it for connection).

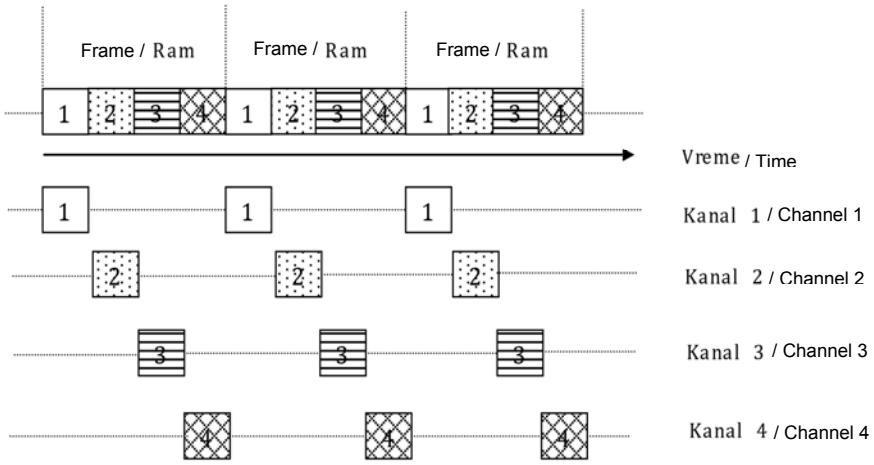


Figure 6 – Connection between time slots and communication channels in the TETRA TDM primary frame (123seminarsonly, 2004)

Рис. 6 – Связь между временными интервалами и каналами связи в первичном фрейме TETRA TDM (123seminarsonly, 2004)

Слика 6 – Приказ везе између временских слотова и комуникационих канала у примарном раму TETRA TDM (123seminarsonly, 2004)

The TETRA 1 systems use Linear differential quaternary phase modulation for modulating speech and data signals with a phase shift of $\pi/4$, i.e. type $\pi/4$–DQPSK (Differential Quadrature Phase Shift Keying), and a maximum throughput of 9 kb/s to communication radio channel, i.e. "time slot" (which is 36 kb/s per TDMA primary framewith on, i.e. with a symbol flow rate (dibit) of 18 ksymbols/s.

This then means that the modulation rate per one radio frequency carrier, i.e. together for all 4 radio communication channels, is 36 kb/s. (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002b), (123seminarsonly, 2004)

When transmitting speech signals and data signals, there is a difference in the system during their transmission since the analog speech signal is first subjected to analog/digital conversion (Figure 7).

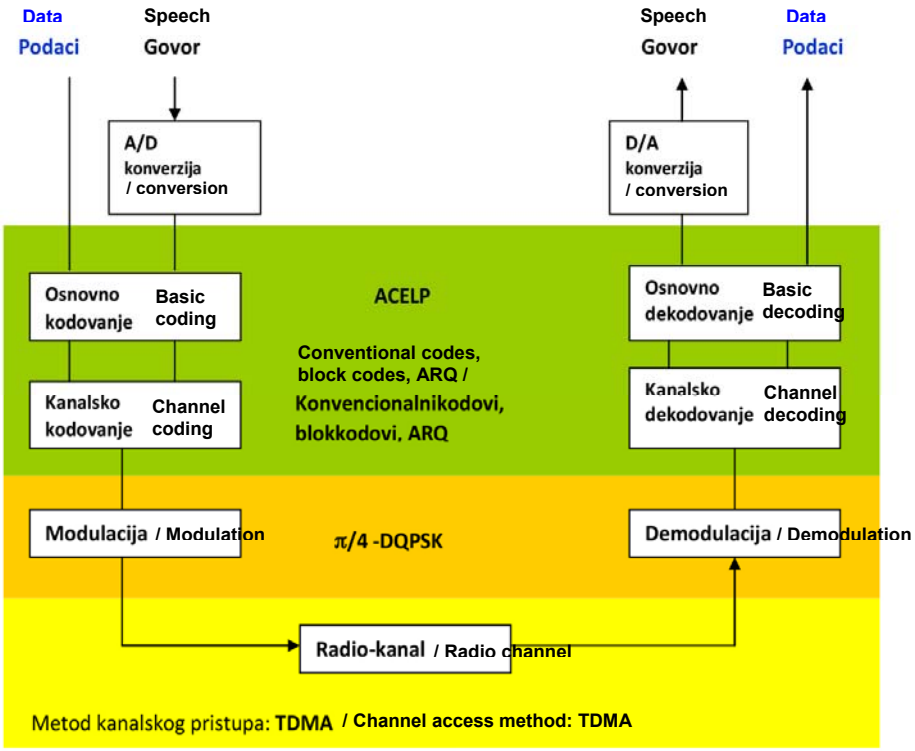


Figure 7 – Overview of the integration of speech and data transmission and signal processing in the TETRA 1 standard (Svrzić & Ćosović, 2002b)
Рис. 7 – *Обзор интеграции передачи речи и данных и обработки сигналов в рамках стандарта TETRA* 1 *(Svrzić & Ćosović, 2002b)*
Слика 7 – Приказ интеграције преноса говора и података и обраде сигнала код стандарда TETRA 1 (Svrzić & Ćosović, 2002b)

After *A/D conversion*, *speech* is transmitted at a bit rate of 4.8 kb/s and *encoded* with a special "*codec*" which applies the *ACELP algorithm* (*Adaptive Code Excited Linear Predictive*) which then ensures high quality of the transmitted *speech signal*. The *TETRA 1 system* also transmits *data signals* as standard with *circuit switching* and *packet switching*. *Digital data* comes directly, and *speech* after *A/D conversion*, to the *ACELP speech codec* in which they are first subjected to a protocol: *basic* and *then channel coding* ("*block*" and "*symbolic*" *coding*, *sequence shifting* and *scrambling*), after which *interference-resistant information* is formed in *communication radio channels*, which is further *modulated* by applying *π/4–DQPSK*, *RF amplified* and *transmitted* to the

air. During *reception*, reverse processes take place: *demodulation of RF signals*, *channel* and *basic decoding*, and for *speech signals*, *D/ A conversion* (again, Figure 7). (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002b)

The bandwidth of one information-communication radio channel is standard-fixed and amounts to 7.2 kb/s, so the speed of digital information data flow can vary from 7.2–28.8 kb/s (at the expense of combining 1-4 communication radio channels). At that, the total speed of transmission of symbols in the radio channel, at the expense of additional official information and control frame in TDM multi frame, corresponds to the modulation speed and is 36 kb/s. (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002b), (123seminarsonly, 2004)

Organization and architecture of mobile radio networks according to the TETRA 1 standard

The basic concept of the organization of the use of TETRA 1 networks

The basic commitment to the use of the *TETRA system* is the organization of a *complex digital trunking network of mobile radio communications* for several *different groups* of *independent* or *partially dependent users*. Users in this sense mean organizations, bodies, institutions, services, etc., which do not have their own *System of functional mobile radio communications* but appear as *independent* or *partially dependent groups of participants* in such a *unique TETRA network*.

Figure 8 shows the *simultaneous use of a single TETRA network* for three groups of different users (police, ambulance, and firefighters). Such a *unique TETRA radio network* is designed as a standard to support *the simultaneous work* of very demanding and specific groups of users in the field of public safety and security, as well as emergency services (see the figure), and transport organizations, service organizations, and industry, local government and various services, and of course, (in specific circumstances) the military.

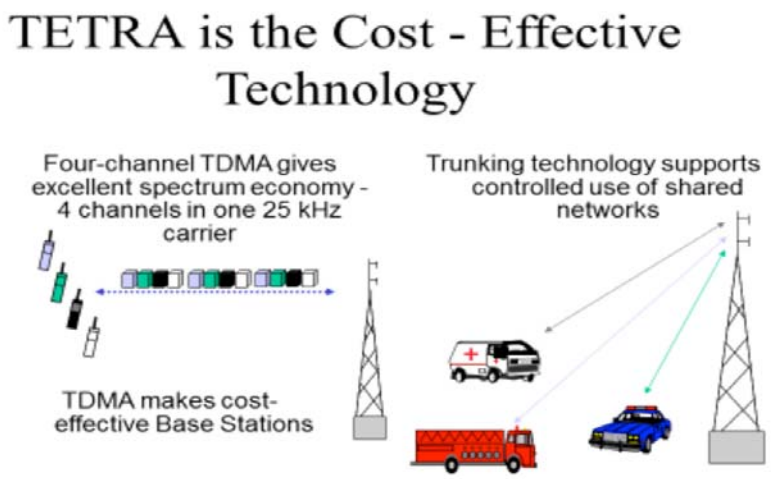


Figure 8 – Overview of simultaneous use of a unique TETRA 1 network for three different user groups (123seminarsonly, 2004)

Рис. 8 – Обзор одновременного использования единой сети TETRA 1 тремя разными группами пользователей (123seminarsonly, 2004)

Слика 8 – Приказ једновременог коришћења јединствене мреже TETRA 1 за три различите групе корисника (123seminarsonly, 2004)

Due to the mentioned specific characteristics, the *TETRA 1 system* has a *multi-layered organization structure*, *complex protection mechanisms* and *very high reliability*, with a great possibility of *radio coverage* (from some local territory to the international level). In fact, it is a concept of the organization of *Virtual Networks*-VNs for each group of users separately, within the *whole-unique TETRA system* (see Figure 9).

VNs enable *the independence* and *autonomy of work* of each of these very diverse groups of users, and at the same time, from that complex, widespread and well-organized network of *UHF mobile radio communications*, they all use exactly the benefits they want. That is why it is very important that in each of such VNs there is an independent *Dispatching Center*-DC with a *Dispatcher Work Station*-DWS and peripherals with great authority.

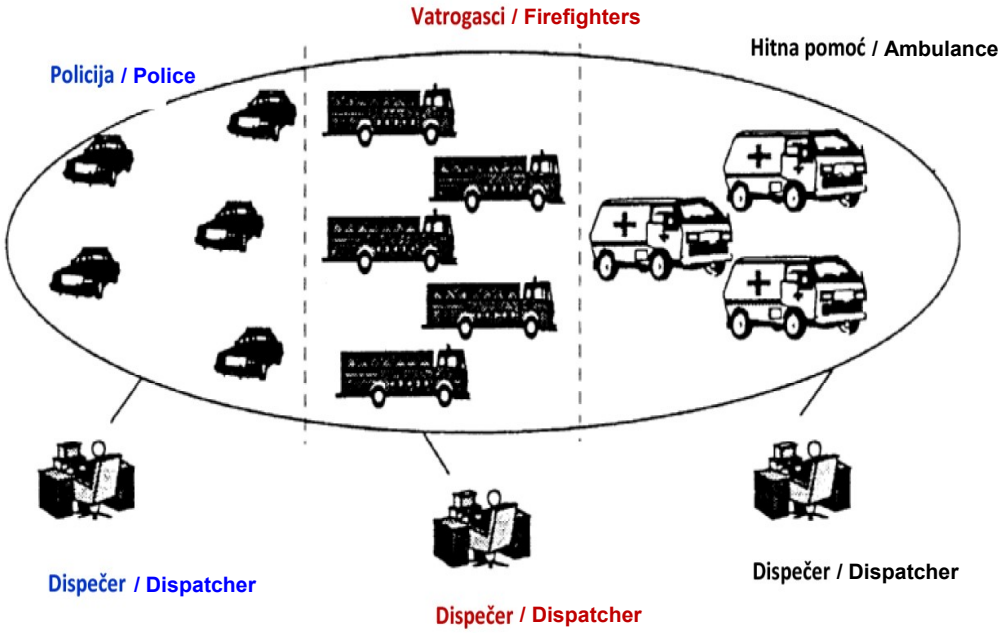


Figure 9 – Overview of the organization of three virtual networks within a single TETRA 1 network (123seminarsonly, 2004)
Рис. 9 – Обзор организации трех виртуальных сетей в рамках единой сети TETRA 1 (123seminarsonly, 2004)
Слика 9 – Приказ организације три виртуелне мреже у оквиру јединствене мреже TETRA 1 (123seminarsonly, 2004)

All *Dispatchers* from *different Virtual Networks* can communicate with each other and, in case of special critical or accidental situations (major traffic accidents, fires, natural disasters), form special *Temporary Functional Groups* (composed of participants from their own network user groups), as well as *Mixed functional groups* (composed of participants from different network groups of users), depending on the given accident situation and defined tasks (Figure 10). At the same time, the participants of such new groups have the opportunity to, with the permission of the *Dispatcher*, change the membership of the group if necessary, so like *the Dispatchers*, they can belong and communicate with more groups. The work of the entire *Virtual Network* is usually managed by one *Dispatcher*, although the network (for some groups of participants) can work without *the Dispatcher*. From its DWS, that *Dispatcher* has an overview of the current position of each member of the group (knows *the radio cell* in which it is located) and its status. Also, he

has an insight into every communication between the participants and can break into it, to convey a message, to interrupt it or to insert a new interlocutor. By listening to *ambient noise*, especially in *Public security services* (even in *the Military*), *the Dispatcher* can monitor the work of individuals in cars or in the field without their active participation. Multiple levels of *identification* and *verification*, as well as strict control of access and communication in the network by *the Dispatcher*, guarantee that *only authorized users can use the system*. In case of theft of a *mobile radio device*, *the Dispatcher* can remotely disable any further operation of that terminal (temporarily or permanently), as well as monitor its movement through the network.

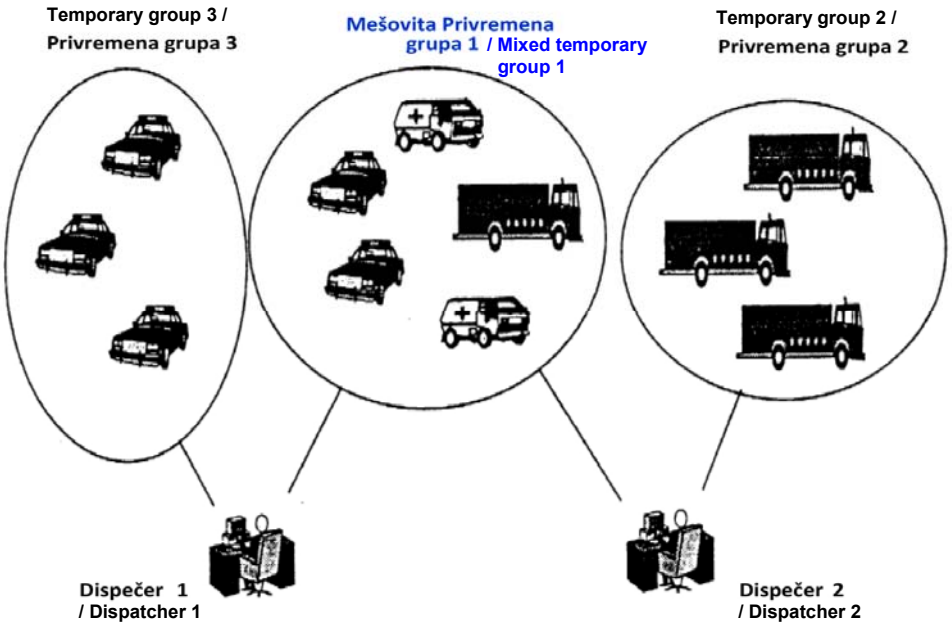


Figure 10 – Overview of the formation of a special-temporary mixed functional group of users in the event of an accident within a single TETRA 1 network (123seminarsonly, 2004)

Рис. 10 – Обзор формирования специально-временной смешанной функциональной группы пользователей при аварии в рамках единой сети TETRA 1 (123seminarsonly, 2004)

Слика 10 – Приказ формирања посебне – привремене, мешовите и функционалне групе корисника у случају акцидентне ситуације у оквиру јединствене мреже TETRA 1 (123seminarsonly, 2004)

In a *single TETRA network*, in which there are *Virtual Networks* (or specialized organized groups), each group of users can seamlessly and efficiently implement their specific, specific requirements, such as:

• Beneficiaries from *the Public Safety* and *Security Sector*:

1. The police or customs authorities may on the spot, i.e. at any location, receive or send fingerprint recordings, various photographs, take important details during the investigation, etc.

2. Firefighters and special units for natural disasters can use Direct Mode (DMO) to cover any area with quality and record and transmit live, to their control points and dispatchers, the situation on the ground.

3. Ambulances and ambulance services can, already from their vehicles, send recordings and the first findings of the injured.

• Users from *the Industry* or *Construction Sector* can send plans, sketches and drawings to the field, isolated facilities, warehouses, and construction sites.

• Users from *the Sector of Transport Organizations* most often send the positions of their means of transport - buses, trucks, ships (AVL-*Automatic Vehicle Location*) using GPS.

• Users from *the Sector of Service and Service Organizations* can verify credit and bank cards in the field when charging for their services to customers. When transferring data from a bank or credit card, a transfer with a high level of protection is used. (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002b), (123seminarsonly, 2004)

General principle of the organization of connections of mobile participants and the basic elements of TETRA networks

For an initial understanding of the principles of connection organization, within the *TETRA 1 standard Specification*, *ETSI EN 300 392-1 v1.4.1* (in "*Annex A*") from 2009, models of *simplified-standard connection configurations through LMNs* (*Land Mobile* Networks) are given, i.e. models of *terrestrial mobile radio networks* which consist of three basic elements:

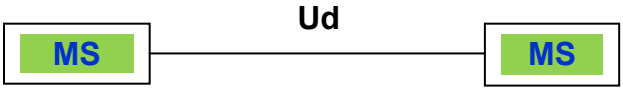
• *mobile radio stations*-MS (*Mobile Station*);
• *Swiching Manager Infrastructure*-SwMI; and
• *Line Stations*-LS, i.e. line (*wired*, *radio-link*,…) connected stations.

Mobile radio stations are connected to the *TETRA SwMI* by a *radio channel*, while LSs are connected to this structure *via wired* and *other communication lines*. The variants of the standard configurations of connection in the network are shown in Figure 11 a), b) and c), where: Um - *radio interface of TETRA 1 network in TMO*, Ud - *radio interface of*

direct connection in DMO, and TI- *wired or other line connection*. (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002b), (ETSI, 2009)

a) Connection between two mobile radio stations in the TMO mode, using SwMI
а) Связь между двумя мобильными радиостанциями в режиме TMO, при использовании SwMI
а) Веза између две мобилне радио-станице у режиму TMO, коришћењем SwMI

b) Connection between a mobile station and a line station in the TMO mode, using SwMI
б) Связь между мобильной станцией и линейной станцией в режиме TMO при использовании SwMI
б) Веза између мобилне и линијске станице у режиму TMO, коришћењем SwMI



c) Connection between two mobile radio stations in the DMO mode, without the use of SwMI
в) Связь между двумя мобильными радиостанциями в режиме DMO, без использования SwMI
ц) Веза између две мобилне радио-станице у режиму DMO, без коришћења SwMI

Figure 11 – Overview of the variants of the standard configurations of TETRA 1 mobile radio networks (ETSI, 2009)

Рис. 11 – Обзор вариантов стандартных конфигураций сетей мобильной радиосвязи TETRA 1 (ETSI, 2009)

Слика 11 – Приказ варијанти стандарда еталонских конфигурација мрежа мобилних радио-веза TETRA 1 (ETSI, 2009)

Functional schemes for the construction of various *mobile radio networks* of *the TETRA 1 standard* represent a set of elements of *radio network equipment* that are interconnected by certain specified

interfaces. As mentioned earlier, each complete *TETRA 1 radio network* contains the basic equipment elements: *Base Transceiver Station*-BTS, *Base Station Control Function*-BCF, *Base Station Controller radio-station*-BSC, *Dispatching desk-DP*, *Mobile*: *hand-held*, *stationary* and *transport radio stations*, *Terminal for maintenance and operation* and *Monitoring and Control Center*.

The *Base transceiver radio station*-BTS is a base stationary radio station which provides participants with a connection in a *specific radio cell* (or *radio zon*e) of its *coverage*. The BTS performs basic functions related to the transmission of radio signals: *connection to mobile radio stations*, *link line encryption*, *spatially separate reception* (*spatial diversity*), *power management of mobile radio stations,* and *radio channel management*.

The device for controlling the base radio station-BCF is an element of equipment from the BTS, which is also part of the equipment of the radio network infrastructure. It is also called *Site Controller*-SC and it contains a system for *switching the available communication radio channels of the respective BTS*, which can *software-manage several other BTSs* from its zone. It also provides *direct or indirect access to external networks* such as ISDN, PSTN, PDN, and PABX, and can also be used for line connection of *Dispatching desks*-DP and *Terminal for maintenance and operation* (TO&M).

The *Base radio station controller*-BSC is an element of radio network equipment which, compared to the BCF, has *greater switching* and *software capabilities*, allowing the *exchange of data between several BCFs*. Also, like the BCF, the BSC provides direct and centralized access to *external connection networks*. In this sense, the BSC has an elastic modular structure and allows the use of a number of interfaces of different types. In *complex TETRA radio networks*, BSCs also perform the functions of *connecting to other TETRA networks*, as well as the functions of *managing centralized databases*. In such cases in the *TETRA network*, one of the BSCs must be declared the *Main Controller of Base Radio Stations*-MBSC and is specially equipped with adequate hardware and software.

The *Dispatching desk*-DP is a line terminal device that is primarily connected to the BSC *via a wired line* providing the exchange of information between the operator (*Network Dispatcher*) and other users in the network. It is often used for *diffuse transmission of information*, *formation of user groups,* etc, in terms of the function of *Local or Central network management*.

The *Mobile radio station*-MS is a terminal radio station (*manual-portable* or *transport-installed in the vehicle*), used by various participants in the movement, while the *Stationary/Fixed radio station*-FRS is a terminal radio station (a station used by participants in one stationary place (*usually indoors*). The *Transport mobile station* (*built into the vehicle*) is an adequate solution for working from a vehicle with a custom antenna system.

The terminal for technical maintenance and operation-TO&M is a line terminal that is, directly or remotely, connected to the BSC or BCF, and is intended for *monitoring the state of the system*, *performing fault diagnostics*, *registration of traffic information*, *making changes to the database of participants*, etc. With the help of these terminals, the so-called function of monitoring and managing the local network LNM (*Local Network Management*) is often realized. (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002b), (123seminarsonly, 2004), (ETSI, 2009)

Architecture and topology of the construction of the TETRA 1 network

Thanks to the modular principle used in the construction of equipment, *TETRA 1 mobile radio networks* can be realized with architecture of different hierarchical levels and with a topology that allows different geographical coverage (from *local*, *regional* to *national level*), and by the type of "*Star*" , "*Loops*" or "*Chains*". *Database management* and *switching functions* in *the TETRA 1 network* are *distributed*, that is, they are distributed throughout the network, which ensures fast call transmission and preservation of limited working capacity of the radio network even when disconnected from some of its elements. (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002b)

At the *national* or *regional level of coverage*, the structure of the radio network can be realized on the basis of relatively small but *complete TETRA subnets*, which are connected by the *Interconnection Interface*-ISI, in order to realize a *common - general national* or *regional network*. In this case, a *complete TETRA subnet* usually means an *autonomous* and *independent radio network* which consists of all the elements of equipment listed in the previous subchapter. In such cases, it is very important that the *complex architecture* and *topology* of *the TETRA network* in question allow the possibility of *Centralized Network Management*. Namely, in such an organization, *each TETRA subnet* independently performs its functions of *Local Control* and *Switching*, but also provides the possibility for *Centralized management from a higher level*. The number of elements of the *TETRA subnet structure* depends

on the type and intensity of traffic, as well as on the requirements for the level of connection efficiency. (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002b). A variant for building a sufficiently demanding and complex-combined configuration of a *complete TETRA subnet* in the *TETRA 1 standard*, with pronounced levels of hierarchy, is shown in Figure 12.

In the case when *spare radio channels* are not required, i.e. when the traffic between different BTSs is not demandingly strong and when it is mostly *cell-oriented*, it is possible (and sufficient) to build *a TETRA subnet* in a simpler *"Star" configuration*. Also, in the case of overlapping line-oriented paths (for example, on long conveyor routes, on railways, etc.), *the TETRA subnet* can be realized in the form of a very long line, i.e. "*Chain of regularly connected BTSs*". In this case, it is rational to provide local access to external networks via each of the *Base Station Control Devices* (BCF), in accordance with the required connection distance. Finally, and if conditions require so, a simple *"island"* type configuration of *the TETRA subnet* can be built, containing only one BCF and usually several BTSs.

In the radio networks of *the TETRA 1 standard*, various ways of ensuring the toughness of the system are provided, enabling the preservation of full or partial working capacity even in the event of failure of some of the elements from the network. It is also possible that, in the network or some part of it, there occurs a certain deterioration of one or a number of parameters, for example *the time of establishing a connection*, *reducing the data transfer speed*, etc. Therefore, for *complex TETRA networks of the national coverage l*evel, several alternative routes are used as a rule to connect with *TETRA networks of the regional level*. In *regional TETRA networks*, similar alternative routes are used to more reliably connect *Base Station Controllers* (BSCs). In addition, for *regional networks*, mutual copying of databases between different *Controllers of base radio stations* is envisaged (Ovchinnikov et al, 2000), (Svrzić & Ćosović, 2002b). Similar principles have been applied in *the national level* and in *the "Star" architecture* of the *TETRA 1 network* of Motorola, *"Dimetra IP/SR6.2"*, which in Serbia operates successfully for the needs of *the Ministry of Interior* and in which one of the users is *the MoD and Serbian Armed Forces.* (Krstić & Marjanović Jakovljević, 2018), (Motorola Solutions, 2008), (Svrzić, 2021)

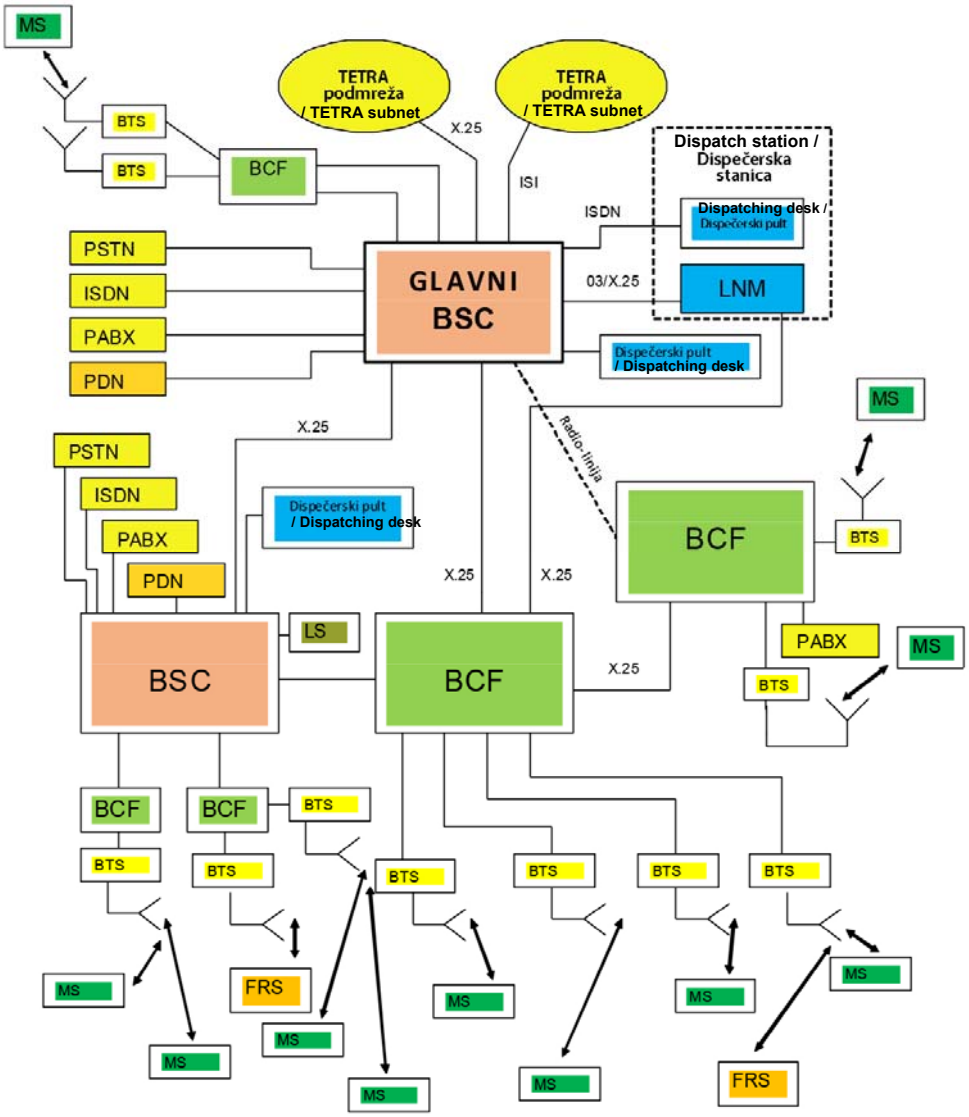


Figure 12 – Representation of a variant of the complex hierarchical configuration of the TETRA 1 subnet (Ovchinnikov et al, 2000)
Рис. 12 – Представление варианта сложной иерархической конфигурации подсети TETRA 1 (Ovchinnikov et al, 2000)
Слика 12 – Приказ варијанте сложене хијерархијске конфигурације подмреже TETRA 1 (Ovchinnikov et al, 2000)

Conclusion

Due to the advantages of *Digital Trunking Mobile Radio Communications Systems* using the *TETRA standard* in relation to the *Systems of analog trunking of mobile radio communications*, they are today almost *exclusively used* for the construction of *UHF systems of digital mobile radio communications of functional users*. The construction and operation of these systems is defined by the basic package of *TETRA 1 specifications*, adopted by ETSI in late 1995 and subsequently amended in late 1977. They define all *infrastructure equipment* (BTS, BCF, BFC), *Local Network Management*-LNM and *Centralized Network Management*-CNM equipment and *Participating Equipment* (MS and LT), as well as all interfaces applied in the system. Also, they define: *group*, *broadband* and *emergency calls*, *then fast system access (<300 ms*), *TMO* and *DMO types of work,* different levels of *application of system access protection (Autentification)* and *information encryption*, *work by telephony* with participants in the networks of functional PABX and public PSTN networks (including *full duplex*), as well as support for the *smooth operation of control points* (*Control* and *Dispatch Centers*), and *integrated data transmission by circuit switching* and *independent packet data transmission by TETRA PDO*. *The Radio interface* for *TMO* and *DMO operating mode* (according to *TDMA organized*) is specified in detail, both for *integrated speech and data transmission-TETRA V + D*, and for independent *optimized packet mode of data signal transmission-TETRA PDO*. Regarding the improvement of *data transmission* and modernization of the system to *TETRA 2-TEDS*, by ETSI TC (*Technical Committee TETRA*) and TCCE (*TETRA Critical Communications Evolution*), these specifications were adequately amended in 2006, and continue to be permanently revised.

During the construction of *National Functional Radio Networks* according to the *TETRA 1 standard*, special emphasis is placed on the possibility of organizing *Virtual Networks*, within such a *complex and unique TETRA network*, which can then be shared by several different users-organizations (such as *police*, *army*, *firefighters* and *emergency services*). Also, it is a great advantage for users-owners of communication systems that, within such a *TETRA radio network,* special-purpose *functional groups of participants* can be formed (*permanently* or *temporarily*), for more successful and professional execution of basic tasks, or tasks assigned to them in different accident situations. As for the type of architecture of mobile radio networks based on the *TETRA 1 standard*, it should be noted that it is adaptable, i.e.,

depending on their complexity, these radio networks can be built based the *"Loop" topology* (for complex ones), based on the topology of the *"Star"* (for those less complex ones) or in the form of a *"Chain of linearly arranged BTSs"* (to cover railways, highways, etc.). In practice, it is also possible to build small *TETRA networks* of the "*island*" type, which then usually contain the infrastructure of only one BCF and several BTSs, covering a smaller part of the territory of special interest.

References

-123seminarsonly. 2004. *Seminar-Reports, Tetra Presentation* [online]. Available at: http://www.123seminarsonly.com/Seminar-Reports/020/46071512-Rk-6-Tetra-Presentation.pdf [Accessed: 1 February 2021].

Dunlop, J., Girma, D. & Irvine, J. 1999. *Digital Mobile Communications and the TETRA System*. New York: John Wiley & Sons, Ltd. ISBN: 0-471-98792-1.

-ETSI-European Telecommunications Standards Institute. 1995. *ETS 300 391-1. Universal Personal Telecommunication (UPT); Specification of the security architecture for UPT phase 1; Part 1: Specification* [online]. Available at: https://www.etsi.org/deliver/etsi_i_ets/300300_300399/30039101/01_60/ets_30039101e01p.pdf [Accessed: 1 February 2021].

-ETSI-European Telecommunications Standards Institute. 1996. *ETS 300 392-2. Radio Equipment and Systems (RES); Trans-European Trunked Radio (TETRA); Voice plus Data (V+D); Part 2: Air Interface (AI)* [online]. Available at: https://www.etsi.org/deliver/etsi_i_ets/300300_300399/30039202/01_60/ets_30039202e01p.pdf [Accessed: 1 February 2021].

-ETSI-European Telecommunications Standards Institute. 2009. *ETSI EN 300 392-1 V1.4.1 European Standard (Telecommunications series); Terrestrial Trunked Radio-TETRA; Voice plus Data (V+D); Part 1: General nerwork desing* [online]. Available at: https://www.etsi.org/deliver/etsi_en/300300_300399/30039201/01.04.01_60/en_30039201v010401p.pdf [Accessed: 1 February 2021].

-ETSI-European Telecommunications Standards Institute. 2019. *ETSI TS 100 392-2 V3.9.1. Technical Specification. Terrestrial Trunked Radio (TETRA); Voice plus Data (V+D); Part 2: Air Interface (AI)* [online]. Available at: https://www.etsi.org/deliver/etsi_ts/100300_100399/10039202/03.09.01_60/ts_10039202v030901p.pdf [Accessed: 1 February 2021].

Krstić, M. & Marjanović Jakovljević, M. 2018. Primena TETRA sistema u Vojsci Srbije. In: *Sinteza 2018 - International Scientific Conference on Information Technology and Data Related Research,* Belgrade, pp.210-216, April 20 (in Serbian). Available at: https://doi.org/10.15308/Sinteza-2018-210-216.

-Motorola Solutions. 2008. *DIMETRA™ System Documentation-Dimetra IP D6.2SR: Dimetra IP System Overview.* London, UK: Motorola Solutions Ltd.

Nouri, M. 2016. *TEDS Colloquium: TETRA Enhanced Data Service (TEDS), slides 1-15* [online]. Available at: https://cupdf.com/document/tetra-enhanced-data-service-teds-5689e2a49ebfe.html [Accessed: 1 February 2021].

Ovchinnikov, A.M., Vorobev, S.V. & Sergeev, S.I. 2000. *Otkrytye standarty cifrovoj trankingovoj radiosvjazi*. Moscow: MCNTI, OOO Mobilnye kommunikacii (Ser. izd. Svjaz i biznes). ISBN: 5-93184-008-7. (In the original: Овчинников, А.М., Воробьев, С.В., Сергеев, С.И. 2000. *Открытые стандарты цифровой транкинговой радиосвязи*. Москва: МЦНТИ, ООО "Мобильные коммуникации" (Сер. изд."Связь и бизнес"). ISBN 5-93184-008-7).

-Rohde & Schwartz. 1994. *ACCESSNET The Trunked Mobile Radio System for Professional Users* [online]. Available at: https://fordonsradio.se/wp-content/uploads/2018/01/accessnet-rs.pdf [Accessed: 1 February 2021].

Svrzić, S. 2021. 25 years of the TETRA standard and technology for contemporary digital trunking systems of professional mobile radio communications. *Vojnotehnički glasnik/ Military Technical Courier*, 69(2), pp.426-460. Available at: https://doi.org/10.5937/vojtehg69-29340.

Svrzić, S. & Ćosović, D. 2000. Analogni tranking sistem mobilnih radio-veza (special report - separat). *Novi glasnik*, 1, pp.3-18 (in Serbian).

Svrzić, S. & Ćosović, D. 2002a. Comparative analysis of the standards for digital trunked mobile radio systems. *Vojnotehnički glasnik/Military Technical Courie*r, 50(6), pp.567-588 (in Serbian). Available at: https://doi.org/10.5937/vojtehg0206567S.

Svrzić, S. & Ćosović, D. 2002b. TETRA novi standard za digitalne tranking sisteme mobilnih radio-veza (special report - separat). *Novi glasnik*, 2-3, pp.3-36 (in Serbian).

Swan, D. 2015. 20 years of TETRA Technology. *RadioResource International*, quarter 2 [online]. Available at: https://radioamador.files.wordpress.com/2012/04/revista.pdf [Accessed: 1 February 2021].

ОПИСАНИЕ ТЕХНОЛОГИИ И СТАНДАРТА TETRA 1 ДЛЯ СОВРЕМЕННЫХ ЦИФРОВЫХ ТРАНКИНГОВЫХ СИСТЕМ ФУНКЦИОНАЛЬНОЙ МОБИЛЬНОЙ РАДИОСВЯЗИ

Сладжан М. Сврзич[а], *Петар* Йованоски[б]

[а] ООО “Тесла системи“, г. Белград, Республика Сербия, **корреспондент**
[б] EVN Macedonia, г. Скопье, Республика Северная Македония

РУБРИКА ГРНТИ: 49.00.00 СВЯЗЬ:
49.33.00 Сети и узлы связи;
49.33.29 Сети связи
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: В конце 1995 года TETRA MoU уже продвигал новый стандарт TETRA в рамках ETSI, который предварительно был назван TETRA 1, и очень скоро стал использоваться, почти

исключительно, для создания функциональных цифровых транкинговых систем УВЧ для мобильной радиосвязи.

Методы: В данной статье описаны важные вопросы по технологии стандарта TETRA 1 и приведен анализ существующих спецификаций с подробным представлением радиоинтерфейса.

Результаты: В данной статье подчеркиваются многочисленные преимущества радиосистем, соответствующих стандарту TETRA по сравнению с функциональными системами аналогового транкинга мобильной радиосвязи, приведен обзор базового пакета спецификаций для реализации системы соответствующей стандарту TETRA 1. В статье также описаны интерфейсы, используемые в системе, с особым акцентом на описание радиоинтерфейса, организованного по TDMA, и метод интегрированной передачи речи и данных. Представлены организация и основные элементы сетевой инфраструктуры TETRA, а также элементы оборудования конечного пользователя, в том числе приведен анализ возможных практических архитектур сетей мобильной радиосвязи, основанных на данном стандарте.

Выводы: После обобщенных описаний технологии, организации и архитектуры внимание было обращено на: основную концепцию организации использования сети TETRA 1, общий принцип организации связи мобильных пользователей и основные элементы сети TETRA, а также на архитектуру и топологию построения сети TETRA 1.

Ключевые слова: Мобильная радиосвязь-MR, профессиональная система мобильной радиосвязи-PMR, аналоговая транкинговая система, цифровая транкинговая система, TDMA, радио-эфирный интерфейс, цифровая транкинговая система мобильной радиосвязи -TETRA, ETSI.

ОПИС ТЕХНОЛОГИЈЕ И СТАНДАРДА TETRA 1 ЗА САВРЕМЕНЕ ДИГИТАЛНЕ ТРАНКИНГ СИСТЕМЕ ФУНКЦИОНАЛНИХ МОБИЛНИХ РАДИО-КОМУНИКАЦИЈА

Слађан М. Сврзић[а], *Петар* Јованоски[б]

[а] Тесла системи д.о.о., Београд, Република Србија, **аутор за преписку**
[б] EVN Macedonia, Скопље, Република Северна Македонија

ОБЛАСТ: телекомуникације
ВРСТА ЧЛАНКА: прегледни рад

Svrzić, S. et al, Description of the TETRA 1 technology and standard for modern digital trunking systems of functional mobile radio communications pp.687-726

Сажетак:

Увод/циљ: Од краја 1995. године, од када је TETRA MoU у оквиру ETSI промовисао нови стандард TETRA, условно назван TETRA 1, брзо је, скоро искључиво,почео да се користи за изградњу функционалних УХФ система дигиталних транкинг мобилних радио-комуникација.

Методе: Наведена су релевантна питања из технологије и стандарда TETRA 1 и анализиране постојеће спецификације, уз детаљнији приказ радио-интерфејса.

Резултати: Истичу се бројне предности које радио-системи по стандарду TETRA имају у односу на функционалне системе аналогних транкинг мобилних радио-комуникација. С тим у вези, представљен је основни пакет спецификација за реализацију система по верзији стандарда TETRA 1. Описани су интерфејси примењени у систему, са посебним освртом на радио-интерфејс, организован по TDMA, као и начин интеграције преноса говора и сигнала података. Приказана јеорганизација, као и основни елементи инфраструктуре мреже TETRA и терминалне учесничке опреме, па се анализира могућност практичних архитектура мрежа мобилних радио-комуникација по том стандарду.

Закључак: Након општих описа технологије, организације и архитектуре, посебно су приказани: основна концепција организације употребе мрежа TETRA 1, општи принцип организације веза мобилних учесника и основни елементи мрежа TETRA, те архитектура и топологија изградње мрежа TETRA 1.

Кључне речи: мобилне радио-комуникације – MR, функционалне мобилне радио-комуникације – PMR, аналогни транкинг, дигитални транкинг, TDMA, радио-интерфејс, дигитални транкинг систем мобилних радио-комуникација – TETRA, ETSI.

Paper received on / Дата получения работы / Датум пријема чланка: 14.02.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 07.06.2021.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 09.06.2021.

ПИСМА УРЕДНИКУ
ПИСЬМА РЕДАКТОРУ
LETTERS TO THE EDITOR

COMMENTS ON THE ARTICLE "MONITORING COVID-19 IS LIKE INSTRUMENT FLYING"

David D. Pokrajac
Delaware State University,
Department of Computer and Information Sciences,
Dover, USA;
University of Niš, Faculty of Science and Mathematics,
Department of Computer Science,
Niš, Republic of Serbia,
e-mail: majstorpoki@gmail.com,
ORCID iD: https://orcid.org/0000-0002-8362-1245

DOI: 10.5937/vojtehg69-32707; https://doi.org/10.5937/vojtehg69-32707

FIELD: Mathematics
ARTICLE TYPE: Letter to the Editor

Dear Editor of the *Military Technical Courier*,

I have read the article "Monitoring COVID-19 is like instrument flying" by Petar V. Kočović, University Union "Nikola Tesla", School for Information Technology and Engineering, Zoran V. Kočović, Omni Logika, and Vladimir P. Kočović, IGT, all from Belgrade, published in *Vojnotehnički glasnik/Military Technical Courier* Vol. 68, No. 3, pp.424-437, doi: https://doi.org/10.5937/vojtehg68-26557. I would like to share with you and the audience of your Journal my professional opinion about the article. Note the opinion expressed is my personal, and as such does not reflect nor communicate the opinion or viewpoints of my employer or any professional or other organizations I may belong to. Note also that prior to communicating to your journal, I have attempted to obtain clarifications directly from the first author, but with no success.

The purpose of the article is to propose the methodology to predict the duration of a Covid-19 epidemic wave (and potentially applicable to any other epidemics of infectious deceases). The central assumption of the article is that the number of new cases per day follows a simple curve (a Gaussian curve) and that, by using the number of cases from the left

Pokrajac, D., Comments on article "Monitoring COVID-19 is like instrument flying", pp.727-733

tail of the curve, we can predict the parameters of the curve. The second assumption is that the epidemic wave can be considered over when the input variable (time) is several standard deviations away from the estimated center of the Gaussian curve on its left tail.

Based on the Statement of the Journal Purpose (as cited from http://www.vtg.mod.gov.rs/about-journal.html:

"*The journal publishes scientific and professional papers covering fundamental research (mathematics, computer science and mechanics) and technological development (electronics, telecommunications, information technologies, mechanical engineering, material science and chemical technologies) as well as technical data on modern weapon systems and military technologies*."), the article may be out of scope of the Journal.

My professional opinion is that the article is methodologically weak.

The central assumptions of the article, as I summarized them above, have never been clearly stated nor justified. The authors claim, page 428:

"The infections start outgrowing exponentially at first, then whatever response the host country enacts, after some time, new infections go back to near zero. At least this is the back-of-the-envelope theory, developed by Enrico Fermi."

No reference for this was provided. However, I was able to find an Internet article https://towardsdatascience.com/the-gaussian-model-4a94a2b3ff1b that contains a figure *identical* to Fig. 4 of the paper in question as well as the identical sentence as quoted from the paper (see above). Eq. (3) from the paper also appears in the Internet article and is not as such referenced in this paper. Note that the publication date of the Internet article is 3/25/2020. I could not determine the exact submission date of the paper in question. However, since the paper discusses actual data from May 10, 2020, this paper was very likely submitted *later* than the Internet publication containing the same graph and the same sentence, which was not referred to in the paper. Also, the figure *identical* to Fig. 5 of the paper can be found on the Internet, at http://deptche.ccu.edu.tw/exam/104phychem.pdf. My opinion is that these question the originality of the approach and the paper itself as published in your Journal.

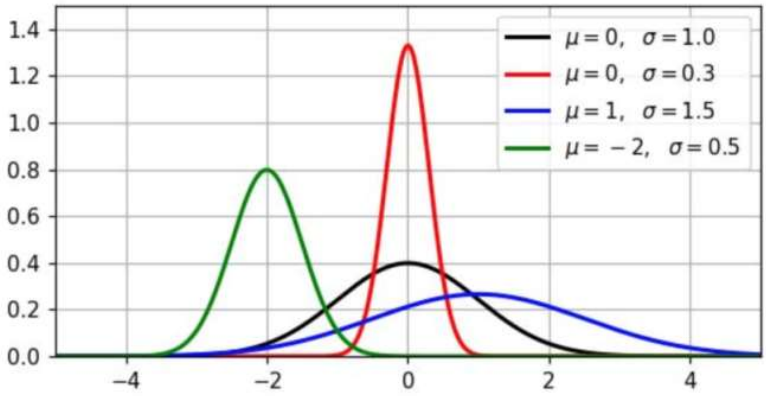


Figure 4 – The Normal, or the Gaussian curve
Рис. 4 – Кривая нормального распределения Гаусса
Слика 4 – Нормална или Гаусова крива

Figure 1 – Figure 4 from Kočović et al, submitted on or after 5/10/2020

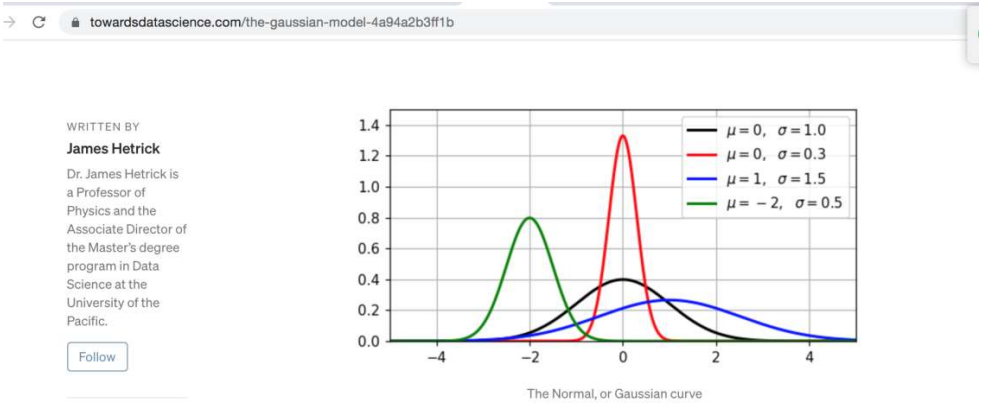


Figure 2 – Figure and text published on the Internet 3/25/2020

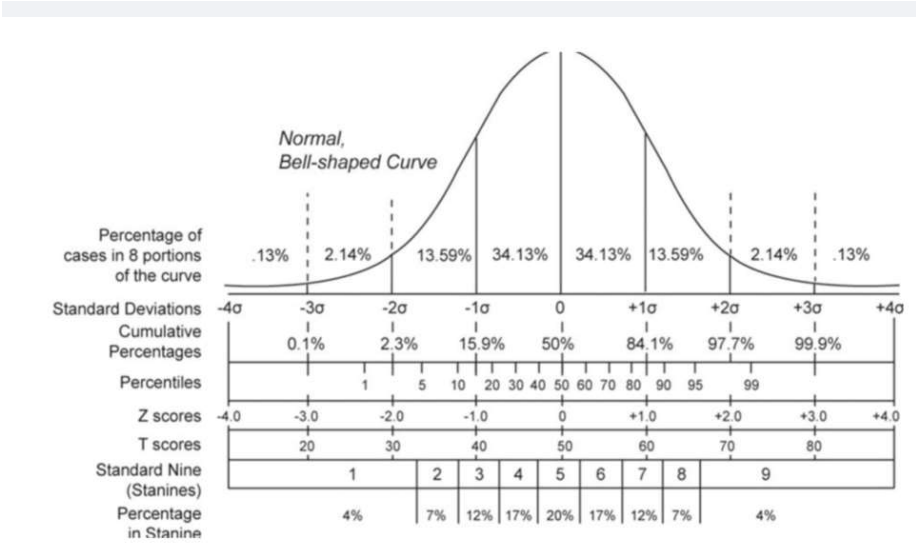


Figure 5 – Gaussian distribution extended to 8 SIGMA
Рис. 5 – Кривая распределения Гаусса расширена за 8 СИГМ
Слика 5 – Гаусова расподела проширена на 8 СИГМА

Figure 3 – Fig. 5 from Kočović et al

deptche.ccu.edu.tw/exam/104phychem.pdf

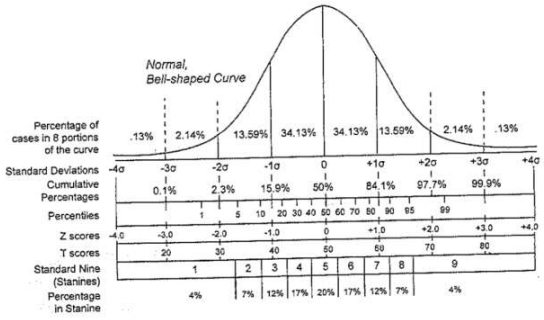


Figure 4 – A figure, identical to Fig. 5 from Kočović et al, can be found on the Internet

Generally, the article does not seem to contain model validation. It is not clear how *well* the model determines the end of an epidemic wave. Specifically, according to the article (page 430), “The forecasted day of

the 7σ is May 26, 2020"; however, it is not possible to determine the accuracy of this prediction based on the article.

Further, the authors make several claims that are not substantiated nor supported by references. On page 429, they state:

"A mathematical model can calculate the whole distribution if histograms are covered with more than 50% of the data"

and later, on the same page:

"*The algorithm calculates distribution if the minimum 3 SIGMA conditions are fulfilled, and there are no extreme peaks in one day."*

It is not clear how "3 SIGMA conditions" are checked and where the condition is defined. Further in the paper, the authors introduce "7-sigma day" (pages 430 and 433) and "8-sigma" model (page 429) but there is no indication whether here 7(8) relates to the width of the *symmetric* interval around the center of the curve (i.e., corresponding to ±3.5 sigma, ±4 sigma) as could be deduced from Fig, 5. Since the important prediction of the end of the epidemic is based on the definition of this criterion, the criterion should have been explicitly and exactly defined in the article.

The following sentences on page 432 are not clear:

"The Gaussian curve can calculate the date of the end of the epidemic with a probability of 99.9996%. This means that the chances are ONE in a MILLION for citizens to become ill with COVID-19 after the Gaussian distribution has ended."

Specifically, how the probability of 99.9996% is related to 1/1,000,000 odds and what is the meaning of "after he Gaussian distribution has ended" i.e. how the distribution can "end"?

It is not clear why the (logistic) sigmoid has been introduced, pages 431-2:

"On the other hand, the authors found a link between Gaussian and Boltzmann or Sigmoid (S) curves."

If the authors needed a definite integral of a Gaussian curve, they could have expressed it using the *erf* function which can be easily numerically calculated.

The authors introduce a "double logarithmic curve" to link the number of newly infected daily and the cumulative number of the infected. It is not well justified why such a graph is needed and how the "7-sigma" criterion could be satisfied in Fig. 7d but not be satisfied in Fig. 9a (since the same data with different representations are used).

The source for the data shown in Figs. 1,2,3,7,8,and 9 is not specified. Similarly, the source for the Serbian data (page 430) is not

specified. When discussing the results for Serbia, it is not defined what "Accuracy of the Gaussian model" is (seems to be the ratio between the cumulative number of the infected as estimated by the model and the true number of cases) nor it is clear what the consequence of the obtained value is (whether the accuracy is good or bad and why). The "area fraction" is not well defined.

The authors utilize the terminology which may not be appropriate. What was shown in Figs. 2 and 3 are *not* histograms but bar plots. Similarly, a "double logarithmic curve" is in fact a log-log plot. The authors claim, page 429, that "the alternative names for the Gaussian distribution are 6 SIGMA or LEAN 6 SIGMA" which does not seem to be correct. Also, some language in the article (footnote, page 428, "The term Back of the envelope calculation is a rough calculation. It is more than a guess, but less than a mathematical proof.", page 430: "As it is shown, the model can predict, mathematically, the end of the epidemic. But, one thing is mathematics, another is real life", as well as the title of the article "MONITORING COVID-19 IS LIKE INSTRUMENT FLYING") is imprecise and colloquial and as such should be avoided in scientific communication.

I strongly believe that the publication of these Comments in your esteemed Journal is necessary part of scientific communication and will contribute to the quality of the Journal and help your readership.

КРИТИЧЕСКИЙ ОБЗОР СТАТЬИ «MONITORING COVID-19 IS LIKE INSTRUMENT FLYING»

Давид Д. Покраяц

Государственный Делавэрский университет,
департамент компьютерных и информационных наук,
г. Довер, США;
Нишский университет, естественно-математический факультет,
департамент компьютерных наук,
г. Ниш, Республика Сербия

РУБРИКА ГРНТИ: 27.00.00 МАТЕМАТИКА;
27.43.17 Математическая статистика,
27.43.51 Применение теоретико-вероятностных и статистических методов
ВИД СТАТЬИ: письмо редактору

КРИТИЧКИ ОСВРТ НА ЧЛАНАК “MONITORING COVID-19 IS LIKE INSTRUMENT FLYING”

Давид Д. Покрајац

Државни универзитет у Делаверу,
Департман за рачунарске и информационе науке,
Довер, САД;
Универзитет у Нишу, Природно-математички факултет,
Департман за рачунарске науке,
Ниш, Република Србија

ОБЛАСТ: математика
ВРСТА ЧЛАНКА: писмо уреднику

Paper received on / Дата получения работы / Датум пријема чланка: 10.06.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 22.06.2021.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 24.06.2021.

ANSWERS TO THE COMMENTS ON THE ARTICLE "MONITORING COVID-19 IS LIKE INSTRUMENT FLYING" SUBMITTED BY DAVID D. POKRAJAC

Petar V. Kočović
University Union "Nikola Tesla", School for Information Technology and Engineering, Belgrade, Republic of Serbia,
e-mail: petar.kocovic@fpsp.edu.rs
ORCID iD: https://orcid.org/0000-0001-8289-1385

DOI: 10.5937/vojtehg69-32740; https://doi.org/10.5937/vojtehg69-32740

FIELD: Mathematics
ARTICLE TYPE: Letter to the Editor

Background

The authors of the article mentioned in the title received a Letter to the Editor submitted by Mr. David Pokrajac, on June 11, 2021 (Pokrajac, 2021). Mr. Pokrajac and the wider public and readers must take into consideration the following facts:

1. This paper[1] was submitted for printing on April 30, 2020,
2. A pre-final version was submitted about 15 days before the final submission, and
3. Some mathematical models, originally developed by the authors, were not published in this article nor on the website of the team of the authors, because the model did not show stability at the time of publishing. During the process of writing this paper, we expected that some data for relevant countries would show better fitting, but this did not happen until April 15, 2020. (Kočović et al, 2021)

Momentum 1

The Covid-19 pandemic in the world, on 15th of April, 2020 A.D., showed the following:

1. In the world, this was the 86th day of the pandemic,
2. In Serbia, this was the 41st day of the pandemic, and
3. In some countries, following the World Health Organization (WHO) guidelines, the counting of the number of infected people was

[1] In this paper, six new instruments were published. At the time of publishing the original paper, only two were published.

changed. In China, this happened on February 17, 2020, when they reported 17,778 cases after 2,450 on average before, and 226 after the change, Figure 1.

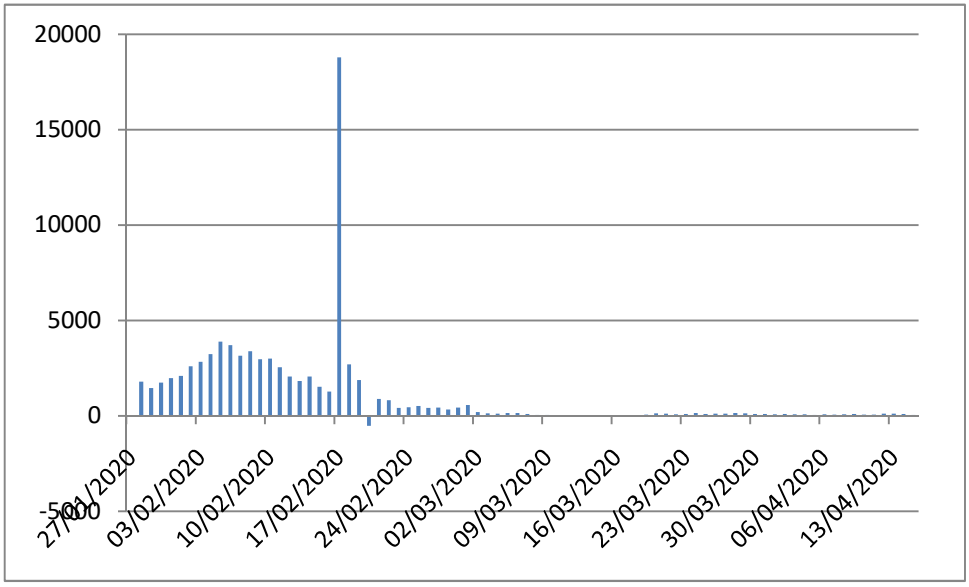


Figure 1 – Histogram of the infected people on a daily basis in China in January 27-April 15, 2020

The same situation happened in Columbia on April 25, 2020, Figure 2.

4. After we had submitted this paper, some countries (e.g. the UK and France) reported a much lower number of infected people, and they kept this smaller number as a new start point. Strange. Although we expected a dramatic reduction in the number of the infected, it did not happen until the submission of our paper (Kočović et al, 2020).

So, our first calculations presented in this paper were basic. What does this mean?

We used only the basic Gauss-Laplace equation/distribution that can be found everywhere. Our main literature sourcebook was Prem Mann (Mann, 1994) which shows the application of the Gauss Normal distribution in many situations, two of them being: i) distribution sales process and ii) the swine flu pandemic monitoring in 2008-2009. We took Figure 4 in our paper from Wikipedia. All figures from Wikipedia are free

for borrowing and publishing in all types of papers and almost all publishing houses accept this. The same situation is with Figure 5 in our paper.

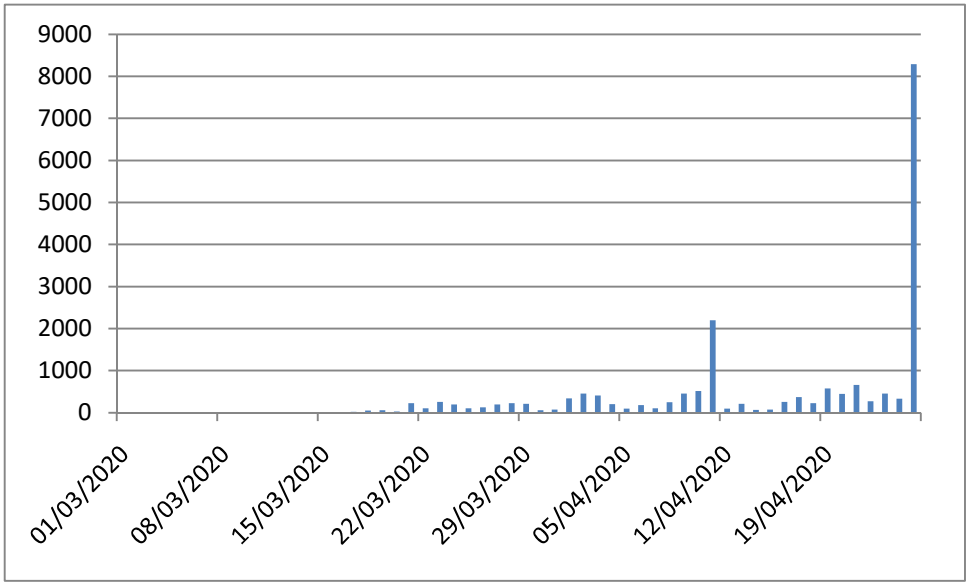


Figure 2 – Histogram of the infected people on a daily basis in Colombia in March 1-April 25, 2020

What had we already prepared in our mathematical model, but did not publish?

We studied all well-known distributions: Binary, Binomial, Fisher, and Student. Only the Gaussian distribution satisfied specified criteria at that time for our forecasting model, but we understand that we will have problems in the future. We developed our model, but we did not know how to call it. At the time, we understood that we had just one part of the distribution (from the beginning to the specific point, left-side) and that for another part we had to calculate using the Method of Least Squares. What first came to our mind was the Kirlian model, named after Soviet inventor Semyon Kirlian who made his famous set of photos where he "added" missing parts. However, giving personal names was not a good idea. We found the "Back-of-the-Envelope" theory developed by Enrico Fermi. Looking for a good name of the technique, the authors thought that this was a good name for the task we had done. Very soon, the

authors found new methodology, the Levenberg-Marquardt algorithm[2] (Wikipedia, 2021). The Levenberg-Marquardt algorithm was the best that the authors found for the non-linear least-squares minimization and curve fitting.[3] When this algorithm was published as a Python library – the authors did not have a dilemma to use this one. Today, but not at the moment of writing the paper, the authors are using two other algorithms. In order to avoid confusion, it should be mentioned that, before publishing the paper, the authors found that two other teams were working using the same model:

1. The University of Singapore (their web site was last seen around May 1, 2020). The authors did not know what mathematical model they used, but a set of data was not equal. The results were very similar to ours. (SUTD Data-Driven Innovation Lab, 2020)
2. Governor Andrew Cuomo's (New York State, USA) speech about the Covid-19 situation (McKinsey, 2020). In his speech, Cuomo discussed possible future pandemic flow and measures that will be used in the future. He used the McKinsey methodology based on the Gaussian Normal distribution.

What did we not publish in our paper? What was not clear at that moment?

Using the Least Squares Minimization Method, we calculated the end of the wave. At that time, it was not clear whether there would be multiple waves. So our statement that the wave will be finished until the publishing date was not correct. Even China did not exit from wave 1. Today we know that all countries are in different phases/waves (from one to four) but at that time this was not visible. In the next months, we adjusted the residual number using our method. This method is shown in Figure 3 below. This is our INSTRUMENT 2.

[2] At the moment of publishing, the Levenberg-Marquardt algorithm was just one of the considerations for the fitting techniques.

[3] Today, but not at the moment of writing the paper, the authors are using two other algorithms: SciPy and Astropy (LMFIT.github, 2021). Also, the SciPy library has some improvements after the publishing of the paper and our calculations are more precise than at the beginning.

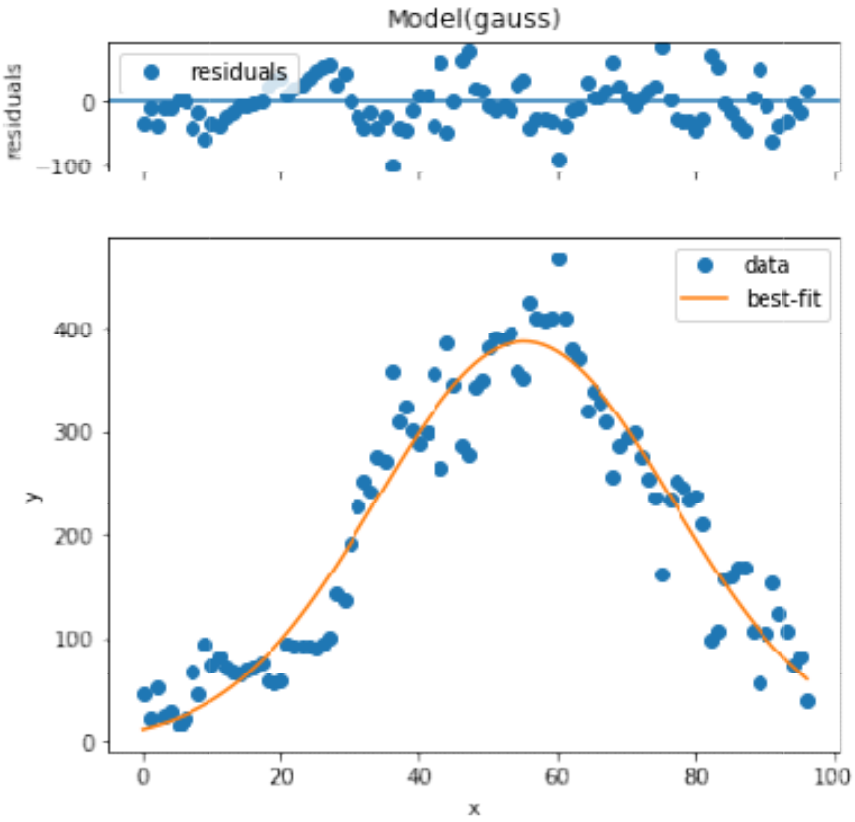


Figure 3 – INSTRUMENT 2: Fitting a Gaussian curve using residuals. Example – Serbia, May 13-August 31, 2020

At the very beginning, we used Microsoft Excel libraries. Soon we shifted to the programing language Python that has additional mathematical libraries for Machine Learning. Figure 3 is the result of our development. The only thing we adjusted during the time is a residual value.

The Sigmoid or S-curve was calculated simply. Calculating a Gaussian curve for every single day in the histogram, and smoothing the S-curve after the 3 SIGMA can be carried out very easily: we can add values to the existing 3SIGMA values, Figure 4.

At the time of writing the paper, the authors thought that a good way of presenting data is to use a log-log curve. In a similar way, a velocity

trajectory is presented in mechanics. The base for calculations is the 7-day average number of infected people. The same results are obtained if a logarithmic function is first calculated over the data which are then plotted on the diagram. More details are given in the video (Kočović, 2020a) which explains why this technique is good when we compare several countries.

Momentum 2

Between 80 and 100 days from the beginning of a wave (in some cases duration was up to 300 days), the wave ended. The next day after a wave ended, a new wave began. As a general rule (defined by the WHO), the pandemic in each particular country will end when 28 days have passed without a new infected case. Some countries, like Spain or Sweden, did not report cases every day. Saturdays and Sundays were the days off for their bio-informatic personnel, so the WHO did not publish results on a daily equidistant basis. To resolve this conflict, we introduced moving averages based on 5 days. But a new question arises: which country is more infected if we want to compare two countries? We accept the criterion of the ECDC (European Centre for Disease Prevention and Control):

„calculation using the sum of infected people in previous 14 days on the base of 100,000 citizens“

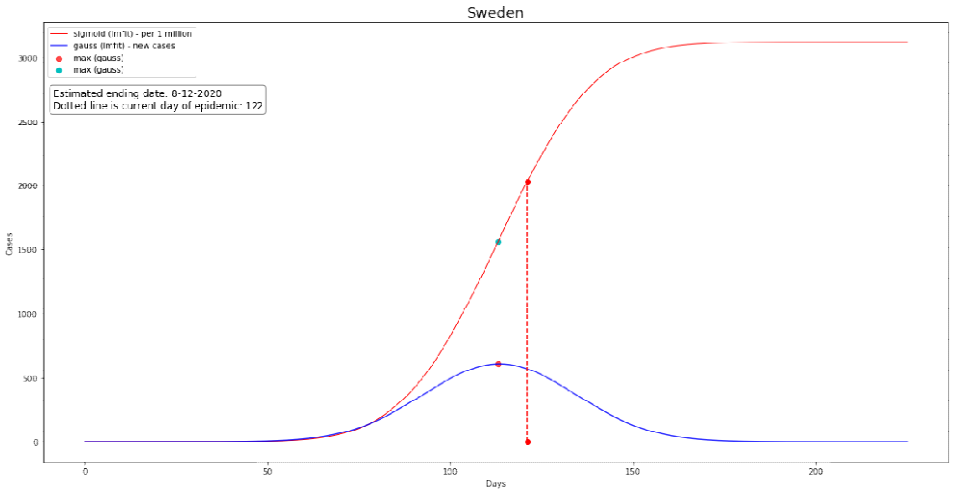


Figure 4 – Gaussian (blue) and Sigmoid (red) curves are plotted in one diagram.

This definition does not divide the sum with 14 (days). Instead, the algorithm keeps the sum for 14 days, Figure 5. Reason? Sums give us better perception! Using this index, the ECDC defined 3 zones:

Green – ECDC (0-15),
Yellow – (16-30), and
Red – (31-50).

The authors extended this definition with the next 9 zones:
51-100 – Red-violet,
101-150 -Violet,
151-300 – Deep violet,
301-500 – Popstar,[4]
501- 1000 – Grey,
1001 – 3,000 – Black,
3,001- 5000 – Onyx Black,
5,001 – 10,000 - Vanta Black, and
10,001+ - MIT Black.

Maldives and the Seychelles reached 2,900 indexes, as the highest in this pandemic until the moment of the publication of this answer!

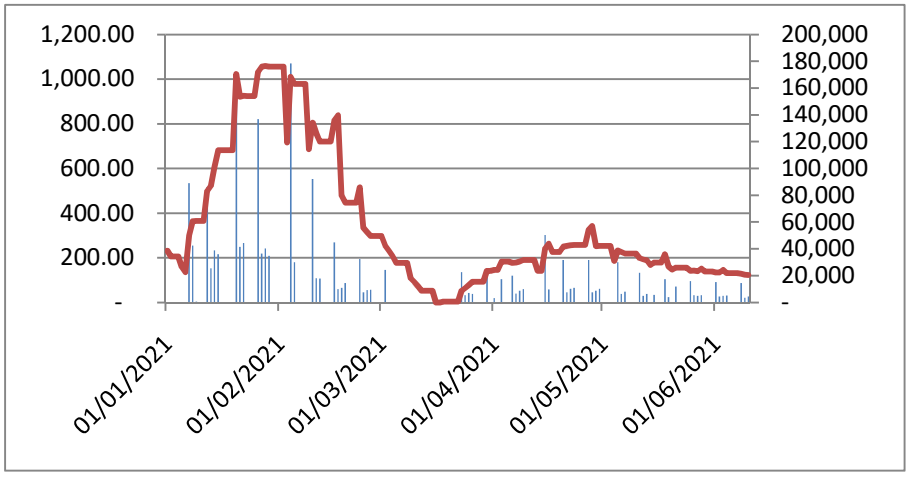


Figure 5 – Spain in the period Jan1-August 11, 2021. The blue bars are the daily numbers of infected people. The red line is the ECDC index. Note that the Spanish Ministry of Health report four days of cases, followed by the next 3 days without reported cases.

[4] See Pantone scale

The line with the ECDC coefficient is much smoother than the daily histogram. But, for better forecast, the authors still used the right-side, nonvisible Gaussian curve fitting model for predicting the end of the wave. So, here is a new, state-of-the-art presentation in the field of visual presentations, Figure 6.

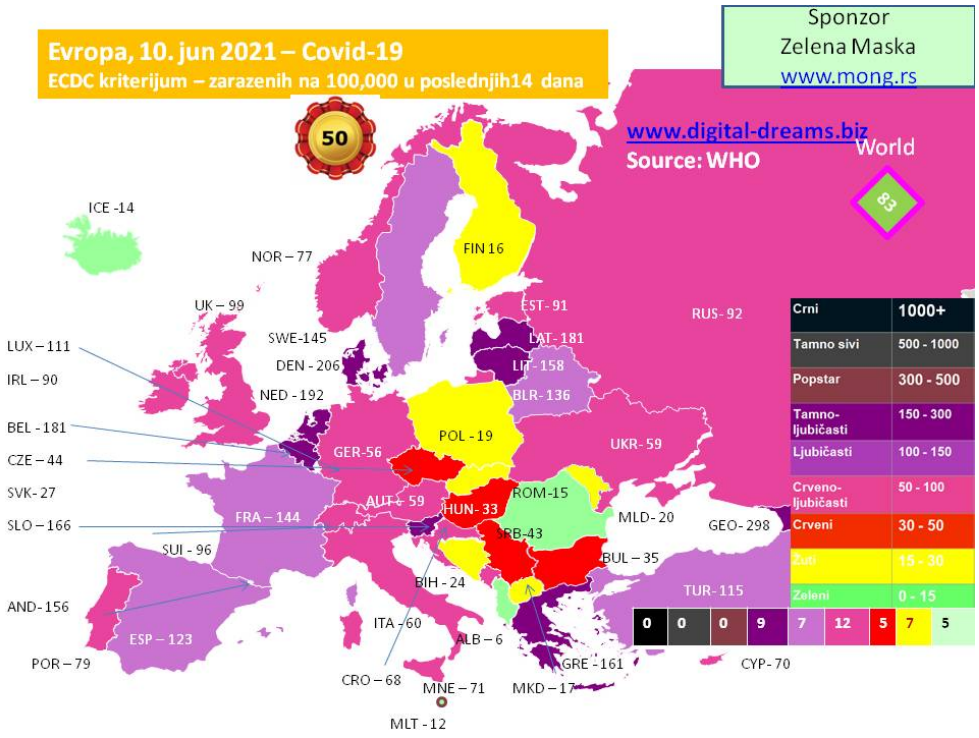


Figure 6 – INSTRUMENT 3: ECDC coefficient for each European country

Vaccination

Vaccination started in December 2020. Until June 11, 2021, 208 countries started with vaccination (Kočović et al, 2021b). Monitoring vaccination is an especially hard task because no authority is collecting data.

The authors developed a special crawler to collect such data from the National Health Bodies from every single country. Few websites such as Our World of Data (Our World in Data, 2021) are collecting data about vaccination but there are small differences in the number of vaccinated people with the first or second dose.

Kočović, P., Answers to the Comments on the article "Monitoring COVID-19 is like instrument flying" submitted by David D. Pokrajac. pp.734-748

There is also a difference between our and their last records of collected data.

An example of vaccination with the first and second dose compared with the ECDC coefficient, using the Serbian data, is shown in Figure 7.

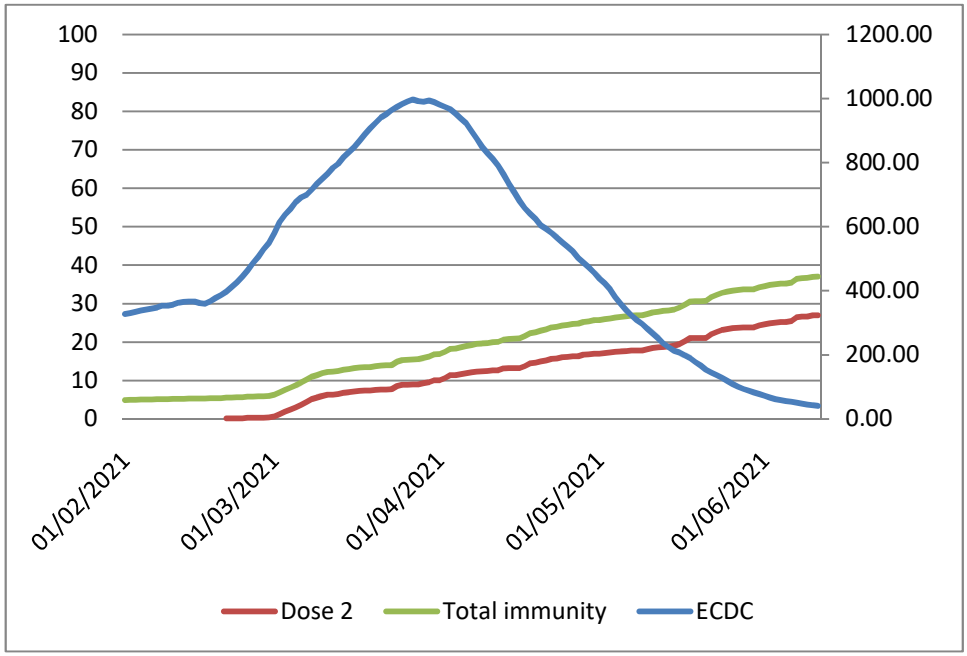


Figure 7 – INSTRUMENT 4: Immunization process in Serbia. Total immunity represents the number of the vaccinated with dose 2 plus the number of those recovered from Covid-19

The leader in vaccination was Israel and this country is the template for comparing the data between two or more countries globally.

To monitor the tempo of vaccination, and for a comparison between two or more countries, the authors have developed a mathematical model based on two-factor regression, Figure 8.

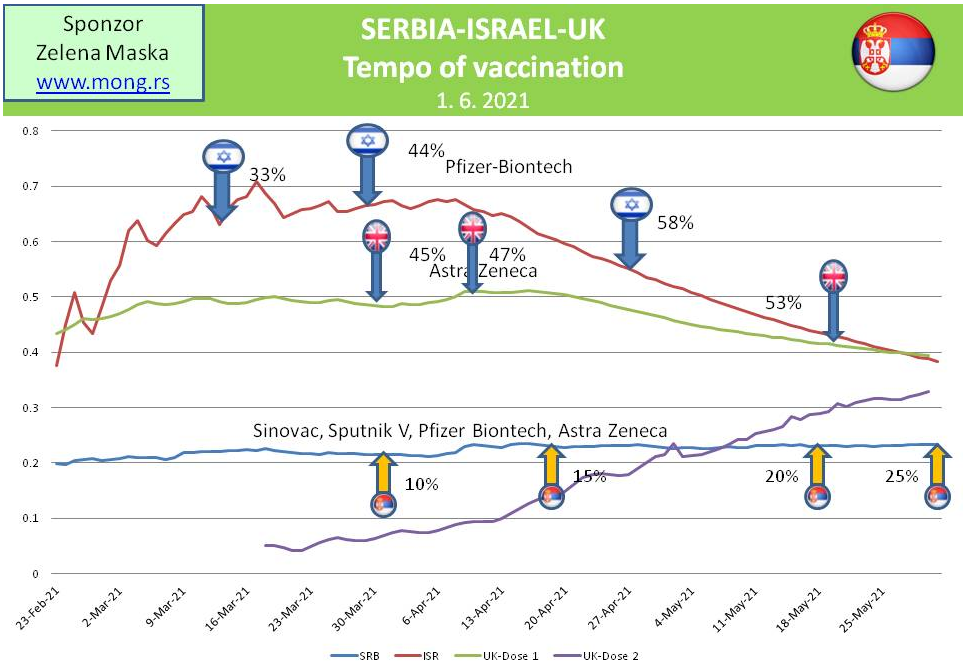


Figure 8 – INSTRUMENT 5: Israel vs the UK vs Serbia. Every line is two-factor regression data calculated for every single day. The period shown in the Figure is February 25-June 1, 2021. The arrows represent the points when Israel and the UK reached 33%, 44% and other important days in both countries when the mentioned countries removed special lockdown measures. In the case of Serbia, the arrows represent the dates when the country reached 10%, 15%, 20%, and 25% of the immunized population. (Note: Astra Zeneca takes 12 weeks between the first and second dose, Sinovac takes 4 weeks after the second dose. All other vaccines need 3 weeks after the second dose to reach full immunization.)

Momentum 3 – Extension of the mathematical model

The idea of the authors was to extend the existing mathematical models and to offer papers with the proven data to the *Military Technical Courier*. One of the basic ideas was an analysis of a wider look at the problem of the Covid-19 virus circulation in the coming months. The analysis consists of finding some correlations between the minimum sunspot number, CO_2 emission, and the start of the pandemics from 1900 until 2020 (Spanish flu, swine flu, avian flu (H5N1), and a Covid-19 storm).

The authors offered the paper with this specific topic to the *Military Technical Courier*, but the Editorial Board rejected it because it is out of the scope of the *Courier*. The authors uploaded the paper onto the ResearchGate.net website (Kocovic, 2020b).

The study analyzes the relation between the sunspot numbers and the start and the end (duration) of the specific pandemics in 20 and 21st centuries, as well as the link between CO_2 emissions. The sunspot numbers and the duration of each specific pandemic are presented in Figure 9.

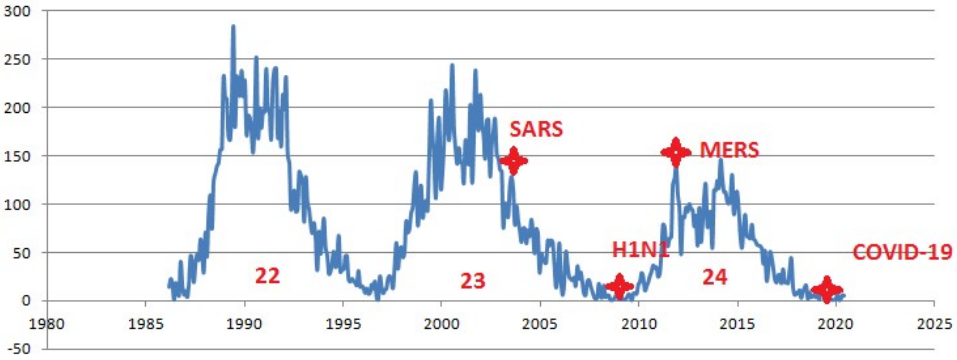


Figure 9 – Outbreaks of SARS, H1N1, MERS, and Covid-19 and their relation with the sunspot numbers and the 11-year intervals

The paper also puts into correlation CO_2 emission with the number of sunspots and possible problems during the winter season in the Northern Hemisphere. At that time, vaccines were under development.

At the beginning of autumn 2020, Covid-19 infection exploded in the Northern Hemisphere (populated by 87% of the world population), Figure 10. As stated in this paper, sunspots, which were on the decline, will take effect in the coming months. The Sun starts to emit more electromagnetic energy from an increasing number of sunspots (which was expected, see Figure 9) from the beginning of May 2021, and the number of the infected (expressed by the ECDC index) starts to drop dramatically.

Because of vaccination, a kind of a compound index was formed. This compound index consists of two parts: i) the percentage of the people vaccinated with the second dose, and ii) the percentage of the population affected by the UV rays class C+x rays rate that came to the Earth from the Sun. Sunspots appear on the Sun presenting an electromagnetic emission of protons and neutrons, visible from the Earth, and, in the spring and summer season, from the Sun's southern

hemisphere. Reason: explosions on the Sun can hit the Earth at the end of spring and during summer if they come from the Sun's southern hemisphere. For example, in the period from May 2nd until June 11th, 2021, in Serbia, the situation was as follows: a Gauss curve was not showing real data. The number of infected people declined more than the Gauss distribution showed. But, if we extract the number of vaccinated people with the 2nd dose (that was between 17 and 27 doses per hundred – there was still between 8 (around May 1st) and 14 (around June 10th) percent fewer of those infected than the Gauss distribution shows. This offset between 8 and 14% was the result of the Sun activity. The authors had only 45 days and did not find the right correlation, and an average of 11% was applied for a better calculation of the infected people. Also, the relation of 7-day sunspot numbers is in correlation with many EU countries (except Spain, Sweden, San Marino, and a few others, which report the number of the infected on a non-daily basis). Figure 10 shows the correlation between swine flu and Covid-19, taking into account only monitoring sunspots in the period 2004-2021.

The authors cannot develop a mathematical model for an exact duration of the pandemic, but the comparison between the last two solar cycles shows an idea about the end of the pandemic of Covid-19.

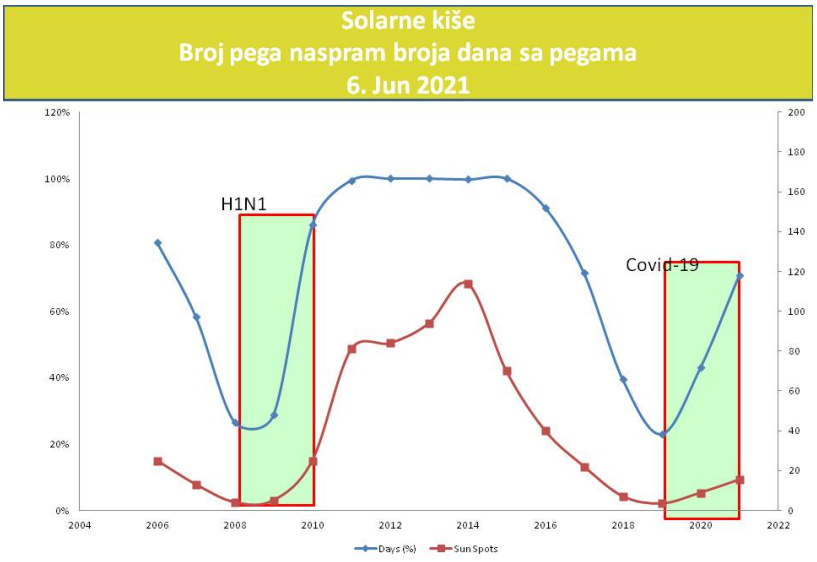


Figure 10 – INSTRUMENT 6: Sunspot numbers in the period 2004-2021. The blue line represents the number of days with sunspots. Note that a cycle of rising and declining in the number of sunspots is approximately 11 years.

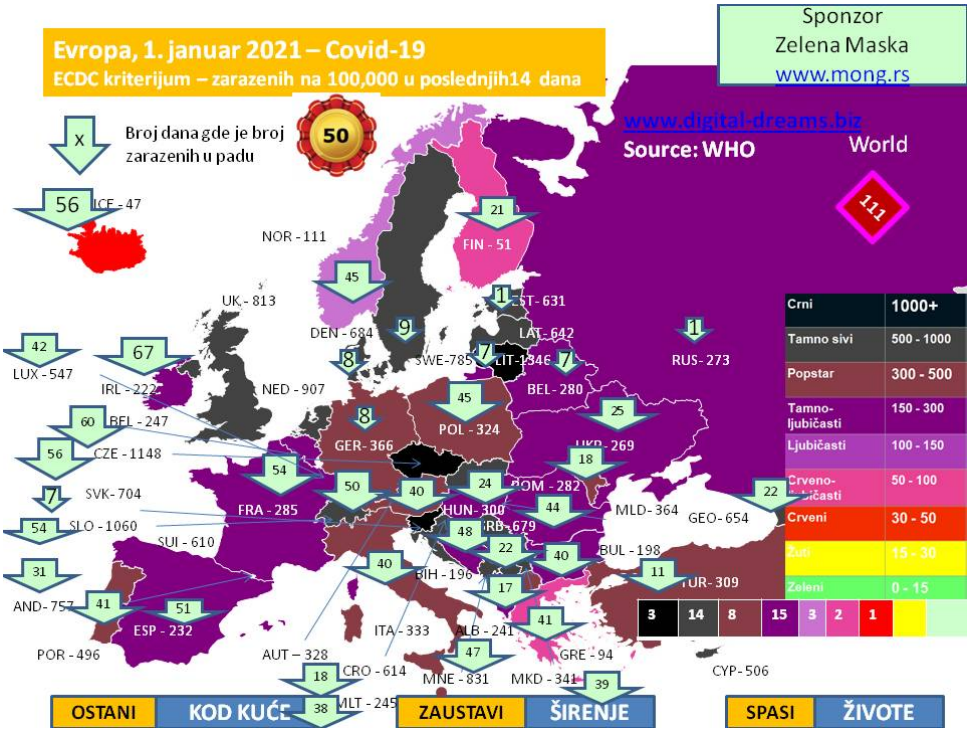


Figure 10 – ECDC coefficients for European countries on January 1, 2021. Compare this figure with Figure 6

Conclusion

The mathematical model presented in the *Military Technical Courier* was only the first approach to the problem. The authors knew that new algorithms had to be developed for monitoring pandemics. And they did it. The results were reported in all Serbian media.

It seems that a mathematical model that will include sunspot numbers and electromagnetic emission can be developed for monitoring the end of the pandemic. A team of authors carefully monitors this correlation and some results will be published when the correlation is found.

References

Kočović, P. 2020a. *Petar Kočović - Gausova kriva i prognoza COVID-19 epidemije* [online] Available at: https://www.youtube.com/watch?v=4kguYa7Po2U [Accessed: 12 June 2021].

Kocovic, P. 2020b. Covid-19 and sunspot number. *Research Gate*. Available at: https://doi.org/10.13140/RG.2.2.27404.44164.

Kočović, P.V., Kočović, Z.V.& Kočović, V.P. 2020. Monitoring COVID-19 is like instrument flying. *Vojnotehnički glasnik/Military Technical Courier*, 68(3), pp.424-437. Available at: https://doi.org/10.5937/vojtehg68-26557.

Kočović, P.V., Kočović, Z.V.& Kočović, V.P. 2021a. Petar Kočović's COVID-19 statistics and trends. *Digital Dreams* [online]. Available at: http://digital-dreams.biz/covid-19/index.php [Accessed: 12 June 2021].

Kočović, P.V., Kočović, Z.V.& Kočović, V.P. 2021b. *Private data base* (Data are collected from national health bodies).

-LMFIT.github. 2021. *Non-Linear Least-Squares Minimization and Curve-Fitting for Python Github* [online]. Available at: https://lmfit.github.io/lmfit-py/ [Accessed: 12 June 2021].

Mann, P.S. 1994. *Statistics for Business and Economics*. Hoboken, New Jersey: Willey. ISBN-10: 047111152X. ISBN-13: 978-0471111528.

-McKinsey. 2020. *COVID-19: Briefing Materials* [online]. Available at: https://www.mckinsey.com/~/media/mckinsey/business%20functions/risk/our%20insights/covid%2019%20implications%20for%20business/covid%2019%20april%2013/COVID-19-facts-and-insights-april-24.ashx [Accessed: 12 April 2020].

-Our World in Data. 2021. *Statistics and Research: Coronavirus (COVID-19) Vaccinations* [online]. Available at: https://ourworldindata.org/covid-vaccinations [Accessed: 12 June 2021].

Pokrajac, D.D. 2021. Comments on the article “Monitoring COVID-19 is like instrument flying”. *Vojnotehnički glasnik/Military Technical Courier*, 69(3), pp.727-733. Available at: https://doi.org/10.5937/vojtehg68-32707.

-SUTD Data-Driven Innovation Lab. 2020. [online]. Available at: https://ddi.sutd.edu.sg/ [Accessed: 1 May 2020].

-Wikipedia. 2021. *Levenberg–Marquardt algorithm* [online]. Available at: https://en.wikipedia.org/wiki/Levenberg%E2%80%93Marquardt_algorithm [Accessed: 13 June 2019].

ОТВЕТ НА КРИТИЧЕСКИЙ ОБЗОР «MONITORING COVID-19 IS LIKE INSTRUMENT FLYING», ПРЕДСТАВЛЕННЫЙ ДАВИДОМ Д. ПОКРАЯЦЕМ

Петар В. Кочович

Университет Унион «Никола Тесла», Факультет информационных технологий и инжиниринга, г. Белград, Республика Сербия

РУБРИКА ГРНТИ: 27.00.00 МАТЕМАТИКА;
27.43.17 Математическая статистика,
27.43.51 Применение теоретико-вероятностных и статистических методов
ВИД СТАТЬИ: письмо редактору

ОДГОВОР НА КРИТИЧКИ ОСВРТ ДАВИДА Д. ПОКРАЈЦА НА ЧЛАНАК “MONITORING COVID-19 IS LIKE INSTRUMENT FLYING”

Петар В. Кочовић

Универзитет Унион „Никола Тесла”, Факултет за информационе технологије и инжењерство, Београд, Република Србија

ОБЛАСТ: математика
ВРСТА ЧЛАНКА: писмо уреднику

Paper received on / Дата получения работы / Датум пријема чланка: 13.06.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 20.06.2021.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 22.06.2021.

Нова верзија шведског ловца *Gripen*[1]

Gripen E

Импресиван је податак да Шведска, која има око 10 милиона становника, и даље одржава домаћи програм ловца који је превасходно намењен домаћим потребама. *Saab Gripen* је мали и окретни ловац који испуњава врло специфичне шведске потребе, али иако је „доступан" у финансијском смислу, то не значи да је направљен било какав компромис у погледу убојитости. Најновија варијанта ловца *Gripen E* укључује и одређене компоненте које други произвођачи ловацанемају .

Gripen E можда изгледа исто као и претходни модели овог ловца, али се ипак ради о многим изменама, па је шведски произвођач *Saab* чак размишљао и о промени његовог назива. У ствари, Е серија се надовезује на претходне серије, једноседа *Gripen A* и двоседа *Gripen B,* као и на следећу серију која је следила, а то је *Gripen C/D*. *И*ако спољa личе, серија Е се умногоме разликује.

Први серијски ловац серије Е – *Gripen E* (6002) полетео је у новембру 2019. године.

[1] The War Zone, February 4, 2021

Vučković, D., SAVREMENO NAORUŽANJE I VOJNA OPREMA / MODERN WEAPONS AND MILITARY EQUIPMENT, pp.749-761

Порекло и иновације ловца Gripen E

Први прототип ловца *Gripen E* полетео је 15. јуна 2017. године. Авион је нешто већи од модела C, око 15,24 метра, али додатни резервоари за гориво у увећаном трупу носе 30 посто више горива. Опремљен је већим усисницима ваздуха, моћнијим мотором *General Electric F414-GE-39E* и са укупно 10 подвесних носача. Модел F је двосед и тренутно је у фази развоја, а намењен је за испоруку Бразилу који је поручио 36 модела E/F.

У децембру 2020. године, првих 60 авиона *Gripen E* испоручено је шведском ратном ваздухопловству где ће бити подвргнути тестирању ради одређивања накнадних модернизација.

Шведско ратно ваздухопловство је недавно објавило да ће серија C/D остати у оперативној употреби и након 2030. године, што ће омогућити увођење нове E серије од 2023. године.

Нови *Gripen E* има 30 посто већи капацитет ношења горива, што омогућује већи долет, два нова подвесна носача, као и нове сензоре и оружја. Нови ловац може носити до седам ракета ваздух-ваздух ван визуелног домета *MBDA Meteor*, опремљен је AESA радаром *Leonardo ES-05* и инфрацрвеним сензором за тражење и праћење *Leonardo Skyward G*. Нови систем за противелектронску борбу подразумева и систем за упозоравање прилаза ракета у кругу од 360 степени.

Нова архитектура авионских инструмената је скоро револуционарна. Омогућено је убацивање новог хардвера и унапређеног софтвера ради омогућавања извршавања нових мисија. Компјутери могу бити брзо замењени, што омогућава константно повећање процесне снаге. То такође значи да клијенти могу пројектовати свој софтвер, па је могућа брза реакција на појаву нових претњи.

Компанија *Saab* ради на могућности адаптације авионичких и мисијских система који би се могли мењати на бојишту, што значи да се нова софтверска унапређења могу изменити и инсталирати чак и док је авион у лету.

Gripen E је први ловац на којем се налази радар типа *AESA* који је монтиран на ротациони носач. То омогућава електронској антени за скенирање, која је обично фиксирана у једној, предњој позицији, да се покреће лево и десно ради увећања поља прегледности.

Ротациони носач омогућава преглед од 140 степени у оквиру постојећег прегледа од 200 степени у односу на нос авиона. Овакво решење омогућава скенирање ситуације лево и десно у односу на путању авиона када пилот не жели да усмери летелицу у одређену област.

На тај начин умањује се могућност непријатеља да лансира ракету, јер се радарски сноп шири бочно у односу на путању авиона. Дакле, могуће је померање и до 90 степени у односу на циљ, при чему се он и даље прати на радару. Ова комбинација је нарочито успешна када се користе ракете ваздух-ваздух типа *Meteor*.

Gripen E са седам ракета MBDA Meteor

Комбинација ракета *Meteor* и радара *AESA* на ротационом носачу је моћна комбинација. Теоретски, пилот може испалити ракете на непријатељске ловце на екстремним даљинама и затим се сакрити иза непријатељевог доплер „чвора" док и даље води своје ракете према циљевима. Овакав начин примене радара постоји и код ловца *Su-57,* али он имамонтиране бочне радаре. Тако се код непријатељских ловаца појављује ефекат мртвог угла. На пример, иако се непријатељев ловац креће брзином од 500 миља на сат, његов радар открива тек омањи радарски одраз. У том случају компјутер ловца одбацује слику циља као да се ради о планинском врху. Ова тактика је нарочито успешна када се ловац налази на већој висини од авиона који га тражи радаром, јер тада долази до мешања са земаљским шумовима и у том тренутку губи радарски одраз циља, па радарски вођене ракете не добијају додатне информације и могу изгубити циљ.

Инфрацрвени сензор служи за поништавање предности „невидљивих" ловаца, а налази се испред предњег дела пилотске кабине. Захваљујући напредним алгоритмима, сензор обрађује врло слабе сигнале који су и до десет пута мањи од контаката који су откривани пре десет година.

Први *Gripen E* за Бразил испоручен је 20. септембра 2020. године.

Маскирање путем електронских уређаја

Gripen E нема геометријску конфигурацију „невидљивог" авиона, јер компанија Saab сматра да са развојем софтверске и хардверске технологије такав авион постаје све видљивији за радаре. Како је врло тешко променити геометријске поставке авиона без великих трошкова,

компанија је одлучила да је боље употребити нове технологије као што је напредно електронско ратовање.

Пројектовање нисковидљивих авиона, као што је *F-35,* врло је скупо. Такође, потребно је много средстава за одржавање „невидљивих" авиона у оперативној употреби. *Gripen* је пројектован за брзо размештање са слабо опремљених база, са невеликим логистичким захтевима и малим бројем особља које га може брзо сервисирати и регенерисати. Очекује се да је за само десетак минута могуће припремити ловца за мисију ваздух-ваздух, наоружати га ракетама и напунити горивом.

Компанија је одабрала постизање „невидљивости" путем средстава за електронску борбу уместо велике инвестиције у генерички „невидљиви" авион. Наравно, за шведско ратно ваздухопловство и евентуалне клијенте то значи и нижу цену.

Систем за електронску борбу је потпуно нов и постиже ефекат „дигиталног штита". Комбинација система за електронску борбу и инфрацрвеног сензора омогућује пасивно трагање за циљевима. То је критичан фактор, јер је могуће поделити формације у активне и пасивне групе које могу размењивати податке између себе.

Систем за електронску борбу ловца укључује активне и пасивне електронске противмере. Систем као што је *Leonardo BriteCloud* представља добар пример технологије која је сада у употреби, а заснована је на систему топлотних и противрадарских мамаца.

Напредни кокпит и обједињавање сензора

Ловац *Gripen E* има потпуно нови кокпит. Након обимних разматрања, шведско ратно ваздухопловство определило се за један велики дисплеј, што представља еволуцију у односу на претходни систем од три велика дисплеја у кокпиту претходне генерације летелице *Gripen C/D*.

Компанија *Saab* успела је да обједини све сензоре и да презентује информације пилоту на једноставан и неоптерећујући начин. На великом дисплеју приказана је комплетна мапа области у којој авион дејствује, затим све руте, као и релевантни циљеви у ваздуху и на копну.

Дисплеј је осетљив на додир, а пилот може сам креирати регионе различитих величина и зумирати их. Примећено је да су пилоти претходних модела *Gripen C* константо зумирали одређене мапе у складу са интересима у одређеној области. Сада је то много лакше, а могуће је на дисплеју поставити и више мапа истовремено, па зумирати и одабирати различите циљеве.

Пре лета пилот уноси одређене мапе, које касније може мењати током лета. Такође, команде измена на дисплеју могу бити пребачене и на пилотску палицу, односно одређену дугмад или прекидаче, како пилоту у одређеном тренутку више одговора.

За ловац *Gripen E* компанија Saab одабрала је Targo II Helmet Mounted Display (HMD) –дисплеј на пилотској кациги. . За разлику од F-35, кокпит ловца *Gripen E* обједињава податке са пилотске каците и нишанског

система Head-Up Display (HUD). Одлучено је да се изради редундантни систем великог централног дисплеја и дисплеја на пилотској кациги, јер пилоти понекад управљају авионом без коришћења података са пилотске кациге.

Пилот опремљен пилотском кацигом Targo II Helmet Mounted Display (HMD)

Пилот одлучује о нивоу аутоматизације. Може одабрати да користи систем ручно, полуаутоматски или потпуно аутоматски. Сам одлучује да ли жели да надгледа податке и управља подацима, а може и да одобри или одбаци сугестије система. Информација је представљена путем симбола

на дисплеју, звука или говорних порука. Циљ је да пилот што лакше донесе критичну одлуку.

Wide Area Display/ централни дисплеј ловца Gripen E

Такође, остварено је обједињавање/фузија између платформи. Шведска је још осамдесетих година почела употребљавати дата-линк између летелица. Под претпоставком да је противник јачи, овај линк је коришћен за размену информација са другим авионима.

На основу сличних искустава развијен је систем који може сугерисати пилоту најбољи одговор на надолазећу претњу. Он може упозорити пилота да непријатељска летелица долази у позицију лансирања и предложити евентуални одговор на такву активност –нагли окрет на једну или другу страну. Дакле, пилот не мора само гледати у дисплеј јер га сама летелица упозорава и предлаже одговарајућу противмеру.

Вук у јагњећој кожи

Перформансе ловца *Gripen* повремено су биле подложне критици. Мада је авион малих габарита, мора носити велики број тешких убојних средстава. *Gripen E* је тежи од својих претходника, има додатне подвесне тачке и повећану количину горива, али и снажнији мотор . Ради се о мотору GE F414, док су претходне серије биле опремљене мотором F404. Поред снажнијег мотора, који производи 9,974 кг потиска, интелигентни систем контроле лета извлачи додатне перформансе авиона. *Gripen E* је пројектован да достигне и престигне своје претходнике иза серије C, без обзира на повећање тежине. Понекад је и пилоту тешко да одреди разлику између оптерећеног и неоптерећеног авиона. Такође, тешко је разликовати авион са ракетама и без њих.

Ловци *Gripen* учествовали су у разним вежбама, као што је *Red Flag*. Чак и када су њима управљали шведски пилоти са мање сати налета у односу на своје западне колеге, успевали су да остваре супериорне резултате са минималном логистичком подршком. Током вежбе *Red Flag* 2006, са умањеном радарском и логистичком подршком, ловци *Gripen* су увезивали своје дата-линкове и на тај начин имитирали америчке авионе за ваздушни надзор типа AWAC. Тако су добијали ниво ситуационе свесности, чак и бољи у односу на своје противнике. Првог дана вежбе остварили су десет обарања, укључујући и обарање ловца типа *Typhoon.* Нису имали губитака и остали су неоткривени и то, углавном, захваљујући свом систему за електронску борбу. Један пилот *Gripen*-а успео је да обори чак пет америчких ловаца *F-16 block 50+* током вежбе Red Flag Alaska. Ловци *Gripen* ниједном нису изгубили ваздушну борбу нити промашили своје циљеве. *Gripen* је био једини ловац који је остварио све планиране стартове, док су други авиони чекали да се време разведри. Такође, остварио је однос победа од чак 15:1 против ловца *F16*.

На вежби са краљевским норвешким ратним ваздухопловством, три шведска ловца *Gripen* у симулираној ваздушној борби против 5 норвешких F16 остварили су победе у односу 5:0, 5:0, 5:1.

Чак и у односу на *F15, Gripen* је остварио победу тако што је из заседе оборио три ловца *F15,* док је трећи успео да побегне захваљујући бољем односу потиска и тежине. Једина предност ловца *F15* била је у борби ван визуелног домета.

Сматра се да је амерички „невидљиви"ловац *F-22* у предности над ловцима*Gripen C/D* старије генерације, али не и у односу на нови *Gripen E*.

Многе земље, као што су Мађарска, Чешка, Тајланд, Јужна Африка, већ користе ловце серије *Gripen C/D,* а неке друге, као што је Швајцарска, разматрају увођење овог ловца у наоружање. За сада је једино Бразил корисник новог модела E.

Драган М. Вучковић (*Dragan* M. Vučković),
e-mail: draganvuckovic64@gmail.com,
ORCID iD: http://orcid.org/0000-0003-1620-5601

Заокружена модернизација руског тенка T-90M[2]

Руски тенк, под ознаком T-90M Proryv-3, модернизован је на основу тенка T-14 Armata. Он је јефтинији од T-14 и биће произведен, односно модернизован, у већим количинама, док ће производња тенка T-14 бити (за сада) лимитирана на само две тенковске бригаде. T-90M садржаће велики број делова тенка T-90MS.

[2] Janes defence international December 2020

T-90M за време тестирања 2018. године

Овај пројекат је еволуирао од пакета модернизације Proryv и Proryv-2 које је спровела компанија Ural Design Bureau of Transport Machine-building (UKBTM). Пројекат Proryv-2 је започет 2005. године, а циљ је био конструисање модерне тенковске куполе са повећаним степеном преживљавања и већом ситуационом свесношћу.

Пројекат је првобитно био намењен за извоз, јер у том тренутку није било захтева руског министарства одбране за модернизацијом T-90, због тога што је тада тенк T-90A улазио у оперативну употребу.

Тенк T-90M има нову варену куполу са модуларним пасивним оклопом, на којој је омогућена замена оклопних модула након оштећивања, нови експлозивно-реактивни оклоп, решеткасти оклоп на странама куполе и посебно заштићени део за резервну муницију. Пројекат не укључује уређај Shtora-1, па је тај део прекривен експлозивно-реактивним оклопом. Поред тога, командир је добио независну панорамску осматрачку справу заједно са перископима ради постизања унапређене ситуационе свесности.

Сви делови модернизационог пакета Proryv-2 нису спроведени, а један део је сачуван као део пакета Proryv-3 и убачен у тенк T-90MS, односно у домаћу верзију – тенк T-90M Резултат тога је тенк T-90M који је једнак најновијим западним тенковима. Нарочита пажња поклоњена је степену преживљавања тенка, као и ватреној моћи заједно са унапређењима у погледу мобилности, дигитализације и умрежавања.

Преживљавање

За разлику од својих претходника, T-90M има нову варену куполу која је знатно дужа и већих габарита у односу на већину купола совјетских дизајна.

Иако се ради о новој куполи, дизајн и даље следи претходне совјетске тенковске нацрте у којима се купола шири уназад. Овакав изглед куполе први пут је почео да се користи на тенковима серије Т-64 на којима купола више није имала округао облик. Такав облик куполе затим се користио и за тенкове из серија Т-72, Т-80 и Т-90, да би коначно био напуштен код тенка Т-14 који има беспосадну куполу.

Одељак за смештај резервне муниције на тенку Т-90М који делује и као противтег предњег дела куполе.

С друге стране, многи западни тенкови, укључујући серије *M1 Abrams, Leopard 2, Challenger 2* и *Leclerc,* имају коцкасте куполе са паралелним странама које обезбеђују већу интерну запремину. Проблем оваквог концепта је потреба за уградњом масивнијег оклопа ради заштите посаде и тенка, чиме се знатно повећава тежина возила. Дизајн куполе Т-90М је можда најсличнији дизајну западних тенкова, а изгледа као развијени пентагон када се гледа одозго. Купола Т-90 знатно је већа од купола осталих руских тенкова, укључујући и део у којем се чува резервна муниција, а који постоји још само на тенку Т-14.

У спремишту за резервну муницију чува се 10 граната, а опремљено је горњим делом који детонира нагоре приликом поготка у тенк. Овакав додатак знатно повећава могућност преживљавања тенка. Код руских тенкова муниција је обично складиштена у аутоматском пуњачу у средини трупа тенка, док су резервне гранате смештане испод или око пуњача. Смештање свих резервних граната у одвојено спремиште даје посади много веће шансе за преживљавање поготка у куполу који би је запалио. Ипак, не види се да ли је могуће приступити спремишту за муницију из тенка или се мора изаћи напоље. Поред тога, непотврђене информације

наводе да је карусел аутоматског пуњача додатно заштићен оклопним плочама.

Труп тенка Т-90М има бочне панеле опремљене касетним пуњењима *4S24 Relikt* која формирају два слоја експлозивно-реактивног оклопа (ЕРО). На бочним странама ЕРО је смештен по вертикали и није ефикасан за спречавање пројектила са бочних страна. Међутим, ЕРО на бочним странама није ни намењен заштити од бочних удара, јер постоје посебне касете опремљене са ЕРО под одређеним углом. Бочни панели ЕРО, у ствари, служе за заштиту тенка од пројектила испаљених под одређеним углом према предњој или задњој страни тенка.

Поред са два слоја ЕРО на боковима, Т-90М је опремљен слојем ЕРО типа *Relikt* на предњој страни тенка, као и модулима ЕРО *Relikt* на бочним странама куполе. Унутрашња страна куполе има још један заштитни слој који штити посаду од парчади.

Тенк Т-90М није опремљен активним системом заштите (*softkill)* типа *Shtora-1,* тако да карактеристичне „очи", односно инфрацрвени ометач типа *OTShU-1-7,* са обе стране топа, не постоји. Овај уређај је иначе ометао системе вођења неких противтенковских ракета, углавном полуаутоматских система вођења тако што је имитирао блесак на задњем делу ракете помоћу којег је стрелац наводио ракету на циљ. Међутим, највећи део модерних противтенковских ракета опремљен је пулсирајућим ксенонским светлом које је синхронизовано са лансирном јединицом пре лансирања ракете. То служи да полуаутоматски систем вођења ракете разликује прави блесак од мамца. У том смислу систем *Shtora-1* могао би ометати само старије типове противтенковских ракета. Уместо тога, тај део је покривен са ЕРО.

Тенк Т-90М је опремљен и мрежом заштите од ручних ракетних бацача око доње стране куполе и решеткастог оклопа на њеној задњој страни, као и на задњој страни тенка. Мрежа и решеткасти оклоп функционишу по истом принципу, обезбеђујући заштиту од пројектила ручних ракетних бацача који су опремљени кондукционим слојем који активира њихов пиезо-електрични упаљач. То укључује системе *2A28's PG-15V, RPG-7, PG-7V* и *PG-9V SPG-9,* као и њихове клонове. Први модели Т-90М имали су решеткасти оклоп на доњим деловима куполе уместо заштитне мреже против ручних ракетних бацача, али је то касније замењено. Иако није званично објашњено зашто, претпоставља се да би решеткасти оклоп онемогућио брзо бекство возача у случају да се купола налази у неповољном положају који покрива његов отвор за излаз.

Тенк Т-90М поседује и пријемнике ласерског озрачења повезане са бацачима димних кутија које се аутоматски активирају након детекције ласерског озрачења. Он нема тврди систем активне заштите (hard-kill), али се може опремити системом као што је *Arena-M*.

Стручњаци руског института за истраживање NII BTVT изјавили су да систем *Arena-M* може бити уграђен на разне руске тенкове, као што су Т-90М, Т-80BVM и Т-72B3M, ради одржавања равнотеже са западним

тенковима. Навели су и да Т-90М може добити исти ЕРО типа „*Malakhit*" који се налази на тенку Т-14, као и аутоматски систем за сузбијање ватре са одвојеним системом напајања, „меки" систем активне заштите и ометач за радио-контролисане мине и импровизоване експлозивне направе.

О пројекту оклопа „*Malakhit*" се мало зна. Патентна документација наводи да оклоп врши детонацију пре удара пројектила. Слична ситуација би требало да се деси и у случају удара поткалибарних пројектила типа (APFSDS), а по наводима истог института ни противтенковска ракета са тандем бојевом главом не би пробила оклоп.

Ватрена моћ

У погледу наоружања, Т-90М је опремљен топом 2А46М-5 који се употребљава и на тенку Т-72В3, а који представља модернизовану верзију топа 2А46М 125 mm који се налази на ранијим верзијама Т-90А. Из компаније *Uralvagonzavod (UVZ)* обавештавају да се унапређења на топу 2А46М-5 налазе у области повећане чврстоће и прецизности, па произвођач тврди да је остварено повећање прецизности од 15 до 20 посто и повећање прецизности од 1,7 пута приликом гађања из покрета у односу на топ типа 2А46М. Топ 2А46М-5 опремљен је и референтним системом на устима цеви који омогућава тобџији да аутоматски коригује грешке при равнању нишанског уређаја нишанџије у односу на мале деформације цеви проузроковане топлотом након опаљења.

Топ је повезан са дигиталним системом за управљање ватром „*Kalina*" који укључује нишанску справу опремљену телевизијским и термалним уређајима (откривају мету величине тенка на даљинама до 5.500 м дању и до 3.000 м ноћу), што омогућава аутоматско праћење циља, као и ласерским даљиномером и означивачем правца ласерског озрачења. Командиру је на располагању панорамска независна нишанска справа *PK PAN „Falcon's Eye"* са телевизијским и термалним каналима, као и са ласерским даљиномером који су повезани са даљински управљаним митраљезом *KORD* 12.7 mm. Овакав склоп омогућује командиру да трага за удаљеним метама и да независно напада лакше мете на мањим даљинама без окретања куполе.

У случају оштећења примарних нишанских справа, командир може употребити и нишанџијину нишанску справу, док командир и нишанџија могу користити и осматрачку справу са телевизијом ниске видљивости која је опремљена сопственим напајањем и ради чак и у случају престанка рада главног погона. Поред тога, систем за управљање ватром „*Kalina*" повезан је са балистичким компјутером који добија податке од метео-сензора, а опремљен је и унапређеним стабилизатором 2Е58.

Аутоматски пуњач тенка Т-90М пуни се са 22 гранате и може сместити поткалибарна зрна типа 3ВМ59 *Svinets-1* и 3ВМ60 *Svinets-2,* од којих свака има пенетратор дуг 735 мм. *Svinets-1* користи пенетратор од волфрама пробојности од 700 до 740 мм ваљаног хомогеног оклопа, док *Svinets-2* користи пенетратор од 800 до 830 мм. Оба податка о пробојности односе се

на оклоп под нагибом на даљини до 2 км. Међутим, ове податке није могуће проверити.

Током тестирања 2019. године, пенетратор *Svinets-2* пробио је плочу од 600 мм челика на необјављеној даљини, тако да ни на основу овог података није могуће одредити комплетан пенетративни потенцијал овог зрна.

Тенк Т-90М може испаљивати и ваздушно-распрскавајуће гранате *3VOF128 Tel'nik*. Овај пројектил је развијен након искустава Русије из различитих конфликата. *Tel'nik* се испаљује на „меке" циљеве и детонира испред мете у конусном облику парчади велике брзине. По питању циљева на великим даљинама, Т-90М располаже противтенковском вођеном ракетом *9M119M1 Invar-M* којом може гађати тенкове или друге тешко оклопљене циљеве. Ова ракета има домет до 5.000 м и опремљена је тандем-кумулативном бојевом главом која пробија до 850 мм хомогеног челика иза ERO.

Поред тога, Т-90М ће користити и противтенковску вођену ракету *3UBK25 Sokol –V* када буде уведена у оперативну употребу. Ова ракета има тандем-кумулативну бојеву главу, а опремљена је инерцијалним навигационим системом вођења и комбинованим телевизијским и инфрацрвеним трагачима у терминалној фази самонавођења. Пројектована је за напад одоздо на слабије оклопљен кров непријатељских тенкова, па би је системи активне заштите теже уништавали.

Мобилност и ситуациона свесност

Тенк Т-90М је опремљен новим дизел мотором V-92S2F V-12 који развија 1,130 КС, а упарен је са новим аутоматским мењачем АРР-172. Тенк може развити до 60 км/ч на путу. Међутим, могуће је да се ради о доњој граници, јер претходни тенк Т-90А има исту брзину. Т-90А тежи до 45,6 тона, а опремљен је мотором од 1.,000 КС, док Т-90М има знатно јачи мотор, док му се маса креће око 48 тона, што би значило бољи однос КС/тона, па самим тим омогућава и већу брзину (иако је могуће да је брзина електронски лимитирана због повећане потрошње горива). Тенк Т-90М поседује и помоћну погонску јединицу која се налази на задњој десној страни тенка, а служи за напајање електронских уређаја, док је главни погон угашен.

Локална ситуациона свесност је такође унапређена, па возило има систем камера које дају слику у кругу од 360 степени. Камере се налазе на куполи, изнад куполе на носачима, као и на задњем делу тенка. Камера на задњем делу тенка се аутоматски активира када возач убаци у брзину у пренос уназад. Возило је опремљено и унапређеним комуникационим системом *R-187 Azart SDR*, највероватније моделом *Azart-BV*.

Тенк Т-90М има и низ унапређења која се односе на побољшање квалитета живота посаде, што је неуобичајено за руске тенкове. За разлику од Т-90А, командир има осам перископа око свог отвора који унапређују локалну ситуациону свесност. Сваки од перископа има своје дугме којим се,

на притисак командира, нишанска справа и даљински управљана оружана станица са митраљезом окреће у жељеном смеру.

На месту командира налазе се два дисплеја од којих један приказује снимак са командирове комбиноване независне нишанске справе и даљински управљане оружне станице, као и са камера које снимају ситуацију у кругу од 360 степени, док се на другом дисплеју приказују подаци система за управљање битком и прате сопствене јединице. Командир има и контролни панел којим врши одабир муниције, што омогућава већу контролу током борбених мисија (он може одабрати муницију ради напада на одређени циљ и пре него што је купола окренута ка том циљу). Нишанџија, такође, има дисплеј испред себе који приказује снимак његове нишанске справе.

Седишта за посаде нису тако луксузна као на тенку Т-14, али се могу подешавати напред или назад. Поред тога, постављена је неклизајућа подлога, као и системи за климатизацију и грејање.

Оперативна употреба

Неименовани извор руског министарства одбране изјавио је, 20. фебруара 2020. године, да су потписана три уговора за тенк Т-90М за укупно 160 возила од којих ће 20 бити потпуно нови тенкови, док ће 140 тенкова бити модернизовано узимајући за основу претходне серије Т-90. Русија има више од 400 тенкова Т-90 претходних серија који могу бити модернизовани.

Прва серија тенкова Т-90М ушла је у оперативну употребу током априла 2020. године. Њима је опремљена Прва гардијска тенковска армија западног војног округа, односно Друга гардијска таманска моторизована дивизија која се састоји скоро искључиво од професионалних војника.

Очекује се да ће остале јединице које поседују тенкове Т-90А бити постепено модернизоване на стандард Т-90М.

До модернизације тенкова Т-72 и Т-90, дошло је, вероватно, због тога што се изгледа одустало од пуне серијске производње тенка Т-14. Од првобитно планираних 2.300 тенкова Т-14 са пропратним возилима исте породице, као што су тешко борбено возило пешадије Т-15 и возило за извлачење Т-16, изгледа да ће бити набављено само 132 возила Т-14 и Т-15 и то, пре свега, због цене.

Наиме, цена једног тенка Т-14 износи између 320 и 250 милиона рубаља (око 4,6 милиона америчких долара) без трошкова резервних делова, логистике и обуке, док модернизација тенка Т-72 на стандард Т-72Б3 кошта 52 милиона рубаља.

Драган М. Вучковић (*Dragan* M. Vučković),
e-mail: draganvuckovic64@gmail.com,
ORCID iD: http://orcid.org/0000-0003-1620-5601

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 мултидисциплинарни научни часопис Министарства одбране и Војске Србије. Часопис објављује научне и стручне чланке из области основних истраживања (математике, рачунарских наука и механике) и технолошког развоја (електронике, телекомуникација, информационих технологија, машинства, материјала и хемијских технологија), као и техничке информације о савременим системима наоружања и савременим војним технологијама. Часопис прати јединствену интервидовску техничку подршку Војске на принципу логистичке системске подршке, области основних, примењених и развојних истраживања, као и производњу и употребу средстава наоружања и војне опреме. Часопис објављује и остала теоријска и практична достигнућа која доприносе усавршавању свих припадника српске, регионалне и међународне академске заједнице, а посебно припадника војски и министарстава одбране.

Уређивачка политика Војнотехничког гласника заснива се на препорукама Одбора за етичност у издаваштву (COPE Core Practices), као и на најбољим прихваћеним праксама у научном издаваштву. Војнотехнички гласник је члан COPE (Committee on Publication Ethics) од 2. маја 2018. године.

Министарство просвете, науке и технолошког развоја Републике Србије утврдило је дана 18. 12. 2020. године категоризацију Војнотехничког гласника, за 2020. годину:

за област основна истраживања:
– на листи часописа за математику, рачунарске науке и механику:
категорија национални часопис **(М53)**,

за област технолошки развој:
– на листи часописа за електронику, телекомуникације и информационе технологије:
категорија истакнути национални часопис **(М52)**,
– на листи часописа за машинство:
категорија истакнути национални часопис **(М52)**,
– на листи часописа за материјале и хемијске технологије:
категорија истакнути национални часопис **(М52)**.

Усвојене листе домаћих часописа за 2020. годину могу се видети на сајту Војнотехничког гласника, страница *Категоризација часописа* (Министарство

просвете, науке и технолошког развоја Републике Србије још увек није објавило званичну категоризацију научних часописа за 2021. годину).

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).

У складу са овим правилником и табелом о врсти и квантификацији индивидуалних научноистраживачких резултата (у саставу Правилника), објављени рад у Војнотехничком гласнику вреднује се са 2 бода (категорија М51), 1,5 бод (категорија М52) и 1 бод (категорија М53).

Часопис се прати у контексту Српског цитатног индекса – СЦИндекс (база података домаћих научних часописа) и Руског индекса научног цитирања (РИНЦ). Подвргнут је сталном вредновању (мониторингу) у зависности од утицајности (импакта) у самим базама и, посредно, у међународним (Clarivate Analytics) цитатним индексима. Детаљи о индексирању могу се видети на сајту Војнотехничког гласника, страница *Индексирање часописа*.

Војнотехнички гласник омогућава 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 српском, руском и енглеском језику (arial, српска ћирилица или српска латиница, 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, разраду, закључак, литературу и апстракт са кључним речима на енглеском и руском језику (без нумерације наслова и поднаслова). Обим чланка треба да буде око 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. Наслов треба да буде преведен и на енглески и руски језик.

Ови наслови исписују се испред сажетка на одговарајућем језику.

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.).

Језик рада

Језик рада може бити српски, руски или 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. Кључне речи дају се на језику на којем је написан чланак (сажетак) и на енглеском језику. 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 мультидисциплинарным научным журналом Министерства обороны и Вооруженных сил Республики Сербия.. В журнале публикуются научные и профессиональные статьи, исследующие такие области как: математика, компьютерные науки и механика, а также области технологического развития: электроника, телекоммуникации, информационные технологии, машиностроение, материалы и химические технологии, в журнале также публикуется: техническая информация о современных системах вооружения и современных военных технологиях. Журнал следит за единой межвидовой технической поддержкой вооруженных сил, основанной на принципах системной логистики, за прикладными и инновационными научными исследованиями, в том числе, в области производства вооружения и военной техники. В журнале публикуются и прочие теоретические и практические достижения, которые способствуют повышению квалификации представителей сербского, регионального и международного академического сообщества, особенно военнослужащих Министерства Обороны и Вооружённых сил.

Редакционная политика журнала «Военно-технический вестник» основана на рекомендациях Комитета по этике научных публикаций (COPE Core Practices), а также на лучшей практике в научно-издательской деятельности. «Военно-технический вестник» является членом COPE со 2 мая 2018 года.

Министерством образования, науки и технологического развития Республики Сербия утверждена 18 декабря 2020 г. категоризация журнала «Военно-технический вестник» за 2020 год:

Категории в области основных исследований:

– Область математика, компьютерные науки, технические науки:
национальный журнал **(M53)**.

Категории в области технологического развития:

– Область электроники, телекоммуникаций и информационных технологий:
высококачественный национальный журнал **(M52)**.

– Область механики:
высококачественный национальный журнал **(M52)**.

– Область материалов и химической технологии:
высококачественный национальный журнал **(M52)**.

С информацией относительно категоризации за 2020 год можно ознакомиться на странице сайта «Военно-технического вестника» *Категоризация Вестника*

(Министерством просвещения, науки и технологического развития Республики Сербия пока не произведено официального ранжирования научных журналов за 2021 год).

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)

В соответствии с вышеуказанным Положением и таблицей с показателями классификации и категоризации индивидуальных научно-исследовательских результатов, являющейся неотъемлемой частью Положения, научная статья, опубликованная в «Военно-техническом вестнике», оценивается следующим способом: 2 балла (категория М51), 1,5 балла (категория М52) и 1,5 балл (категория М53).

Журнал соответствует стандартам Сербского индекса научного цитирования (СЦИндекс/SCIndeks) – наукометрической базы данных научных журналов Республики Сербия, а также Российского индекса научного цитирования (РИНЦ). Журнал постоянно подвергается мониторингу и оценивается количественными наукометрическими показателями, отражающими его научную ценность, в т.ч. опосредованно в международных индексах цитирования (Clarivate Analytics).

С информацией об индексировании можно ознакомиться на странице сайта журнала *Индексирование Вестника*.

«Военно-технический вестник» обеспечивает читателям возможность открытого доступа, в соответствии с положениями об авторских правах, утверждёнными Creative Commons (CC BY). С инструкцией об авторских правах можно ознакомиться на странице *Авторские права и политика самоархивирования*, перейдя по ссылке http://www.vtg.mod.gov.rs/index-ru.html.

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 сербском, русском или английском языках (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, основную часть, выводы, список использованной литературы и резюме с ключевыми словами на английском языке (без нумерации заголовков и подзаголовков). Объём статьи не должен превышать один авторский лист (16 страниц формата А4 с пробелом Single).

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. Заголовок должен быть переведён на английский язык. Название заголовка (подзаголовка) пишется перед резюме на соответствующем языке.

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.).

Язык работы

Работа может быть написана на сербском, русском или 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. Ключевые слова даются на языке, на котором написана статья (резюме), и на английском языке. 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:
«Војнотехнички гласник»
ул. Велька Лукича Куряка 33
11042 Белград, Республика Сербия
e-mail: vojnotehnicki.glasnik@mod.gov.rs.
тел: +381 11 3603 260, +381 66 8700 123

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 a multidisciplinary scientific journal of the Ministry of Defence and the Serbian Armed Forces. The journal publishes scientific and professional papers covering fundamental research (mathematics, computer science and mechanics) and technological development (electronics, telecommunications, information technologies, mechanical engineering, material science and chemical technologies) as well as technical data on modern weapon systems and military technologies. The journal covers inter-service technical support to the Army on the principle of logistic system support; fundamental, applied and development research; production and use of weapons and military equipment. Also, the journal publishes other 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.

The editorial policy of the Military Technical Courier is based on the COPE Core Practices and the journal articles are consistent with accepted best practices in their subject areas. As of 2 May 2018, the Military Technical Courier is a member of COPE (Committee on Publication Ethics).

The Ministry of Education, Science and Technological Development of the Republic of Serbia classified the Military Technical Courier for the year 2020, on December 18, 2020

in the field fundamental research:
– on the list of periodicals for mathematics, computer sciences and mechanics,
category: national journal **(M53)**,
in the field technological development:
– on the list of periodicals for electronics, telecommunications and IT,
category: quality national journal **(M52)**,
– on the list of periodicals for mechanical engineering,
category: quality national journal **(M52)**,
– on the list of periodicals for materials and chemical technology,
category: quality national journal **(M52)**.

The approved lists of national periodicals for the year 2020 can be viewed on the website of the Military Technical Courier, page *Journal categorization* (The Ministry of Education, Science and Technological Development of the Republic of Serbia has not yet published the official evaluation of scientific journals for 2021).

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.

In accordance with the Regulations and the table about types and quantification of individual scientific and research results (as a part of the Regulations), a paper published in the *Military Technical Courier* scores 2 (two) points (category M51), 1,5 (one and a half) point (category M52) and 1 (one) point (category M53).

The journal is in the Serbian Citation Index – SCIndex (data base of national scientific journals), 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 and indirectly in the international (e.g. Clarivate Analytics) citation indexes. More detailed information can be viewed on the website of the Military Technical Courier, page *Journal indexing*.

Military Technical Courier enables open access and applies the Creative Commons Attribution (CC BY) licence provisions 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 Serbian, Russian or 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 the abstract with keywords, introduction, body, conclusion and references (without heading and subheading enumeration). The article length should not exceed 24 pages of A4 paper format.

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. The title should be given in English as well.

The titles precede the abstract and the summary in an appropriate language.

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.)

Language

The article can be in Serbian, Russian or 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.

Editorial Team

Address of the Editorial Office:
Vojnotehnički glasnik / Military Technical Courier
Veljka Lukića Kurjaka 33
11042 Belgrade, Republic of Serbia
e-mail: vojnotehnicki.glasnik@mod.gov.rs.
tel.: +381 11 3603 260, +381 66 8700 123

Ликовно-графички уредник
Марија Марић, e-mail: marija.maric@mod.gov.rs

Лектор
Добрила Милетић, e-mail: miletic.dobrila@gmail.com

Превод на енглески
Јасна Вишњић, e-mail: jasnavisnjic@yahoo.com

Превод на руски
Др *Карина* Авагјан, e-mail: karinka2576@mail.ru

CIP – Каталогизација у публикацији
Народна библиотека Србије, Београд

623+355/359

ВОЈНОТЕХНИЧКИ гласник : научни часопис Министарства одбране и Војске Србије = Военно-технический вестник : научный журнал Министерства обороны и Вооружённых сил Республики Сербия = Military Technical Courier : scientific Journal of the Ministry of Defence and the Serbian Armed Forces / главни и одговорни уредник Драган Памучар. - Год. 1, бр. 1 (1. јан. 1953)- . - Београд : Универзитет одбране у Београду, Војна академија, 1953- (Београд : Војна штампарија). - 23 cm

Тромесечно. - Текст на срп., рус. и енгл. језику. - Друго издање на другом медијуму: Vojnotehnički glasnik (Online) = ISSN 2217-4753
ISSN 0042-8469 = Војнотехнички гласник
COBISS.SR-ID 4423938

Цена: 600,00 динара

Тираж: 100 примерака

На основу мишљења Министарства за науку, технологију и развој Републике Србије, број 413-00-1201/2001-01 од 12. 9. 2001. године, часопис „Војнотехнички гласник“ је публикација од посебног интереса за науку.

УДК: Народна библиотека Србије, Београд

Адреса редакције: Војнотехнички гласник,
Вељка Лукића Курјака 33, 11042 Београд

http://www.vtg.mod.gov.rs
http://aseestant.ceon.rs/index.php/vtg/issue/current
http://scindeks.nb.rs/journaldetails.aspx?issn=0042-8469
http://elibrary.ru/title_about.asp?id=53280
https://doaj.org/toc/2217-4753

Војнотехнички гласник је лиценциран код EBSCO Publishing-a.
Комплетан текст *Војнотехничког гласника* доступан је у базама података EBSCO Publishing-a.

e-mail: vojnotehnicki.glasnik@mod.gov.rs

Претплата на штампано издање: e-mail: vojnotehnicki.glasnik@mod.gov.rs; тел. 066/87-00-123.

Часопис излази тромесечно.

Први штампани број *Војнотехничког гласника* објављен је 1. 1. 1953. године.

Прво електронско издање *Војнотехничког гласника* на Интернету објављено је 1. 1. 2011. године.

Штампа: Војна штампарија – Београд, Ресавска 40б, e-mail: vojna.stamparija@mod.gov.rs

Художественный редактор
Мария Марич, e-mail: marija.maric@mod.gov.rs

Корректор
Добрила Милетич, e-mail: miletic.dobrila@gmail.com

Перевод на английский язык
Ясна Вишнич, e-mail: jasnavisnjic@yahoo.com

Перевод на русский язык
Д.филол.н. *Карина* Кареновна Авагян, e-mail: karinka2576@mail.ru

CIP – Каталогизация в публикации
Национальная библиотека Сербии, г. Белград

623+355/359

ВОЈНОТЕХНИЧКИ гласник : научни часопис Министарства одбране и Војске Србије = Военно-технический вестник : научный журнал Министерства обороны и Вооружённых сил Республики Сербия = Military Technical Courier : scientific Journal of the Ministry of Defence and the Serbian Armed Forces / главни и одговорни уредник Драган Памучар. - Год. 1, бр. 1 (1. јан. 1953)- . - Београд : Универзитет одбране у Београду, Војна академија, 1953- (Београд : Војна штампарија). - 23 cm

Тромесечно. - Текст на срп., рус. и енгл. језику. - Друго издање на другом медијуму: Vojnotehnički glasnik (Online) = ISSN 2217-4753
ISSN 0042-8469 = Војнотехнички гласник
COBISS.SR-ID 4423938

Цена: 600,00 динаров

Тираж: 100 экземпляров

На основании решения Министерства науки и технологий Республики Сербия, № 413-00-1201/2001-01 от 12. 9. 2001 года, журнал «Военно-технический вестник» объявлен изданием, имеющим особое значение для науки.

УДК: Национальная библиотека Сербии, г. Белград

Адрес редакции: Војнотехнички гласник,
Ул. Велька Лукича Куряка 33, 11042 Белград, Республика Сербия

http://www.vtg.mod.gov.rs
http://aseestant.ceon.rs/index.php/vtg/issue/current
http://scindeks.nb.rs/journaldetails.aspx?issn=0042-8469
http://elibrary.ru/title_about.asp?id=53280
https://doaj.org/toc/2217-4753

«Военно-технический вестник» включен в систему EBSCO. Полный текст «Военно-технического вестника» можно найти в базах данных EBSCO Publishing.

e-mail: vojnotehnicki.glasnik@mod.gov.rs

Подписка на печатную версию журнала: e-mail: vojnotehnicki.glasnik@mod.gov.rs; тел. +381 66 87 00 123.

Журнал выпускается ежеквартально.

Первый номер журнала «Военно-технический вестник» выпущен 1.1.1953 года.

Первая электронная версия журнала размещена на интернет странице 1.1.2011 года.

Типография: Војна штампарија – Белград, Ресавска 40б, e-mail: vojna.stamparija@mod.gov.rs

Graphic design editor
Marija Marić, e-mail: marija.maric@mod.gov.rs

Proofreader
Dobrila Miletić, e-mail: miletic.dobrila@gmail.com

English translation and polishing
Jasna Višnjić, e-mail: jasnavisnjic@yahoo.com

Russian translation and polishing
Dr. *Karina* Avagyan, e-mail: karinka2576@mail.ru

CIP – Catalogisation in the publication
National Library of Serbia, Belgrade

623+355/359

ВОЈНОТЕХНИЧКИ гласник : научни часопис Министарства одбране и Војске Србије = Военно-технический вестник : научный журнал Министерства обороны и Вооружённых сил Республики Сербия = Military Technical Courier : scientific Journal of the Ministry of Defence and the Serbian Armed Forces / главни и одговорни уредник Драган Памучар. - Год. 1, бр. 1 (1. јан. 1953)- . - Београд : Универзитет одбране у Београду, Војна академија, 1953- (Београд : Војна штампарија). - 23 cm

Тромесечно. - Текст на срп., рус. и енгл. језику. - Друго издање на другом медијуму: Vojnotehnički glasnik (Online) = ISSN 2217-4753
ISSN 0042-8469 = Војнотехнички гласник
COBISS.SR-ID 4423938

Price: 600.00 RSD

Printed in 100 copies

According to the Opinion of the Ministry of Science and Technological Development No 413-00-1201/2001-01 of 12th September 2001, the *Military Technical Courier* is a publication of special interest for science.

UDC: National Library of Serbia, Belgrade

Address: Vojnotehnički glasnik/Military Technical Courier,
Veljka Lukića Kurjaka 33, 11042 Belgrade, Republic of Serbia

http://www.vtg.mod.gov.rs/index-e.html
http://aseestant.ceon.rs/index.php/vtg/issue/current
http://scindeks.nb.rs/journaldetails.aspx?issn=0042-8469
http://elibrary.ru/title_about.asp?id=53280
https://doaj.org/toc/2217-4753

Military Technical Courier has entered into an electronic licensing relationship with EBSCO Publishing. The full text of *Military Technical Courier* can be found on EBSCO Publishing's databases.

e-mail: vojnotehnicki.glasnik@mod.gov.rs

Subscription to print edition: e-mail: vojnotehnicki.glasnik@mod.gov.rs; Tel. +381 66 87 00 123.

The journal is published quarterly.

The first printed issue of the *Military Technical Courier* appeared on 1st January 1953.
The first electronic edition of the *Military Technical Courier* on the Internet appeared on 1st January 2011.

Printed by Vojna štamparija – Belgrade, Resavska 40b, e-mail: vojna.stamparija@mod.gov.rs


69
ОД 1953.
ВТД
ГОДИНА


69
OD 1953.
VTD
GODINA


69
С 1953.
ВТБ
ЛЕТ


69
SINCE
1953
MTD
YEARS