Artillery fire control based on artificial intelligence algorithm of unmanned aerial vehicle

Azad Agalar Bayramov[1,2], Samir Suleyman Suleymanov[1,2], Fatali Nariman Abdullayev[1,2]
[1]Republican Seismic Survey Center of the Azerbaijan National Academy of Sciences, Baku, Azerbaijan
[2]Center for Strategic Scientific Research, Baku, Azerbaijan

Article Info

Article history:

Received Mar 5, 2025
Revised Oct 15, 2025
Accepted Dec 13, 2025

Keywords:

Artificial intelligence
Artillery fire
Firepower
Model
UAV

ABSTRACT

The article presents the developed artillery fire remote control complex using unmanned aerial vehicles (UAVs) based on an artificial intelligence (AI) algorithm. The developed complex for artillery fire control includes sensor modules for assessing the environment, collecting and processing information, planning and decision-making, and developing a command for the commander of an artillery battalion, division, or brigade. The main advantage of the developed artillery fire control system using UAVs based on an AI algorithm is the most rapid decision-making without human intervention, based on a quick assessment of the environment, the type of enemy weapons, and their category of importance, and an assessment of the distance to the enemy's military arms. An algorithm is proposed to minimize the power of artillery fire to suppress the enemy.

Corresponding Author:

Azad Agalar Bayramov
Republican Seismic Survey Center of the Azerbaijan National Academy of Sciences
25, Nigar Rafibeyli str., AZ1001, Baku, Azerbaijan
Email: azad.bayramov@yahoo.com

1. INTRODUCTION

In recent years, automated control systems have been increasingly used to increase the efficiency of artillery fire [1]-[5]. At the same time, the use of artificial intelligence (AI) in fire control systems is of particular importance. As is known, AI has impacted military dynamics between warring countries in the 21st century. For example, in the works [6]-[14], the impact of AI on modern warfare has been assessed.

Unlike existing methods, the use of AI technology in the automation of artillery fire control systems allows for the rational use of artillery weapons of different calibers, depending on the required specific firepower per unit of front width and the changing situation at the tactical level of the front. Taking into account the changing situation, rational control of artillery destruction power can be achieved using an unmanned aerial vehicle (UAV) with a proportional-integral-derivative (PID) controller based on AI [15]-[22]. Unfortunately, most scientific works on this topic are not available to a wide range of scientists. Based on minimal information from the available literature, one can only guess what artillery fire control systems exist.

Application of fire power in recent conflicts by UAVs, for example, in Karabakh or Ukraine, has been innovative and dynamic. It was noted in the work [1] that long-range precision fires with loitering UAVs and artillery munitions assisted by spotter UAVs have been very effective. Automated and networked integration of various fire power assets, UAVs, weapon locating radars, electronic warfare systems, and fire control system has proved very lethal.

In paper [1]-[5] the analyses the application of UAVs in the role of the forward observer for artillery operations, based on the experience of the armed forces worldwide has been done. It is proposed to introduce UAVs into the artillery fire support system to increase the capabilities of artillery weapons in Croatian

Armed Forces. The analysis of small UAVs suggests that the Orbiter 3B system (UAV mass is 30 kg, flight time is 7 h, the maximum speed of the UAV is 93 km/h) is highly suitable for tactical reconnaissance and the support of short-to-medium-range artillery.

Levchenko *et al.* [4] notes that artillery aiming control technology is rapidly developing, and currently the fire control mode is fully automatic. This paper analyzed the development related technologies of aiming control mode, puts forward an AI development mode of artillery weapon equipment aiming control. The paper discusses the characteristics and differences between AI artillery and computer automatic control (signal perception and control strategy layers, and drive execution).

The Azerbaijan Armed Forces are well poised to explore and optimally exploit potential of UAVs. An automated networked sensor shooter link integrating the intelligence, surveillance, reconnaissance architecture, and the targeting entities have been ensured. Also, there are a common GIS and common communication protocol in UAV control system.

This paper presents a complex for remote control of artillery fire using a UAV with AI. The unmanned robotic artillery fire control system includes sensor modules for assessing the environment, collecting and processing data, planning and decision-making, and developing commands for the commander of an artillery battery, battalion, division or brigade. Also, the paper outlines the developed methodology for minimizing firepower to suppress enemy force.

2. PROPOSED ALGORITHM: ARTILLERY FIRE CONTROL AUTOMATION COMPLEX

The main disadvantage of existing fire control methods for artillery systems is that they do not take into account the control of the firepower of the front line unit, as well as the variability of the combat situation: the movement of enemy forces, the destruction of enemy military equipment, the replenishment of fresh enemy forces. Unlike existing methods, the use of AI in artillery fire control automation systems allows for the rational use of artillery weapons of different calibers, depending on the required specific firepower per unit of front width and the changing tactical situation of the frontal situation at the front. Taking this into account, rational control of artillery destruction power can be achieved using a UAV with a AI PID controller [15]-[22].

Figure 1 shows the PID controller architecture of an intelligent artillery fire control using a UAV. The main components of the intelligent system management controller are:

- Sensor module 1; it helps to collect information about environmental parameters (situation) and the phenomena being studied that may affect a specific system or process;
- Module 2; this module includes blocks for processing and integrating input data, sensor data synthesis, logical inference and interpretation, situation recognition, obstacle recognition, and threat assessment;
- Module 3; this module includes blocks of operational assessment, planning and correction of actions (for example, UAV flight modes), development of a mission plan, exceptions, and condition monitoring;
- Module 4; this module includes command generation blocks for a surveillance camera, autopilot and other autonomous controllers.

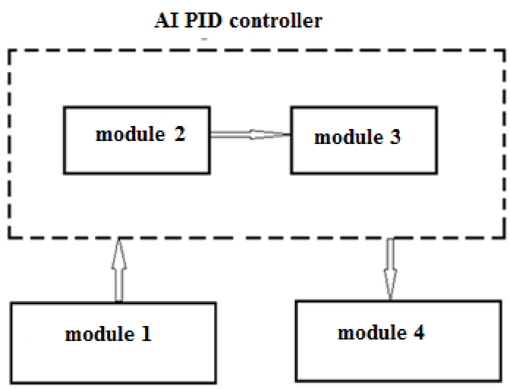

Figure 1. Architecture of AI PID controller for artillery fire

The importance of weapon categories is divided into different *K* categories depending on their purpose and role in military operations. Figure 2 shows a diagram of artillery fire control using UAVs based on AI. Let us briefly describe the principle of this control.

The UAV conducts reconnaissance of the near and far zones of the front, using data from daily ground reconnaissance. The "near" enemy front line is conventionally assumed to be S_{ij}=2÷5 km, the "far" front line is S_{ij}=15÷20 km from "our" artillery battery (division, brigade). The UAV identifies the types of enemy weapons and determines their K_i importance categories.

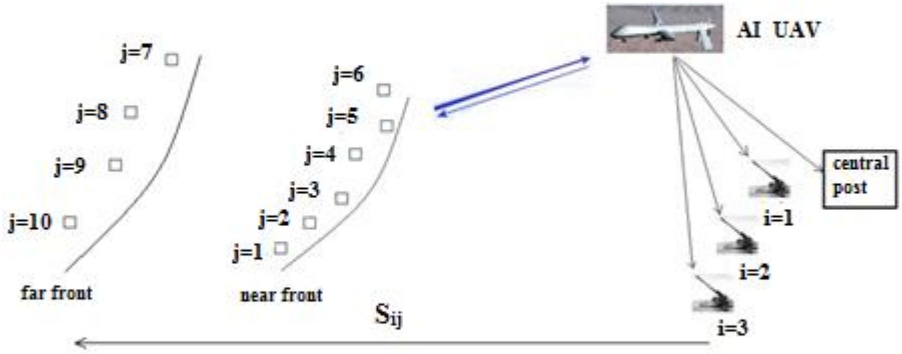

Figure 2. A diagram of artillery fire control using AI UAVs

Depending on the type of operation (offensive or defensive), experts assess to varying degrees the importance of weapons and equipment belonging to these categories K (Table 1) [23]-[25]. These K_i values, given in Table 1 for different categories of weapons and equipment, are relative in nature; depending on the opinion of experts, their mutual ratio can take on different values depending on the sources.

The higher the K_i weapon's importance value, the more important it is to destroy it first. This principle is embedded in the control program for the complex being developed. The UAV determines the distances S_{ij} from each of "our" artillery (mortar) installations (i = 1, 2, 3...) to each military object (artillery installation, mortar) of the enemy on the "near" (j = 1, 2,...,6...) and "far" fronts (j = 7, 8, ..., 10...). Based on the values of K_i and S_{ij}, the UAV prepares decisions and sends them to the central post to the commander of the battery (division, brigade), as well as the commander of each artillery unit.

Table 1. The importance of weapons

Categories, K	Weapons and equipment	Importance of categories, K_i	
		Offensive	Defense
I	Small arms	3,3	3,7
II	Tank	100	94
III	Infantry fighting vehicle	69	71
IV	Armored personnel carrier	36	30
V	Anti-tank weapon	55	73
VI	Artillery gun	92	95
VII	Artillery multiple rocket launcher	95	99
VIII	Mortar	48	55
IX	Helicopter	89	109
X	Air defense equipment	44	56

3. RESULTS AND DISCUSSION

The main advantage of an unmanned artillery fire control system operating using UAVs with AI is the fastest possible decision-making without human factor based on a flexible assessment of the environment (situation), the type of enemy weapons and the category of their importance, as well as the distance to enemy military installations. As can be seen from the analysis of the problems of automating artillery fire control [1]-[5], the development of existing and future automated control systems at the tactical level is almost always carried out in conditions of a limited number of artillery systems. Therefore, as the first objective function of the problem of optimal synthesis of an automated workstation for the commander of an artillery battery (brigade, division), it is proposed to use the total firepower P_0 of its components.

This optimization problem is proposed to be solved using the following objective function:

$$P_0 = \sum_{i=1}^{n1} P_1 \cdot x_{1i} + \sum_{i=1}^{n2} P_2 \cdot x_{2i} + \cdots + \sum_{i=1}^{nm} P_m \cdot x_{mi} \rightarrow \min \quad (1)$$

Here, P_1 and n_1 are the firepower and the number of a caliber of the artillery device 1 (field-gun, mortar, multiple rocket launcher) (Table 1); P_2 and n_2 are the firepower and the number of a caliber of the artillery device 2 (field-gun, mortar, multiple rocket launcher); P_m and n_m are the firepower and the number of a caliber of the artillery device *m* (field-gun, mortar, multiple rocket launcher); and x_{mi} determines the selection of specific components.

Thus, knowing the firepower of enemy artillery units *P* and using (1), the minimum necessary firepower (rational amount) of "our" batteries (division, brigade) to suppress enemy fir can be estimated:

$$P0 > P$$

In addition, to rationally use the firepower of "our" artillery systems, the dynamic power method can be used [24], [25].

Suppose that *m* is a number (*j*=1,2,...,*m*) of firing devices and *k* is a number (*i*=1,2,...,*k*) of targets. Let denote by p_{ji} the probability that the *j*-th small weapon will destroy the *i*-th target. These values are listed in Table 2 in the first column for the corresponding target number. Let denote the satisfactory probability of hitting each target as p_i^0 (*i*=1,2,…,*k*). C_i (*i*=1,...,*m*) is a cost of an artillery shell. Depending on the degree of importance, these probabilities are written in the last row of Table 2.

Table 2. Data of task

Firing devices	A cost of an artillery shell	Maximum number of artillery shells	Targets									
			Target № 1		Target № 2			Target № i			Target № k	
№ 1	C_1	N_1	p_{11}	x_{11}	p_{12}	x_{12}	…	p_{1i}	x_{1i}	…	p_{1k}	x_{1k}
№ 2	C_2	N_2	p_{21}	x_{21}	p_{22}	x_{22}	…	p_{2i}	x_{2i}	…	p_{2k}	x_{2k}
№ 3	C_3	N_3	p_{31}	x_{31}	p_{32}	x_{32}	…	p_{3i}	x_{3i}	…	p_{3k}	x_{3k}
…	…	…	…	…	…	…	…	…	…	…	…	…
№ j	C_j	N_j	p_{j1}	x_{j1}	p_{j2}	x_{j2}	…	p_{ji}	x_{ji}	…	p_{jk}	x_{jk}
…	…	…	…	…	…	…	…	…	…	…	…	…
№ m	C_m	N_m	p_{m1}	x_{m1}	p_{m2}	x_{m2}	…	p_{mi}	x_{mi}	…	p_{mk}	x_{mk}
			p_1^0	x_1	p_2^0	x_2		p_i^0	x_i		p_k^0	x_k

To destroy targets, you need to distribute them among firing devices. Let denote the number of projectiles that must be used to hit the *i*-th target with the *j*-th device as x_{ji} (see 2nd column for the corresponding numbered target in Table 2). Let C_j denote the cost of the projectile used by the *j*-th shooter, and N_j the number of such projectiles at his disposal (see columns 2 and 3 of Table 2).

Statement of the problem. The value x_{ij} must be found when the following conditions are met:

1) Targets must be destroyed with a given probability;
2) The number of shells expended by each artillery unit must not exceed the number of shells available;
3) The total cost of the shells used should be minimal.

Let formulate a mathematical model of the given problem:

Let number the artillery shells aimed at the *i*-th target sequentially as $s = 1, 2, \ldots, x_i$. Here: $x_i = \sum_{j=1}^{m} x_{ji}$. Let denote the probability that the *s*-th artillery shell will destroy the target as p_s. It is clear that, $p_s \in \{p_{1i}, p_{2i}, \ldots, p_{mi}\}$. Let write an algorithm that calculates the probability $P_{s,i}$ destruction of a target after *s* number of shots:

When $s = 1$, then $P_{1,i} = p_1$. Let denote $Q_1 = 1 - p_1$. Then, for any $s = 2, \ldots, x_i$ there is $P_{s,i} = P_{s-1,i} + Q_{s-1,i} p_s$, $Q_{s,i} = Q_{s-1,i}(1 - p_2)$.

Thus, condition 1 of the problem can be expressed as follows:

$$P_{s,i} \geq p_i^0,\ i = 1, 2, \ldots, k \tag{2}$$

The condition that the number of artillery shells expended by each artillery unit does not exceed the number of artillery shells at its disposal is expressed as follows:

$$\sum_{i=1}^{k} x_{ji} \leq N_j,\ j = 1, 2, \ldots, m \tag{3}$$

From the statement of the problem it is clear that the numbers *x* are non-negative integers:

$$x_{ji} \geq 0, j = 1, 2, \ldots, m, i = 1, 2, \ldots, k \quad (4)$$

The requirement that the total cost of consumed projectiles be minimal can be expressed as follows:

$$\Im(x_{11}, x_{12}, \ldots, x_{mk}) = \sum_{j=1}^{m} \left(C_j \sum_{i=1}^{k} x_{ji}\right) \rightarrow min \quad (5)$$

It is necessary to find integers x_{ji} satisfying conditions (2)-(4) that give a minimum to the functional $\Im(x_{11}, x_{12}, \ldots, x_{mk})$.

Considering the relevance of issues related to the technical condition of an unmanned artillery fire control complex, the another criterion for choosing the composition of the technical means of an automated complex can be proposed: this is an indicator of its reliability, that is, the average time before the device fails.

Let consider the most vulnerable element of the automated complex. In order to increase its reliability, this criterion is written as follows:

$$T = min\{t_1, t_2 \ldots t_k\} \rightarrow max \quad (6)$$

Here: t_1, t_2, …, t_k are average time between failures of selected k components of the automated complex. These parameters $\{y_{ij}$: i=1,n; j=1,$m\}$ can be calculated taking into account the meaning of the variables and formula (6):

$$t_1 = \sum_{j=1}^{n1} T_{1,j} \cdot y_{1j}\,; \ldots; t_k = \sum_{j=1}^{nm} T_{n,j} \cdot y_{nj}$$

4. CONCLUSION

Thus, the paper presents a complex for remote control of unmanned artillery fire, developed using UAVs with AI. The developed unmanned system includes sensor modules for assessing the environment, collecting and processing data, planning and decision-making, and preparing commands for the commander of an artillery battery, battalion, division or brigade. To solve the problem of optimal synthesis of an automated workstation for an artillery battery commander, it was proposed to use the total firepower of its components as an objective function. A mathematical model was proposed for the optimal use of artillery installations and shells to destroy enemy targets using UAVs.

ACKNOWLEDGMENTS

The authors would like to thank researchers of the Center for Strategic Scientific Research (www.setm.tech) Baku Azerbaijan for their assistance in this research.

FUNDING INFORMATION

The authors declare that no funding was received at the time of conducting this research.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Azad Agalar Bayramov	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓			
Samir Suleyman Suleymanov		✓	✓	✓		✓	✓	✓	✓	✓	✓			
Fatali Nariman Abdullayev	✓	✓		✓	✓			✓	✓	✓		✓	✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors state no conflict of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article

REFERENCES

[1] V. Bartulović, Z. Trzun, and M. Hoić, "Use of unmanned aerial vehicles in support of artillery operations," *Strategos*, vol. 7, no. 1, pp. 71–92, 2023.

[2] B. D. Pandey, "Integrating drones for long range precision fires and time sensitive targeting: an Indian perspective," *Synergy*, vol. 2, no. 2, pp. 170–185, 2023, [Online]. Available: https://cenjows.in/wp-content/uploads/2023/10/Ch-09-Devender-Pandey.pdf.

[3] V. N. Krasilnikov, A. N. Kozar, V. S. Moiseev, and O. V. Krasilnikov, *Portable automated fire control systems for tactical artillery (In Russian: Переносные комплексы автоматизированного управления огнем артиллерии тактического звена)*. Kazan: Fatherland, 2009.

[4] D. Markov, A. Kolev, and V. Ivanova, "An enhanced solution for automated fire control systems," *Information & Security*, vol. 53, no. 1, pp. 59–101, 2022, doi: 10.11610/isij.5307.

[5] T. Zieliński, "Unmanned aircraft systems in support of the land forces. Selected issues," *Journal of Science of the Gen. Tadeusz Kosciuszko Military Academy of Land Forces*, vol. 184, no. 2, pp. 195–210, Apr. 2017, doi: 10.5604/01.3001.0010.4909.

[6] C. Khemraj, J. Kumar, A. Srivastava, and G. Srivastava, "Autonomous UAV (unmanned aerial vehicle) for navigation & surveillance purposes," *Global Journal of Researches in Engineering Automotive Engineering*, vol. 12, no. 2, pp. 31–33, 2012, [Online]. Available: http://www.engineeringresearch.org/index.php/GJRE/article/view/569.

[7] L. Rabiu, A. Ahmad, and A. Gohari, "Advancements of unmanned aerial vehicle technology in the realm of applied sciences and engineering: a review," *Journal of Advanced Research in Applied Sciences and Engineering Technology*, vol. 40, no. 2, pp. 74–95, 2024, doi: 10.37934/araset.40.2.7495.

[8] R. Zhai, Z. Zhou, W. Zhang, S. Sang, and P. Li, "Control and navigation system for a fixed-wing unmanned aerial vehicle," *AIP Advances*, vol. 4, no. 3, Mar. 2014, doi: 10.1063/1.4866169.

[9] X. Tian, Y. Bar-Shalom, G. Chen, E. Blasch, and K. Pham, "A unified cooperative control architecture for UAV missions," in *Signal Processing, Sensor Fusion, and Target Recognition XXI*, May 2012, vol. 8392, pp. 83920X-83920X–9, doi: 10.1117/12.919793.

[10] M. Ghosh and A. Thirugnanam, "Introduction to artificial intelligence," in *Artificial Intelligence for Information Management: A Healthcare Perspective*, Springer, 2021, pp. 23–44.

[11] C. Han, Z. Li, C. Li, J. Hou, P. Dai, and W. Li, "Study on Artillery aiming control and the development of intelligent autonomous technology," *Journal of Physics: Conference Series*, vol. 2460, no. 1, p. 012167, Apr. 2023, doi: 10.1088/1742-6596/2460/1/012167.

[12] S. Rezwan and W. Choi, "Artificial intelligence approaches for UAV navigation: recent advances and future challenges," *IEEE Access*, vol. 10, pp. 26320–26339, 2022, doi: 10.1109/ACCESS.2022.3157626.

[13] G. U. Osimen, O. Newo, and O. M. Fulani, "Artificial intelligence and arms control in modern warfare," *Cogent Social Sciences*, vol. 10, no. 1, Dec. 2024, doi: 10.1080/23311886.2024.2407514.

[14] M. Sundhararajan, X.-Z. Gao, and H. Vahdat Nejad, "Artificial intelligent techniques and its applications," *Journal of Intelligent & Fuzzy Systems*, vol. 34, no. 2, pp. 755–760, Feb. 2018, doi: 10.3233/JIFS-169369.

[15] A. Salem, M. A. M. Hassan, and M. E. Ammar, "Tuning PID controllers using artificial intelligence techniques applied to DC-motor and AVR system," *Asian Journal of Engineering and Technology*, vol. 2, no. 2, pp. 129–138, 2014.

[16] G. L. Sinsley, J. A. Miller, L. N. Long, B. R. Geiger, A. F. Niessner, and J. F. Horn, "An intelligent controller for collaborative unmanned air vehicles," *Proceedings of the 2007 IEEE Symposium on Computational Intelligence in Security and Defense Applications, CISDA 2007*, pp. 139–144, 2007, doi: 10.1109/CISDA.2007.368146.

[17] R. Strzelecki, G. L. Demidova, D. V. Lukichev, N. A. Polyakov, A. A. Abdullin, and S. Y. Lovlin, "Survey on fuzzy logic methods in control systems of electromechanical plants," *Scientific and Technical Journal of Information Technologies, Mechanics and Optics*, vol. 19, no. 1, pp. 1–14, Feb. 2019, doi: 10.17586/2226-1494-2019-19-1-1-14.

[18] J. Nowaková and M. Pokorný, "Intelligent controller design by the artificial intelligence methods," *Sensors*, vol. 20, no. 16, p. 4454, Aug. 2020, doi: 10.3390/s20164454.

[19] L. Zhou and G. Chen, "Intelligent vibration control for high-speed spinning beam based on fuzzy self-tuning PID controller," *Shock and Vibration*, vol. 2015, 2015, doi: 10.1155/2015/617038.

[20] I. Thangaraju, M. Muruganandam, and M. Madheswaran, "Performance analysis and experimental verification of buck converter fed DC series motor using hybrid intelligent controller with stability analysis and parameter variations," *Journal of Electrical Engineering and Technology*, vol. 10, no. 2, pp. 518–528, 2015, doi: 10.5370/JEET.2015.10.2.518.

[21] M. I. Al-Saedi, H. Wu, and H. Handroos, "Intelligent controller of a flexible hybrid robot machine for ITER assembly and maintenance," *Fusion Engineering and Design*, vol. 89, no. 7–8, pp. 1795–1803, 2014, doi: 10.1016/j.fusengdes.2014.04.016.

[22] P. Mishra, V. Kumar, and K. P. S. Rana, "A novel intelligent controller for combating stiction in pneumatic control valves," *Control Engineering Practice*, vol. 33, pp. 94–104, 2014, doi: 10.1016/j.conengprac.2014.09.001.

[23] S. Suleymanov and A. Bayramov, "Artificial intelligence application for unmanned aerial vehicle navigation," in *Modeling, Control and Information Technologies: Proceedings of International Scientific and Practical Conference*, 2023, pp. 21–24, doi: 10.31713/MCIT.2023.004.

[24] S. M. Babayev, E. N. Sabziev, and A. A. Bayramov, "Mathematical formulation of optimal composition of the mobile tactical groups during the attack,"in *2017 International Conference on Military Technologies (ICMT)*, 2017.

[25] E. N. Sabziev, A. A. Bayramov, and S. B. Babayev, "Optimization of the tactical group composition with minimum manpower losses," *Informatics and Control Problems*, vol. 44, no. 1(3), pp. 9–15, Jul. 2024, doi: 10.54381/icp.2024.1.02.

BIOGRAPHIES OF AUTHORS

Azad Agalar Bayramov is Sc.D. Professor at Republican Seismic Survey Center of the Azerbaijan National Academy of Sciences and Center for Strategic Scientific Research, Baku, Azerbaijan. His research areas are signal processing, modeling, military sciences, risk analysis, AI control systems. ScD Bayramov has filed a number of patents and industrial designs on his innovative ideas and has been awarded with three international patents: two USA patents and one Euro-Asian. He has more 600 scientific published articles with 14 H-index. He supervised 11 Ph.D. students. He can be contacted at email: azad.bayramov@yahoo.com.

Samir Suleyman Suleymanov received the Ph.D. degree in physics science from the Baku State University, Azerbaijan. He used to hold several administrative posts with the Azerbaijan National Academy of Sciences. He is the Director of the Center for Strategic Scientific Research. Also, he is head of department of Republican Seismic Survey Center of the Azerbaijan National Academy of Sciences. He has authored or coauthored more than 100 publications. His research interests include soft computing, electronics, AI, and control systems. He can be contacted at email: ofis.setm@gmail.com.

Prof. Dr. Fatali Nariman Abdullayev is a deputy director of Republican Seismic Survey Center of the Azerbaijan National Academy of Sciences and Center for Strategic Scientific Research, Baku, Azerbaijan. His vast experience and expertise in the field of control systems sciences have enabled him to become a national point of reference in the area of renewable energy and waste utilization. He has also served as a consultant to Azerbaijan National Academy of Sciences, Prime Minister's Department, on the organization of science management. He can be contacted at email: fataliabdullayev66@gmail.com.