Operation System for Modern Unmanned Aerial Vehicles

Oleksandr Solomentsev [0000-0002-3214-6384] and Maksym Zaliskyi [0000-0002-1535-4384]

Pavlo Skladannyi[2] [0000-0002-7775-6039]

[1] Borys Grinchenko Kyiv University, Kyiv, Ukraine
[2] National Aviation University, Kyiv, Ukraine
avsolomentsev@ukr.net, maximus2812@ukr.net,
p.skladannyi@kubg.edu.ua

Abstract. The paper concentrates on the problem of design of operation system for modern UAV based on statistical data processing procedures. Modern UAV is a complex system that contains mechanical, electronic and aerodynamic components. Operation system performs the function of equipment efficiency and reliability providing. In general case, operation system consists of equipment, processes, personnel, documentation, control and measuring devices, etc. This system structure is considered according to adaptability, control and data processing principles. Adaptability is considered as the main property of the operation system that allows providing efficient UAV intended use in priori uncertainty conditions. Authors substantiate the efficiency indicator that takes into account effectiveness, time resources and costs. The three strategies of operation system elements inspection are considered. The first strategy (catchall inspection) is associated with simultaneous inspection of all elements of operation system. The second strategy (sliding window inspection) provides some predetermined elements inspection. The third strategy (random inspection) is associated with random selection of elements for inspection. Analytical formulas for the third strategy are obtained based on Markov circuit tool. Analysis of three strategies for UAV inspection proved the advantages of catchall inspections.

Keywords: UAV, operation system, efficiency, adaptability, statistical data processing.

1 Introduction

Today unmanned aerial vehicles (UAVs) are used in different branches of human activity [1]. The UAV is technical equipment that contains mechanical, electronic and aerodynamic components [2]. In the literature devoted to the UAV, different authors consider it hardware and software parts. There are three options of software:

1. Software for UAV control (generation and processing of control signals).
2. Software for implementation of UAV’s functional purpose (signal generation and processing after observation for the different objects, these signals transmitting for customer, etc.).

 CybHyg-2019: International Workshop on Cyber Hygiene, Kyiv, Ukraine, November 30, 2019.

3. Software for UAV's operational data monitoring (diagnostic variables monitoring and processing, reliability parameters monitoring and processing, decision making about preventive and corrective actions, etc.).

The third option of software is included in the operation system (OS) [3]. The OS plays an important place during UAV efficiency providing [4].

Modern UAV is complex technical system that controlled by several operators. Therefore, the OS of modern UAV should be considered as object of design and improvement.

Analysis showed that the modern challenge during UAV operation is artificial intelligence principles utilization. These principles allow providing efficient intended use of equipment in conditions that had not been taken into account during design stage.

2 Literature Analysis and Problem Statement

Literature [5 – 10] analysis showed that operation system contains the equipment (in this case UAV), processes, documentation, personnel, measuring equipment, resources, etc. The main process in OS is UAV intended use [11]. Other processes are additional.

The OS can be considered as an object of design and improvement especially in terms of intellectualization [12].

The sufficient attention is paid to the first and second option of UAV software [13; 14], but the third software option is not enough considered in scientific literature.

More over, the questions of UAV usage in the airspace are not considered in Ukrainian domestic regulatory documentations in civil aviation branch. The standardization issues for maintenance and reliability of UAV and other aviation equipment are presented in [15 – 18]. According to these documents, different maintenance strategies are developed, e.g. MSG-1, MSG-2, MSG-3 [19].

Methodology of UAV operation system design is considered in [12]. The authors concentrate on four principles: adaptation, aggregation, system approach and process approach. According to modern researches in software branch, these principles should be supplemented by other results associated with intelligence system utilization.

The corrective and preventive actions are implemented based on the results of statistical data processing [20]. The origin data for processing are diagnostic variables or reliability parameters.

The technical condition of UAV can change during operation. This change causes to nonstationarity in trends of diagnostic variables or reliability parameters. Analysis of such processes can allow predicting residual life time of UAV. In literature these problems are called changepoint analysis [21]. Timely and correct detection of changepoint increases efficiency of corrective and preventive actions.

For comparative analysis of statistical data processing results, it is necessary to choose the efficiency indicator. Different types of efficiency indicator in OS are considered in [22]. Efficiency is system property to achieve the aim. So efficiency should depend on effectiveness, cost, time resources.

The aim of operation system is to provide the required level of efficiency at the observation time. This aim can be achieved through statistical data processing procedures usage and corrective and preventive actions generation and implementation.

The OS efficiency is the following function:

$$\mathrm{Ef} = f(\vec{A}, \vec{\Theta}, \vec{R}, \vec{D} / T_{\mathrm{obs}}) \forall \mathrm{Ef} \in \Omega,$$

where $\vec{A}$ is a vector of statistical data processing algorithms, $\vec{\Theta}$ is a vector of OS components conditions, $\vec{R}$ is a vector of requirements for OS components, $\vec{D}$ is a vector of possible decision making, T_{obs} is a observation time in sliding window, Ω is a range of possible values of efficiency.

In this paper the dependence of efficiency on vector of statistical data processing algorithms will be researched. From mathematical point of view this problem can be solved through choosing the best algorithm $\vec{A}$ for maximum efficiency providing:

$$f(\vec{A}, \vec{\Theta}, \vec{R}, \vec{D} / T_{\mathrm{obs}}) \rightarrow \max .$$

3 The Operation System Structure

The structure of OS is shown in Fig. 1.

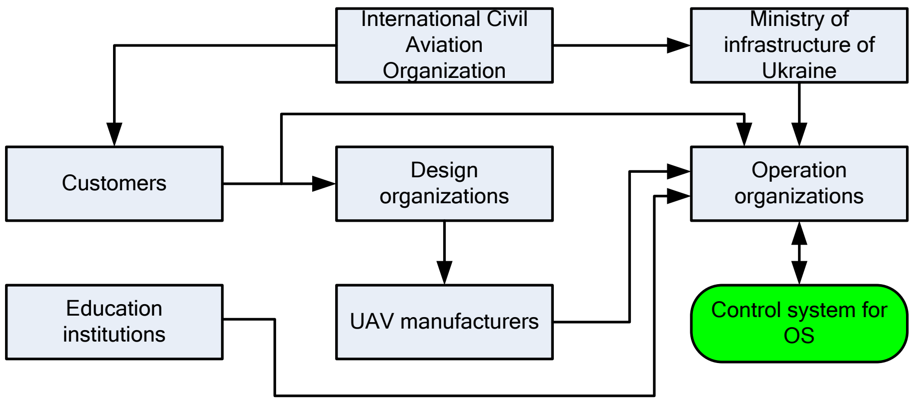

Fig. 1. The UAV OS structure

International civil aviation organization generates standards and recommendations for national aviation administration in the branch of UAV operation. Ministry of infrastructure of Ukraine regulates the question of airspace usage by UAV, inspects aviation organizations from the safety point of view, etc.

Customers form requirements for types and characteristics of UAVs. These requirements are taken into account by design and operation organizations. The UAV specialists are trained in education institutions.

Operation organization is the main component of OS structure. Control system for OS inspects UAV components, processes the statistical data, generates and implements corrective and preventive actions.

The control system interacts with all elements in Fig. 1 in case of intelligence principles based mode usage.

The generalized diagram of processing procedure is shown in Fig. 2.

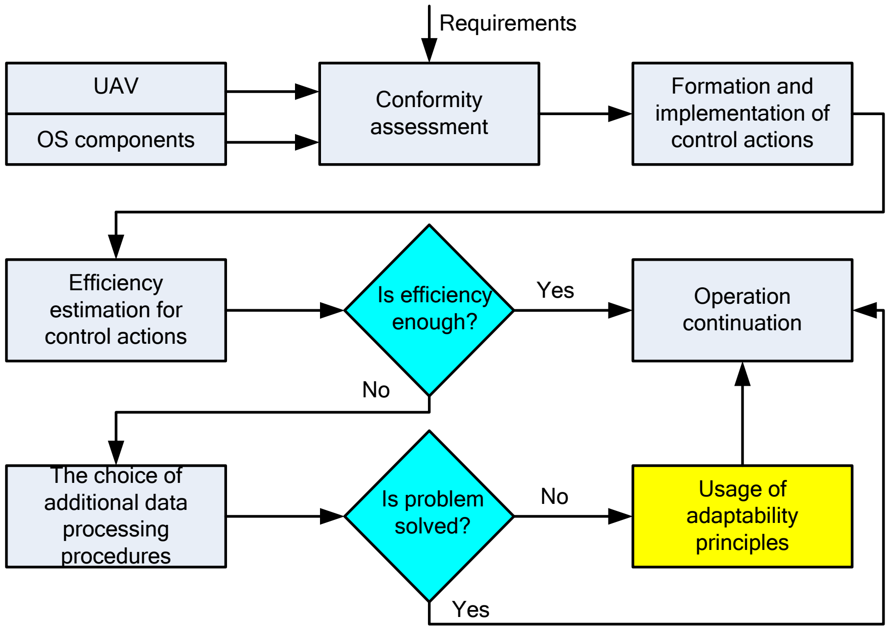

Fig. 2. The generalized diagram of processing procedure

Fig. 2 shows the basic principles of efficiency estimation and control. There are procedures of conformity assessment, formation and implementation of control actions, efficiency estimation during regular mode. In case of intelligence based mode the additional procedures are executed when efficiency decreases.

The authors assumed that the problem of efficiency decreasing can be solved based on artificial intelligence principles utilization.

Let's consider the algorithms for data processing according to Fig. 2. The list of algorithms can be presented as:

– A_1 is an algorithm of data collecting;
– A_2 is an algorithm of conformity assessment;
– A_3 is an algorithm of parameters stability assessment in case of changepoint;
– A_4 is an algorithm of preventive and corrective actions formation;
– A_5 is an algorithm of preventive and corrective actions implementation;

– A_6 is an algorithm of decision making about efficiency providing after control actions implementation;

– A_7 is an algorithm of decision making about additional data processing procedures;

– A_8 is an algorithm of decision making about usage of intelligence based procedures;

– A_9 is an algorithm of statistical processing for diagnostic variables;

– A_{10} is an algorithm of statistical processing for reliability parameters.

Algorithms A_7, A_8, A_9, A_{10} have complex structure and contain the set of procedures.

All algorithms are generalized. For detailed description of algorithms, it is necessary to solve synthesis and analysis problems, to choice best option for criterion of maximum efficiency, etc. Initial information for synthesis and analysis problems is measured data trends model.

Considered algorithms contain detection, estimation, filtration, extrapolation, interpolation, and other procedures. There are algorithms with known sample size, and sequential algorithms. The sequential procedures have advantages in duration of decision making [23].

Usage of adaptability principles is based on the following approaches:

– logic based solution finding;
– fuzzy logic;
– Bayesian network;
– adaptable learning after observation;
– semantic network;
– neural network, etc [24; 25].

More over, during diagnostic variables measuring, expert evaluation and subjective probability based estimates can be used [26].

There are different types of adaptation:

1) adaptation to the models and models parameters;
2) adaptation to the external conditions;
3) adaptation to internal changes in OS;
4) adaptation to the new requirements of regulatory and normative documents;
5) adaptation to OS aims, etc.

4 Efficiency of Inspection Strategies

Let’s consider the problem of efficiency indicator substantiation based on the analysis of different strategies of UAV OS components inspection. The efficiency indicator takes into account the probability of correct detection of unconformities in the OS and operational costs. In the general case, the numerical values of the efficiency indicator are random variables, so we can use its statistical characteristics, e.g. mean value.

Let the operation system of UAV contains N components. Each component can be in one of two conditions: serviceable and failure.

Serviceable condition corresponds to the case of component compliance with established requirements. Failure condition corresponds to the case without compliance with established requirements. Let the quantity of components with failure is n.

The value n is a discrete random variable in the range $[0; N]$. The failure can occur with failure rate $\lambda(t)$. Assume that during the inspection, new failures can't occur. The operational cost of one inspection is C.

The mathematical expectation of the probability of correct detection is defined as:

$$m_1(D) = \frac{m_1(n)}{\lambda(t) T_{\text{obs}}} = \frac{m_1(n)}{n}, \tag{1}$$

where $m_1(n)$ is a mathematical expectation of detected unconformities number, T_{obs} is an observation interval (the sum of OS functioning time T_{OS} and inspection procedure time Δt).

The mathematical expectation of the efficiency indicator can be represented as:

$$m_1(\text{Ef}) = \frac{m_1(D)}{C_{\max} / (C_{\max} - C_{\Sigma})}, \tag{2}$$

where C_{Σ} is a total cost for OS components inspections, $C_{\max}$ is a maximum allowable costs for operation.

Variables $m_1(D)$ and $m_1(\text{Ef})$ are in the range $[0;1]$.

Let consider three strategies:

1) catchall inspection (all N elements of operation system are simultaneously inspected during time Δt) – CI strategy;

2) sliding window inspection (all N elements of operation system are inspected during m inspection procedure each of which is characterized by time Δt) – SWI strategy;

3) random inspection (at each of m inspections, M components are verified randomly so that the total number of verified components is a random variable in the interval $[M; N]$) – RI strategy.

In the case of CI strategy mathematical expectation of the probability of correct detection and the mathematical expectation of the efficiency indicator can be calculated according to the following equations:

$$m_1(D/\text{CI}) = \frac{n}{\lambda(t)\left(T_{\text{OS}} + \Delta t\right)},$$

$$m_1(\text{Ef}/\text{CI}) = \frac{n(C_{\max} - NC)}{\lambda(t)\left(T_{\text{OS}} + \Delta t\right) C_{\max}}.$$

In the case of SWI strategy according to equation (1) and (2) the probability of correct detection and the efficiency can be presented as follows:

$$m_1(D/\mathrm{SWI}) = \frac{n}{\lambda(t)m\left(T_{\mathrm{OS}} + \Delta t\right)},$$

$$m_1(\mathrm{Ef}/\mathrm{SWI}) = \frac{n(C_{\max} - NC)}{\lambda(t)m\left(T_{\mathrm{OS}} + \Delta t\right)C_{\max}}.$$

In case of RI strategy, it can be written:

$$m_1(D/\mathrm{RI}) = \frac{\sum_{j=0}^{n} j p_j^{(m)}}{m\lambda(t)\left(T_{\mathrm{OS}} + \Delta t\right)},$$

$$m_1(\mathrm{Ef}/\mathrm{RI}) = \frac{(C_{\max} - NC)\sum_{j=0}^{n} j p_j^{(m)}}{m\lambda(t)\left(T_{\mathrm{OS}} + \Delta t\right)C_{\max}}.$$

In this equation $p_j^{(m)}$ is a final probability that characterize the random selection of M elements from N among which n elements don't conform the requirements during m inspections procedures.

The system condition for the random inspection can be described using the graph (see Fig. 3), and the definition of the calculation formulas is carried out using the Markov model, for which the final probabilities are determined on the basis of the transition matrix of conditional probabilities.

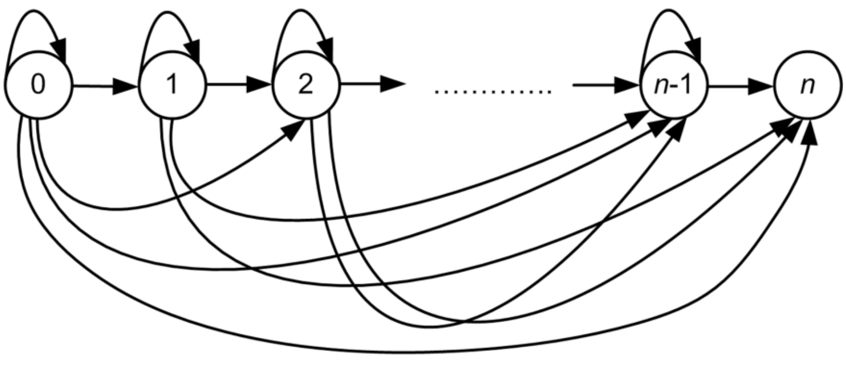

Fig. 3. The system condition graph: condition 0 – no unconformities were detected, condition 1 – only one unconformity was detected, …., condition n – all n unconformities were detected.

The final probability depends on m and can be written as:

$$p_j{}^{(m)} = \sum_{r_{m-1}=0}^{j}\left[P_{0\,r_{m-1}}\sum_{r_{m-2}=r_{m-1}}^{j}\left[P_{r_{m-1}\,r_{m-2}}\cdots\sum_{r_1=r_2}^{j}\left(P_{r_2\,r_1}P_{r_1\,j}\right)\right]\right],$$

where $m\in\left[1,\dfrac{N}{M}-1\right]$, $P_{i\,j}$ is a conditional probability of $j-i$ unconformities detection in the next stage of inspection if i unconformities are detected during previous stages. In this case:

$$P_{i\,j} = \frac{(n-i)!(N-n+i)!M!(N-M)!}{(j-i)!(n-j)!(M-j+i)!N!(N-n-M+j)!}.$$

Comparing obtained equations for different inspection strategies, it can be concluded that UAV OS efficiency in case of the first strategy of catchall inspection more than efficiency for both considered the second (SWI) and third (RI) strategies, i.e.

$$\frac{m_1(\mathrm{Ef}\,/\,\mathrm{CI}))}{m_1(\mathrm{Ef}\,/\,\mathrm{SWI})} = \frac{\dfrac{n(C_{\max}-NC)}{\lambda(t)\left(T_{\mathrm{OS}}+\Delta t\right)C_{\max}}}{\dfrac{n(C_{\max}-NC)}{\lambda(t)m\left(T_{\mathrm{OS}}+\Delta t\right)C_{\max}}} = m,$$

$$\frac{m_1(\mathrm{Ef}\,/\,\mathrm{CI}))}{m_1(\mathrm{Ef}\,/\,\mathrm{RI})} = \frac{\dfrac{n(C_{\max}-NC)}{\lambda(t)\left(T_{\mathrm{OS}}+\Delta t\right)C_{\max}}}{\dfrac{(C_{\max}-NC)\sum_{j=0}^{n} jp_j{}^{(m)}}{m\lambda(t)\left(T_{\mathrm{OS}}+\Delta t\right)C_{\max}}} = \frac{nm}{\sum_{j=0}^{n} jp_j{}^{(m)}}.$$

So the first strategy of UAV OS components inspection has efficiency exactly in m times higher compared with the second strategy and at least in m times compared with the third strategy (as $\sum_{j=0}^{n} jp_j{}^{(m)} \le n$) [28-32].

Let's consider the numerical example of different strategies efficiency calculation. Let UAV OS contains $N=50$ components with $n=10$ unconformities among them. The quantity of inspections $m=5$, the time of OS functioning $T_{\mathrm{OS}}=1000$ hours, inspection duration $\Delta t=4$ hours, total costs $C_{\max}=5000$ usd, operational cost $C=10$ usd, failure rate $\lambda(t)=0.01$ unconformity per hour.

So mathematical expectation of detected unconformities number $m_1(n)=7.051$. According to obtained formulas can be get

$$m_1(D\,/\,\mathrm{CI}) = 0.996,$$

$$m_1(\mathrm{Ef}\,/\,\mathrm{CI}) = 0.9,$$

$$m_1(D/\mathrm{SWI}) = 0.2\,,$$

$$m_1(\mathrm{Ef}\ /\mathrm{SWI}) = 0.18\,,$$

$$m_1(D/\mathrm{RI}) = 0.14\,,$$

$$m_1(\mathrm{Ef}\ /\mathrm{RI}) = 0.13\,.$$

So in this case the best option is the strategy of catchall inspection.

5 Conclusions

Analysis showed that not enough attention is paid to systematic review of UAV OS. Therefore, the OS structure is proposed based on system approach and control theory. Authors concentrated on consideration of control system for UAV OS. Control system collects and processes statistical operational data from all OS components; such approach allows making decision about corrective and preventive actions.

The generalized diagram of processing procedure is considered in the paper. This diagram suggests two modes of OS: regular mode and adaptable mode. The adaptability principles utilization expands the possibilities of flexible control of UAV operation. Three strategies of OS components inspection were analyzed. The numerical example showed advantages of catchall inspection.

References

1. Kharchenko, V.P., Kuzmenko, N.S., Ostroumov, I.V.: Identification of unmanned aerial vehicle flight situation. In: 2017 IEEE 4th International Conference on Actual Problems of Unmanned Aerial Vehicles Developments (APUAVD), pp. 116-120, Kyiv, Ukraine (2017).
2. Kutsenko, O.V., Ilnytska, S.I., Kondratyuk, V.M., Konin, V.V.: Unmanned aerial vehicle position determination in GNSS landing system. In: 2017 IEEE 4th International Conference on Actual Problems of Unmanned Aerial Vehicles Developments (APUAVD), pp. 79-83, Kyiv, Ukraine (2017).
3. Barlow, R.E., Proschan, F.: Mathematical theory of reliability, New York, John Wiley and Sons, 256 p. (1965).
4. Solomentsev, O.V., Zaliskyi, M.Yu., Zuiev, O.V., Asanov, M.M.: Data processing in exploitation system of unmanned aerial vehicles radioelectronic equipment. In: IEEE 2nd International Conference Actual Problems of Unmanned Air Vehicles Developments (APUAVD), pp. 77-80, Kyiv, Ukraine (2013).
5. Nakagawa, T.: Maintenance theory of reliability, London, Springer-Verlag, 270 p. (2005).
6. Solomentsev, O., Zaliskyi, M., Kozhokhina, O., Herasymenko, T.: Efficiency of data processing for UAV operation system. In: IEEE 4th International Conference on Actual Problems of UAV Developments (APUAVD), pp. 27-31, Kyiv, Ukraine (2017).
7. Zaliskyi, M., Petrova, Yu., Asanov, M., Bekirov, E.: Statistical data processing during wind generators operation. International Journal of Electrical and Electronic Engineering & Telecommunications, Vol. 8, No. 1, pp. 33-38, doi:10.18178/ijeetc.8.1.33-38 (2019).

8. Goncharenko, A.V.: Optimal UAV maintenance periodicity obtained on the multi-optional basis". In: IEEE 4th International Conference on Actual Problems of UAV Developments (APUAVD), pp. 65-68, Kyiv, Ukraine (2017).
9. Timchenko, V.L., Lebedev, D.O., Kuklina, K.A., Timchenko, I.V.: Robust-optimal control system of quadrocopter for maritime traffic's monitoring. In: IEEE 4th International Conference on Actual Problems of UAV Developments (APUAVD), pp. 192-195, Kyiv, Ukraine (2017).
10. Levin, B.R.: Theory of reliability of radio engineering systems, Moscow, Radio, 274 p. (in Russian) (1978).
11. Hryshchenko, Y.: Reliability problem of ergatic control systems in aviation. In: IEEE 4th International Conference on Methods and Systems of Navigation and Motion Control (MSNMC), Kyiv, Ukraine, pp. 126-129 (2016).
12. Solomentsev, O.V., Melkumyan, V.H., Zaliskyik M.Yu., Asanov, M.M.: UAV operation system designing. IEEE 3rd International Conference on Actual Problems of Unmanned Air Vehicles Developments (APUAVD), Kyiv, Ukraine, pp. 95-98 (2015).
13. Odarchenko, R., Polihenko, O., Kharlai, L., Tkalich, O.: Estimation of the communication range and bandwidth of UAV communication systems. In: IEEE 4th International Conference on Actual Problems of UAV Developments (APUAVD), pp. 159-162, Kyiv, Ukraine (2017).
14. Kuzmenko, N.S., Ostroumov, I.V., Marais, K.: An accuracy and availability estimation of aircraft positioning by navigational aids. In: IEEE International Conference on Methods and Systems of Navigation and Motion Control (MSNMC), Kyiv, Ukraine, pp. 36-40 (2018).
15. Certification Maintenance Requirements. AC No 25-19A, FAA, 15 p. (2011).
16. British Standards Institution, BS EN 13306: Maintenance Terminology, 31 p. (2001).
17. Condition-based Maintenance Recommended Practicies. SAE standard ARP-6204 (Put onto operation 15.09.2014), 115 p. (2014).
18. Condition-based Maintenance Plus for Material Maintenance. Departament of Defense Instruction 4151.22 (Put onto operation 16.10.2012), USA, 8 p. (2012).
19. SKYbrary MSG-3 – Maintenance Steering Group, Operator/Manufacturer Scheduled Maintenance Development, Accessed September 19, 2006, http://www.skybrary.aero/index.php/MSG-3 (2016).
20. Solomentsev, O., Zaliskyi, M., Herasymenko, T., Kozhokhina, O., Petrova, Yu.: Data processing in case of radio equipment reliability parameters monitoring. In: Advances in Wireless and Optical Communications (RTUWO 2018), Riga, Latvia, pp. 219-222 (2018).
21. Zhyhlyavskyi, A.A., Kraskovskyi, A.E.: Changepoint detection of random processes in problems of radio engineering, St. Petersburg, LU Publishing, 224 p. (in Russian) (1988).
22. Zuiev, O., Solomentsev, O., Zaliskyi, M.: Questions of radioelectronic equipment diagnostics programs efficiency analysis. In: Signal Processing Symposium 2013 (SPS 2013), Jachranka Village, Poland, pp. 1-3 (2013).
23. Zaliskyi, M., Solomentsev, O.: Method of sequential estimation of statistical distribution parameters. In: IEEE 3rd International Conference Methods and Systems of Navigation and Motion Control (MSNMC), Kyiv, Ukraine, pp. 135-138 (2014).
24. Bessmertnyi, I.A.: Artificial intelligent, St. Petersburg, ETMO, 132 p. (in Russian) (2010).
25. Migas, S.S.: Intelligence informational systems, St. Petersburg, SPbGIEU, 160 p. (in Russian) (2009).
26. Al-Azzeh J.S., Al Hadidi M., Odarchenko R., Gnatyuk S., Shevchuk Z., Hu Z. Analysis of self-similar traffic models in computer networks, International Review on Modelling and Simulations, № 10(5), pp. 328-336, 2017.

27. Kozlovskyy V., Parkhomey I., Odarchenko R., Gnatyuk S., Zhmurko T. Method for UAV trajectory parameters estimation using additional radar data. 2016 IEEE 4th International Conference Methods and Systems of Navigation and Motion Control, MSNMC 2016 – Proceedings 7783101, c. 39-42.
28. Fedushko S., Syerov Yu., Skybinskyi O., Shakhovska N., Kunch Z. (2020) Efficiency of Using Utility for Username Verification in Online Community Management. Proceedings of the International Workshop on Conflict Management in Global Information Networks (CMiGIN 2019), Lviv, Ukraine, November 29, 2019. CEUR-WS.org, Vol-2588. pp. 265-275. http://ceur-ws.org/Vol-2588/paper22.pdf
29. Gnatyuk S., Kinzeryavyy V., Stepanenko I. et al, Code Obfuscation Technique for Enhancing Software Protection Against Reverse Engineering, Advances in Intelligent Systems and Computing, Vol. 902, pp. 571-580, 2020.
30. Odarchenko R., Abakumova A., Polihenko O., Gnatyuk S. Traffic offload improved method for 4G/5G mobile network operator, Proceedings of 14th International Conference on Advanced Trends in Radioelectronics, Telecommunications and Computer Engineering (TCSET-2018), pp. 1051-1054, 2018.
31. R. Odarchenko, V. Gnatyuk, S. Gnatyuk, A. Abakumova, Security Key Indicators Assessment for Modern Cellular Networks, Proceedings of the 2018 IEEE First International Conference on System Analysis & Intelligent Computing (SAIC), Kyiv, Ukraine, October 8-12, 2018, pp. 1-7.
32. M. Zaliskyi, R. Odarchenko, S. Gnatyuk, Yu. Petrova. A. Chaplits, Method of traffic monitoring for DDoS attacks detection in e-health systems and networks, CEUR Workshop Proceedings, Vol. 2255, pp. 193-204, 2018.