UDC 004.81
DOI: 10.15587/1729-4061.2022.266276

DEVELOPMENT OF THE METHOD OF COMPLEXING THE RESULTS OF RADIO MONITORING AND REMOTE EARTH SENSING

Maksym Rohovets
PhD, Head of Department
Department No. 11*

Serhiy Hatsenko
Corresponding author
PhD, Deputy Head
Department of Intelligent**
E-mail: gans1501@ukr.net

Hryhorii Radzivilov
PhD, Associate Professor, Deputy Head of Institute
Institute for Research***

Yurii Pribyliev
Doctor of Technical Sciences, Associate Professor, Professor
Department of Information Technology Application and Information Security**

Roman Vozniak
PhD, Deputy Head of Department
Department of Information Technology Application and Information Security
Institute for Providing Troops (Forces) and Information Technologies**

Mykola Dorofeev
PhD, Leading Researcher, Leading Test Engineer
Scientific and Research Department of Tests of Missile and Artillery Weapons
Military unit A3444
Streletska str., 1, Chernihiv, Ukraine, 14033

Vitalii Yarovyi
Adjunct***

Oleh Hrebeniuk
Adjunct*

Dmitry Picus
Senior Lecturer****

Yurii Ryndin
Senior Lecturer****

*Korolyov Zhytomyr Military Institute
Myru ave., 22, Zhytomyr, Ukraine, 10004
**The National University of Defense of Ukraine
named after Ivan Chernyakhovskyi
Povitroflotskyi ave., 28, Kyiv, Ukraine, 03049
***Military Institute of Telecommunications and Information Technologies
named after Heroes of Kruty
Kyivska str., 45/1, Kyiv, Ukraine, 01011
****Department of Operations Management
of Military Intelligence and Special Operations Units
Military Academy (Odesa)
Fontanska road, 10, Odesa, Ukraine, 65009

The objects of the research are the objects of monitoring of groups of troops (forces). The relevance of the research lies in the need for a comprehensive analysis of monitoring objects from several sources of information. The results of the analysis show that the most reliable and accurate information comes from aerial monitoring, orbital remote sensing of the Earth and radio monitoring. At the same time, instrumental errors of radio monitoring devices do not allow determining the location of sources of radio radiation with the accuracy necessary for localization (neutralization) of threats. A method of integrating the results of radio monitoring and remote sensing of the Earth has been developed. The essence of the proposed research is the complex processing of monitoring results from various sources of information extraction. The difference between the proposed method and the known ones is that the specified method contains the following improved procedures:

– taking into account the type of uncertainty about the state of the monitoring object (complete uncertainty, partial uncertainty, full awareness);

– carry out a multi-level analysis of the state of the monitoring object according to 4 levels and 3 significant events;

– detection of a monitoring object as part of a group monitoring object.

The use of the proposed approach to radio monitoring information processing and monitoring using unmanned aerial vehicles/devices of remote sensing of the Earth allows to reduce the time required for deciphering aerospace images by at least 1.3 times. At the same time, the accuracy of determining the coordinates will be limited by the resolution of the equipment of unmanned aerial vehicles/devices of remote sensing of the Earth and is of the order of 0.5 m

Keywords: complex monitoring, monitoring objects, a priori uncertainty, remote sensing of the Earth, unmanned aerial vehicles

Received date 27.07.2022
Accepted date 12.10.2022
Published date 30.10.2022

***How to Cite:** Rohovets, M., Hatsenko, S., Radzivilov, H., Pribyliev, Y., Vozniak, R., Dorofeev, M., Yarovyi, V., Hrebeniuk, O., Picus, D., Ryndin, Y. (2022). Development of the method of complexing the results of radio monitoring and remote earth sensing. Eastern-European Journal of Enterprise Technologies, 5 (4 (119)), 16–23. doi: https://doi.org/10.15587/1729-4061.2022.266276*

1. Introduction

The results of the analysis of the socio-political situation in the world indicate that the biggest challenge to the security of states at the global level is such negative phenomena as terrorism, illegal drug trafficking, etc. [1, 2]. Taking into account the political, economic and geographical position of Ukraine, the same problems have a destructive effect on the level of national security and our state. In order to reduce these risks, in 2018, Ukraine joined the global system of control over the illegal circulation of drugs, weapons and counterfeit goods [3].

In addition, Ukraine, as a state that restrains the military aggression of the Russian Federation (RF), is forced to conduct hostilities on the territory of the state. In order to monitor the situation in the territory of the Joint Forces operation (JFO), the OSCE Special Monitoring Mission operates, which has both unmanned aerial vehicles (UAV) and other technical devices of control at its disposal [4].

The results of the analysis of the effectiveness of the use of technical devices of monitoring on the territory of the JFO indicate that the most reliable and accurate information comes from aerial monitoring, orbital devices of remote sensing of the Earth and radio monitoring (RM).

At the same time, the instrumental errors of PM devices do not allow determining the location of sources of radio emissions (SRE) with the accuracy necessary for localization (neutralization) of threats. At the same time, the data obtained by the RM can be used to target other types of monitoring, including the use of UAV and air defense systems (ADS).

Under such conditions, the scientific problem of creating a methodological apparatus of a complex collection of materials (information) obtained by technical types of monitoring both at the stage of analyzing the operational situation and at the stage of combat planning becomes relevant.

2. Analysis of literary data and formulation of the problem

The work [5] presents cognitive modeling algorithm. The main advantages of cognitive tools are defined. The lack of consideration of the type of uncertainty about the state of the object of analysis should be attributed to the shortcomings of this approach.

The work [6] reveals the essence of cognitive modeling and scenario planning. The approach proposed by the authors does not allow taking into account the type of uncertainty about the state of the object of analysis and does not take into account the noise of the initial data.

The work [7] carried out an analysis of the main approaches to cognitive modeling. Cognitive analysis allows: to investigate problems with unclear factors and relationships; it takes into account changes in the external environment and use objectively formed trends in the development of the situation in one's interests. At the same time, the issue of describing complex and dynamic processes remains unexplored in this paper.

The work [8] presents a method of analyzing large data sets. The specified method is focused on finding hidden information in large data sets. The method includes the operations of generating analytical baselines, reducing variables, detecting sparse features, and specifying rules. The disadvantages of this method include the impossibility of taking into account different decision evaluation strategies, the lack of taking into account the type of uncertainty of the input data.

Such works as [9, 10] are devoted to the problem of researching the accuracy of determining the location of the SRE. At the same time, the conclusions of the conducted scientific researches indicate that the main reason for the error in determining the coordinates of the SRE by devices of RM is the low linear accuracy in the direction finding process. As a result, the RM system is able to determine only the area of the probable location of the SRE. In addition, the SRE is not always in the same position as the objects of monitoring (military formations of the enemy, groups of smugglers, illegal armed formations, etc.). In other words, the management bodies of monitoring objects (MO) can be scattered in space [11, 12]. From the analysis of the Table 1, the distance between SRE and MO can range from 1 to 40 km. In this case, determining the location of the MO is complicated due to the enemy's application of the concept of building a control and communication system in the area of a distributed control point [13–20].

Table 1

Distance of communication nodes from control points

Control post (command post)	Distance, km
The main control point of the first level	1–3
The main control point of the second level	1–3
The main control point of the third level	3–10
The main control point of the zonal level	20–25
The main control point of the territorial level	20–40

Under such conditions, determining the location of MO and/or SRE with the necessary accuracy is possible only through detailed reconnaissance of the likely area by devices of UAV and/or ADS. At the same time, the data of the RM will be used to target the devices of species monitoring.

The existing REI devices have a rather low linear accuracy of the local value of the enemy's REI, which is 10...15 % of the direction-finding range. The increase in requirements for operational intelligence regarding the accuracy of establishing the coordinates of enemy objects suggests the need to find ways to increase the reliability and accuracy of the enemy's local RES identified by REI devices. One of the real ways to solve this task is the possibility of clarifying the location of reconnaissance objects and their operational-tactical affiliation based on the engineering reconnaissance features of the terrain of the area where the enemy's reconnaissance zone is located.

One of the requirements for the complex processing of intelligence data obtained by various types of intelligence is to ensure the possibility of a generalized assessment of the military-political and operational situation.

Accumulation, systematization and generalization of intelligence data create an informational basis for the development by officials of the command posts of the REI and team-intelligence center units of various assessments of the state and capabilities of the enemy's intelligence groups, i.e. intelligence assessments.

3. The aim of objectives of research

The aim of research is to develop a methodological approach for complex information processing of RM and monitoring with the use of UAV/ADS. This will make it possible to increase the accuracy and reliability of detection and identification of monitoring objects.

To achieve the aim, the following objectives were set:

– to carry out a formalized description of the task of analyzing the state of objects in special purpose information systems;

– to develop a method of integrating the results of radio monitoring and remote sensing of the earth;

– to evaluate the potential effectiveness of the method.

4. Research materials and methods

The object of the research is the objects of monitoring of groups of troops (forces).

The research hypothesis was the possibility of increasing the reliability and accuracy of the identification of monitoring objects by using a special methodological approach to complex information processing.

In the course of the conducted research, the general provisions of the theory of artificial intelligence were used to solve the problem of analyzing the state of monitoring objects. Thus, the theory of artificial intelligence is the basis of the mentioned research. The research uses fuzzy cognitive models, an advanced genetic algorithm and evolving artificial neural networks. The simulation was carried out using MathCad 2014 software (USA) and an Intel Core i3 PC (USA).

5. Research results on the development of a method of integrating the results of radio monitoring and remote sensing of the earth

5. 1. Setting the task of assessing the condition of the monitoring object based on the results of radio monitoring and remote sensing of the earth

Let the control system of the process of radio monitoring and remote sensing of the earth be presented in the form of a sign oriented graph.

In general, the task of determining the state of the monitoring object is reduced to calculations according to the formula:

$$A_i(k+1)= = f\left(\left(A_i(k)+\sum_{j\neq i, j=1}^{N} A_j(k)W_{ij}\right)\times \iota_{ij}\right)\times \zeta_{ij}, \quad (1)$$

where $A_i(k+1)$ is the new state of the graph vertex, $A_i(k)$ is the previous state of the graph, W_{ij} is the weight matrix, f is the graph threshold function, ι_{ij} is the operator that takes into account the degree of awareness of the state of the object; ζ_{ij} is the operator to take into account the degree of noise in the data about the state of the object. The calculation process is iterative – after setting the initial states of the vertices, the values of the states are recalculated until the difference between the current and previous states turns out to be less than some given value.

Expression (1) allows to form a description of the state of the monitoring object by the devices of its representation in the form of a graph.

The graph is built for each individual object. The specified description is universal and allows to describe the object of analysis taking into account the hierarchy and individual specificity of each monitoring object. When expression (1) is written in the form of a multidimensional time series, the description process can be given for a dynamic system. Expression (1) while constructing a mathematical description of the state of the monitoring object takes into account the degree of awareness of the state of the object and the noise level of the data.

5. 2. Development of a method of integrating the results of radio monitoring and remote sensing of the earth

The devices of UAV/ADS provide detection of MO of both the territorial level and the first level with a resolution of up to 0.5 m and determination of their location with an accuracy of 30–50 m. At the same time, the processing of the results of such monitoring consists in deciphering aerospace images.

Decryption is a complex informational and logical process, which is carried out by the operator during the target research of the image and consists in the detection, recognition, classification, as well as the general assessment of MO [5, 12, 21–28].

In general, the structure of the decryption process can be represented by four levels (Fig. 1) [23–33].

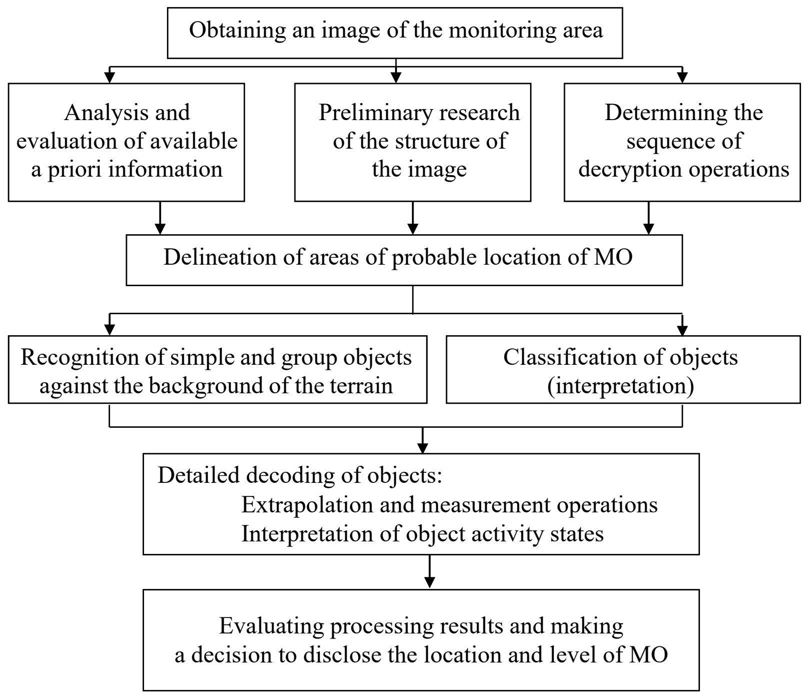

Fig. 1. Typical diagram of the process of deciphering aerospace images

At the first level, awareness of the task and planning of the decryption process is carried out.

At the second level, the search and detection of MO is carried out in accordance with the task.

At the third level, a detailed analysis of the image is carried out, the purpose of which is to recognize and interpret the detected MO.

At the fourth level, the processing results are evaluated. It is the most difficult stage of the decryption process, during which the relationship between the detected objects is determined, the MO control system is exposed, which, in fact, represents the operational situation that has developed. During the assessment of the situation, the composition, condition and position of the MO is revealed, which allows the information consumer to make a decision regarding the planning of further actions.

The decryption process is determined by three compatible events, which are described by probability indicators: detection of MO – R_v; recognition of MO – R_R and detailed deciphering – R_{dd}.

The probability of detecting MO – R_v depends on the angular dimensions of the field of view (image dimensions) 2β, the angular dimensions of the MO image γ, the contrast of MO with the background K, the brightness of the background L_f, the search time t and for an image with a given resolution can be determined by the empirical dependence of the appearance:

$$R_v = 1 - \exp\left(-\frac{K^2\gamma^3 L_f^{0.3} t}{A(2\beta)^2}\right),$$

where $A=6.3\cdot10^{-2}$ (angle min)^3*(kandel/m^2)$^{0.3}$*c*degree^{-2} is the normalized coefficient, K is the MO contrast with the background, L_f is the background brightness, γ is the angular dimensions of the MO image; t is the search time, β is the image size.

Given K, L_f, γ and R_v, the efficiency of the detection process depends on the total area of the image on which the search is carried out. The area of intelligence collection determined for deciphering by one operator depends on the spatial resolution of the image and is 1,000–5,000 km^2. Such a search area with relatively small linear dimensions of the OR (0.05–1.0 km) determines costs in terms of processing time and efficiency of the entire decryption process.

The probability of correct recognition of a simple MO, provided it is detected, depends on the linear dimensions in the image, the linear resolution l of the on-board special equipment on the terrain L and the shape of the MO, which is characterized by the coefficient β_f and is determined by empirical dependence:

$$R_{rec} = \exp\left[-\left(\beta_f L / l\right)^2\right]. \quad (2)$$

At the same time, the probability of recognizing a simple MO located in the structure of a group object increases, which is taken into account by the coefficient C, which is determined during practical processing depending on the number of simple objects in the structure of a group MO. Coefficient C can take on the following values with the structural complexity of the object while increasing:

– on one simple individual object – 1.1–1.5;
– on two simple objects – 1.2–2.5;
– on three simple objects – 1.3–3.0;
– on four simple objects – 1.4–3.5.

Taking into account the values of the coefficient C, which reflects the complexity of the structure of the integrated (group) MO, which is deciphered, the probability of recognition is determined in the form:

$$R_{rec} = C\exp\left[-\left(\beta_f L / l\right)^2\right]. \quad (3)$$

The probability of recognizing a group object a_k, consisting of simple objects z_i, $i=\overline{1,m}$, is estimated by the full probability formula:

$$R(\alpha_k) = \sum_{i=1}^{m} R_{rec}(z_i) R(\alpha_k / z_i), \quad (4)$$

where $R_{rec}(z_i)$ is defined by the expression (2).

The probability of determining the characteristics of MO with a given accuracy depends on the geometric properties of the image and the method of conducting measurements. This indicator characterizes the efficiency of the detailed decryption stage.

Analysis of a typical diagram of the decoding process (Fig. 1) shows that the stage of detailed decoding (8, 9) is an independent process of measuring linear characteristics and interpreting the obtained values. At the same time, while detecting and recognizing MO on the terrain image (at least three operations: 2, 5 and 6) can be carried out using additional information coming from other types of monitoring. Thus, while performing operation 2, information from the RM system about the likely type of object and the area of its location can be used. This will make it possible to organize and carry out the process of detailed decryption in a more targeted manner. While performing operations 5 and 6, using information from the RM system about the area of the probable location of the MO and about its type increases the probability and reduces the time of its recognition on an aerial photo.

The interaction of the RM and monitoring using UAV/ADS can be carried out by using the information obtained by the RM system about the probable area of deployment of the MO, its individual elements to find (refine) the coordinates of the object in the picture. In other words, the process of deciphering the aerospace image will begin with a detailed analysis of the area where the MO is likely to be located, revealed by the RM system. This will reduce the time needed to search and recognize MO and increase the accuracy of determining the coordinates of MO elements that are exposed by PM devices.

5. 3. Evaluation of the potential effectiveness of the proposed method

Let it be necessary to expose the group MO. At the same time, the RM system exposed a certain control point (CP) and determined the coordinates of its location m_x^{cn} and m_y^{cn} with accuracy R_{ak}^{cn}. Using the available data, not the entire image is deciphered, but the section described by the circular normal distribution law:

$$q_{cn}(x,y) = \frac{1}{2\left(R_{ak}^{cn}\right)^2 \pi} \exp\left[-\frac{\left(x-m_x^{cn}\right)^2 + \left(y-m_y^{cn}\right)^2}{2\left(R_{ak}^{cn}\right)^2}\right]. \quad (5)$$

At the same time, the density of the distribution of CP elements $q_{io}(x,y)$ is determined according to the Table 1. Thus, $q_{cn,io}(x,y)$ will be described by the convolution of the functions $q_{cn}(x,y)$ and $q_{cn}(x,y)$, i.e.

$$q_{cn,io}(x,y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} q_{cn}(x,y) q_{io}(x-\xi, y-\eta)\, d\xi d\eta, \quad (6)$$

where ξ, η is the distance of communication nodes from the CP of a certain level.

The area of possible dislocation of the connection node Q_{cn} and CP Q_{io} is determined by constructing a projection of the horizontal section of the body of the function $q_{cn}(x,y)$, $q_{cn,io}(x,y)$ for a given probability of a serration hitting the SRE in a circle with a radius (Fig. 2).

At the same time, the radius of the area of possible location of MO can be calculated as:

$$r = \begin{cases} d - R_{ak}^{cn}, & \text{if } d - R_{ak}^{cn} > 0; \\ 0, & \text{if } d - R_{ak}^{cn} \le 0; \end{cases} \quad (7)$$

$$r = D + R_{ak}^{cn},$$

where D and d are respectively, the minimum and maximum distance of the communication node from the CP.

Calculation of the area of the possible location of the object Q_{io} of a given probability for the circular normal distribution law (Fig. 2) is carried out according to the expression:

$$Q_{io}=2\pi rKL, \qquad (8)$$

where K is the coefficient that determines the probability of finding a communication node in the middle of a circle with a radius R_{ak}^{cn}.

The size of the circle (Fig. 2) depends on the probability that the SRE will be in its middle.

To calculate the coefficient K, the expression is used:

$$K=\sqrt{-2\ln(1-P_c)}L, \qquad (9)$$

where R_d is the given probability of a communication node hitting a circle with a radius R_{ak}^{cn}.

At the same time, the value of the coefficient K_i and the dimensions of the circle R_{ak}^{cu}, depend on R_d (R_d=0...1) and vary from 0 to ∞.

The probability of finding a communication node inside a circle with a radius R_{ak}^{ak} of K=1 is 0.63.

Given that the accuracy of the deployment location of the communication node for the direction-finding method depends on the accuracy of determining the angles and the distance to the SRE $\sigma=f(\Delta\theta, \Delta r)$, the area of the possible location of the MO will increase according to a linear law (Fig. 3).

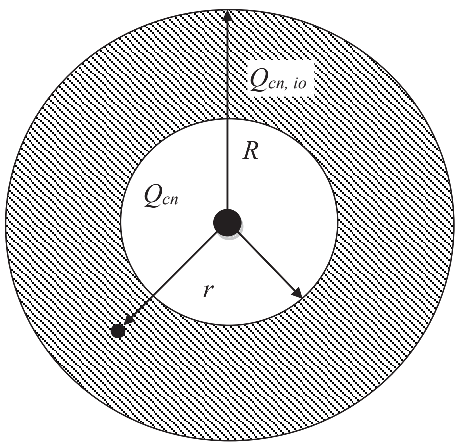

Fig. 2. Projections of the horizontal section of the body of the function $q_{cn}(x,y)$, $q_{cn,io}(x,y)$ for $R_{dis,set}$=const

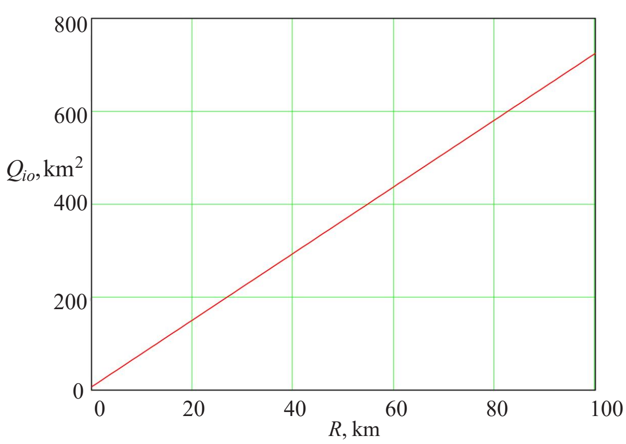

Fig. 3. Dependence of the area of the area of the possible location of the monitoring object on the accuracy for $R_{dis,set}\geq 0.63$

While deciphering a picture from the distance of the most convenient visual search (250–300 mm), the OR search time for this scheme of complex processing is reduced by x times (Fig. 4):

$$x=\left(\frac{\text{arctg}4\sqrt{S/\pi}}{\text{arctg}4\sqrt{Q/\pi}}\right)^2, \qquad (10)$$

where S is the area of the given area in the picture; Q is the area occupied by the OR with a given probability; x is the time indicator (in times).

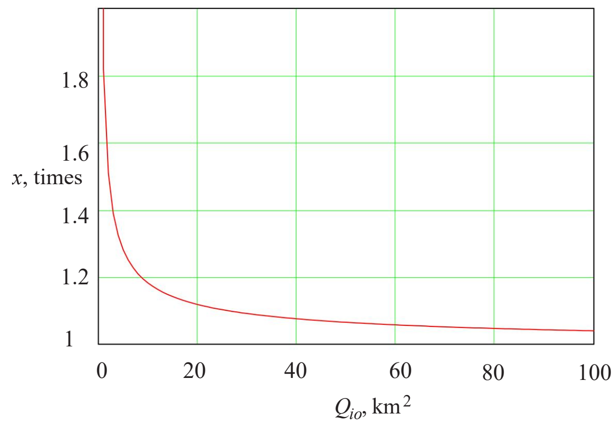

Fig. 4. Dependence of the time indicator of the decryption process on the size of the monitoring object at a fixed image size

In this case, the probability of finding the decrypted object will be determined by the probability of its detection.

The obtained theoretical results were used as the basis of a mathematical model of complex data processing of the RM and monitoring using UAV/ADS. Let the main CP of the third level be monitored. The communication node is defined by the RM devices as one of the elements included in the group MO. At the same time, the accuracy of determining the location by RM devices is R_{ak}^{cn}=10 km. The distance of the communication node from the main PU of the 3rd level is determined according to the table 1 and is $\xi=\eta$=25 km. UAV/ADS devices obtained a picture of the area S=10000 km^2 with a resolution of 0.5 m (Fig. 5–7).

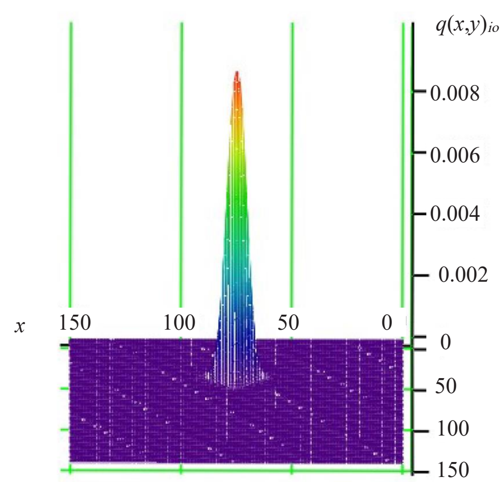

Fig. 5. Graphic representation of the distribution law of the coordinates of the communication node according to radio monitoring data

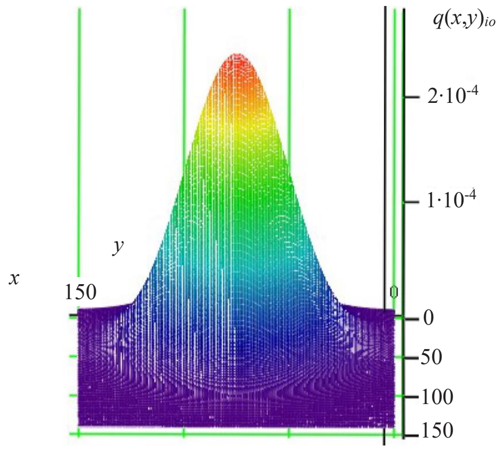

Fig. 6. Graphic representation of the distribution law of the coordinates of the monitored object according to radio monitoring data

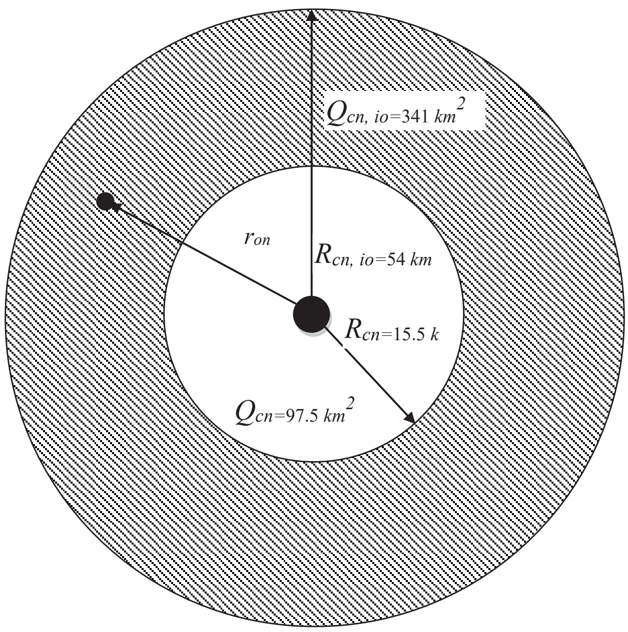

Fig. 7. Projections of the horizontal section of the body of the function $q_{cn}(x,y)$, $q_{cn,io}(x,y)$, $R_{dis,set}$=0.7

The area of the possible location of MO of the given probability $R_{dis,set}$=0.7 is 341 km^2.

Given that the resolution of the image is 0.5 m, the accuracy of determining the coordinates of the object during decoding will be 0.5 m.

According to the results of the calculation (10), the time to decipher the MO image is reduced by 1.3 times.

6. Discussion of the results of the development of the method of integrating the results of radio monitoring and remote sensing of the earth

The developed formalized approach allows for the assessment of highly dynamic, complex and hierarchical objects. It creates the universality of the approach and allows for the assessment of various types of objects that have different origins and belong to the management chain.

A method of integrating the results of radio monitoring and remote sensing of the earth has been developed.

The main advantages of the proposed evaluation method are, in comparison with researches [5–10]:

– it has a flexible hierarchical structure of indicators, which allows reducing the task of multi-criteria evaluation of alternatives to one criterion or using a vector of indicators (1) for selection;

– unambiguousness of the obtained assessment of the object state (expressions (1)–(10), Table 1);

– universality of application due to adaptation of the system of indicators during work (1);

– it does not accumulate learning error due to the use of learning procedures;

– taking into account the type of uncertainty and noise of the initial data (1);

– high reliability of the obtained solutions while searching for a solution in several directions (expressions (1)–(10)).

The disadvantages of the proposed method include:

– the loss of informativeness while assessing the condition of the monitoring object due to the construction of the belonging function;

– lower accuracy of assessment on a single parameter of object condition assessment;

– the loss of credibility of the obtained solutions while searching for a solution in several directions at the same time;

– lower assessment accuracy compared to other assessment methods.

This method will allow:

– to carry out an assessment of the condition of the object;

– to determine effective measures to improve management efficiency;

– to increase the speed of assessment of the object state;

– to reduce the use of computing resources of decision making support systems.

The proposed approach should be used to solve problems of evaluating complex and dynamic processes characterized by a high degree of complexity.

The analysis of the results of the research shows that the application of the methodological approach of integrated processing of RM information and monitoring with the use of UAV/ADS allows to reduce the time required for the detection of MO by at least 1.3 times. At the same time, the accuracy of determining the coordinates will be limited by the resolution of the UAV/ADS equipment and is of the order of 0.5 m.

This research is a further development of researches aimed at developing methodological principles for increasing the efficiency of information and analytical support, which were published earlier [2, 4, 11, 34, 35].

The directions of further research should be aimed at reducing computing costs while processing various types of data in special purpose systems.

7. Conclusions

1. The description of the task of analyzing the state of objects in special purpose information systems is formalized, which is flexible and universal. As a criterion for the efficiency of the specified method, the efficiency of the process of analyzing the state of the object with the given reliability of the obtained estimate was chosen. In the course of the research, the concept of presenting the evaluation method in special purpose information systems was formulated. In this concept, the analysis process is presented in the form of a hierarchical graph.

This makes it possible to create a hierarchical description of a complex process by levels of generalization and conduct an appropriate analysis of its state.

2. A method of integrating the results of radio monitoring and remote sensing of the earth has been developed, which allows:

– to take into account the type of uncertainty and noisy data;

– to take into account the available computing resources of the system for analyzing the state of the object;

– to conduct a multi-level analysis of the state of the monitoring object on 4 levels and 3 significant events.

3. The proposed method of integrating the results of radio monitoring and remote sensing of the earth using UAV/ADS makes it possible to reduce the time required for MO detection by at least 1.3 times, with restrictions only on the resolution of the UAV/ADS equipment.

Conflict of interests

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Acknowledgement

The author team expresses gratitude for providing assistance in the preparation of the article:

– Doctor of Technical Sciences, Professor Oleksiy Kuvshinov – deputy head of the educational and scientific institute of the National Defense University of Ukraine named after Ivan Chernyakhovsky;

– honored worker of science and technology of Ukraine, Doctor of Technical Sciences, Professor Vadym Slyusar – chief researcher of the Central Research Institute of armament and military equipment of the Armed Forces of Ukraine;

– Doctor of Technical Sciences, professor Oleksandr Rotshtein – Professor of the Mahon Lev Polytechnic Institute;

– PhD, Associate Professor Oleksandr Bashkirov – leading researcher of the Central Research Institute of armament and military equipment of the Armed Forces of Ukraine.

References

1. Bashkyrov, O. M., Kostyna, O. M., Shyshatskyi, A. V., Viliukha, Yu. I. (2015). Rozvytok intehrovanykh system zv'iazku ta peredachi danykh dlia potreb Zbroinykh Syl. Ozbroiennia ta viiskova tekhnika, 1 (5), 35–40.
2. Dudnyk, V., Sinenko, Y., Matsyk, M., Demchenko, Y., Zhyvotovskyi, R., Repilo, I. et. al. (2020). Development of a method for training artificial neural networks for intelligent decision support systems. Eastern-European Journal of Enterprise Technologies, 3 (2 (105)), 37–47. doi: https://doi.org/10.15587/1729-4061.2020.203301
3. Sova, O., Shyshatskyi, A., Salnikova, O., Zhuk, O., Trotsko, O., Hrokholskyi, Y. (2021). Development of a method for assessment and forecasting of the radio electronic environment. EUREKA: Physics and Engineering, 4, 30–40. doi: https://doi.org/10.21303/2461-4262.2021.001940
4. Pievtsov, H., Turinskyi, O., Zhyvotovskyi, R., Sova, O., Zvieriev, O., Lanetskii, B., Shyshatskyi, A. (2020). Development of an advanced method of finding solutions for neuro-fuzzy expert systems of analysis of the radioelectronic situation. EUREKA: Physics and Engineering, 4, 78–89. doi: https://doi.org/10.21303/2461-4262.2020.001353
5. Alpeeva, E. A., Volkova, I. I. (2019). The use of fuzzy cognitive maps in the development of an experimental model of automation of production accounting of material flows. Russian Journal of Industrial Economics, 12 (1), 97–106. doi: https://doi.org/10.17073/2072-1633-2019-1-97-106
6. Zagranovskaia, A. V., Eissner, Iu. N. (2017). Simulation scenarios of the economic situation based on fuzzy cognitive maps. Modern economics: problems and solutions, 10 (94), 33–47. doi: https://doi.org/10.17308/meps.2017.10/1754
7. Simankov, V. S., Putiato, M. M. (2013). Issledovanie metodov kognitivnogo analiza. Sistemnyi analiz, upravlenie i obrabotka informatcii, 13, 31–35.
8. Ko, Y.-C., Fujita, H. (2019). An evidential analytics for buried information in big data samples: Case study of semiconductor manufacturing. Information Sciences, 486, 190–203. doi: https://doi.org/10.1016/j.ins.2019.01.079
9. Ramaji, I. J., Memari, A. M. (2018). Interpretation of structural analytical models from the coordination view in building information models. Automation in Construction, 90, 117–133. doi: https://doi.org/10.1016/j.autcon.2018.02.025
10. Pérez-González, C. J., Colebrook, M., Roda-García, J. L., Rosa-Remedios, C. B. (2019). Developing a data analytics platform to support decision making in emergency and security management. Expert Systems with Applications, 120, 167–184. doi: https://doi.org/10.1016/j.eswa.2018.11.023
11. Zuiev, P., Zhyvotovskyi, R., Zvieriev, O., Hatsenko, S., Kuprii, V., Nakonechnyi, O. et. al. (2020). Development of complex methodology of processing heterogeneous data in intelligent decision support systems. Eastern-European Journal of Enterprise Technologies, 4 (9 (106)), 14–23. doi: https://doi.org/10.15587/1729-4061.2020.208554
12. Yeromina, N., Kurban, V., Mykus, S., Peredrii, O., Voloshchenko, O., Kosenko, V. et. al. (2021). The Creation of the Database for Mobile Robots Navigation under the Conditions of Flexible Change of Flight Assignment. International Journal of Emerging Technology and Advanced Engineering, 11 (5), 37–44. doi: https://doi.org/10.46338/ijetae0521_05
13. Chen, H. (2018). Evaluation of Personalized Service Level for Library Information Management Based on Fuzzy Analytic Hierarchy Process. Procedia Computer Science, 131, 952–958. doi: https://doi.org/10.1016/j.procs.2018.04.233
14. Chan, H. K., Sun, X., Chung, S.-H. (2019). When should fuzzy analytic hierarchy process be used instead of analytic hierarchy process? Decision Support Systems, 125, 113114. doi: https://doi.org/10.1016/j.dss.2019.113114

15. Osman, A. M. S. (2019). A novel big data analytics framework for smart cities. Future Generation Computer Systems, 91, 620–633. doi: https://doi.org/10.1016/j.future.2018.06.046
16. Gödri, I., Kardos, C., Pfeiffer, A., Váncza, J. (2019). Data analytics-based decision support workflow for high-mix low-volume production systems. CIRP Annals, 68 (1), 471–474. doi: https://doi.org/10.1016/j.cirp.2019.04.001
17. Harding, J. L. (2013). Data quality in the integration and analysis of data from multiple sources: some research challenges. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-2/W1, 59–63. doi: https://doi.org/10.5194/isprsarchives-xl-2-w1-59-2013
18. Kosko, B. (1986). Fuzzy cognitive maps. International Journal of Man-Machine Studies, 24 (1), 65–75. doi: https://doi.org/10.1016/s0020-7373(86)80040-2.
19. Gorelova, G. V. (2013). Cognitive approach to simulation of large systems. Izvestiia IuFU. Tekhnicheskie nauki, 3, 239–250.
20. Koshlan, A., Salnikova, O., Chekhovska, M., Zhyvotovskyi, R., Prokopenko, Y., Hurskyi, T. et. al. (2019). Development of an algorithm for complex processing of geospatial data in the special-purpose geoinformation system in conditions of diversity and uncertainty of data. Eastern-European Journal of Enterprise Technologies, 5 (9 (101)), 35–45. doi: https://doi.org/10.15587/1729-4061.2019.180197
21. Rotshtein, A. P. (1999). Intellektualnye tekhnologii identifikatcii: nechetkie mnozhestva, geneticheskie algoritmy, neironnye seti. Vinnitca: «UNIVERSUM», 320.
22. Emelianov, V. V., Kureichik, V. V., Kureichik, V. M., Emelianov, V. V. (2003). Teoriia i praktika evoliutcionnogo modelirovaniia. Moskva: Fizmatlit, 432.
23. Gorokhovatsky, V., Stiahlyk, N., Tsarevska, V. (2021). Combination method of accelerated metric data search in image classification problems. Advanced Information Systems, 5 (3), 5–12. doi: https://doi.org/10.20998/2522-9052.2021.3.01
24. Levashenko, V., Liashenko, O., Kuchuk, H. (2020). Building Decision Support Systems based on Fuzzy Data. Advanced Information Systems, 4 (4), 48–56. doi: https://doi.org/10.20998/2522-9052.2020.4.07
25. Meleshko, Y., Drieiev, O., Drieieva, H. (2020). Method of identification bot profiles based on neural networks in recommendation systems. Advanced Information Systems, 4 (2), 24–28. doi: https://doi.org/10.20998/2522-9052.2020.2.05
26. Kuchuk, N., Merlak, V., Skorodelov, V. (2020). A method of reducing access time to poorly structured data. Advanced Information Systems, 4 (1), 97–102. doi: https://doi.org/10.20998/2522-9052.2020.1.14
27. Shyshatskyi, A., Tiurnikov, M., Suhak, S., Bondar, O., Melnyk, A., Bokhno, T., Lyashenko, A. (2020). Method of assessment of the efficiency of the communication of operational troop grouping system. Advanced Information Systems, 4 (1), 107–112. doi: https://doi.org/10.20998/2522-9052.2020.1.16
28. Raskin, L., Sira, O. (2016). Method of solving fuzzy problems of mathematical programming. Eastern-European Journal of Enterprise Technologies, 5 (4 (83)), 23–28. doi: https://doi.org/10.15587/1729-4061.2016.81292
29. Lytvyn, V., Vysotska, V., Pukach, P., Brodyak, O., Ugryn, D. (2017). Development of a method for determining the keywords in the slavic language texts based on the technology of web mining. Eastern-European Journal of Enterprise Technologies, 2 (2 (86)), 14–23. doi: https://doi.org/10.15587/1729-4061.2017.98750
30. Stepanenko, A., Oliinyk, A., Deineha, L., Zaiko, T. (2018). Development of the method for decomposition of superpositions of unknown pulsed signals using the secondorder adaptive spectral analysis. Eastern-European Journal of Enterprise Technologies, 2 (9 (92)), 48–54. doi: https://doi.org/10.15587/1729-4061.2018.126578
31. Gorbenko, I., Ponomar, V. (2017). Examining a possibility to use and the benefits of post-quantum algorithms dependent on the conditions of their application. Eastern-European Journal of Enterprise Technologies, 2 (9 (86)), 21–32. doi: https://doi.org/10.15587/1729-4061.2017.96321
32. Lovska, A. A. (2015). Peculiarities of computer modeling of strength of body bearing construction of gondola car during transportation by ferry-bridge. Metallurgical and Mining Industry, 1, 49–54.
33. Lovska, A., Fomin, O. (2020). A new fastener to ensure the reliability of a passenger car body on a train ferry. Acta Polytechnica, 60 (6), 478–485. doi: https://doi.org/10.14311/ap.2020.60.0478
34. Shyshatskyi, A., Zvieriev, O., Salnikova, O., Demchenko, Ye., Trotsko, O., Neroznak, Ye. (2020). Complex Methods of Processing Different Data in Intellectual Systems for Decision Support System. International Journal of Advanced Trends in Computer Science and Engineering, 9 (4), 5583–5590. doi: https://doi.org/10.30534/ijatcse/2020/206942020
35. Mahdi, Q. A., Shyshatskyi, A., Prokopenko, Y., Ivakhnenko, T., Kupriyenko, D., Golian, V. et. al. (2021). Development of estimation and forecasting method in intelligent decision support systems. Eastern-European Journal of Enterprise Technologies, 3 (9 (111)), 51–62. doi: https://doi.org/10.15587/1729-4061.2021.232718