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DEVELOPMENT OF A METHOD FOR THE SEARCH OF SOLUTIONS IN THE SPHERE OF NATIONAL SECURITY USING BIO-INSPIRED ALGORITHMS

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The object of research are decision support systems. The subject of research is the decision-making process in management problems using bio-inspired algorithms.

A method for the search of solutions in the field of national security using bio-inspired algorithms is proposed. The proposed method is based on a combination of an artificial bat algorithm and evolving artificial neural networks. The method has the following sequence of actions:

– input of initial data;

– processing of initial data taking into account the degree of uncertainty;

– numbering of bat agents (BA);

– placement of bat agents taking into account the degree of uncertainty about the state of the analysis object in the search space;

– setting the initial BA speed and the echolocation frequency of each BA;

– starting a local search;

– launching a global search;

– training knowledge bases of bat agents.

The originality of the proposed method consists in the arrangement of bat agents taking into account the uncertainty of initial data, improved global and local search procedures taking into account the noise degree of data about the state of the analysis object.

Another feature of the proposed method is the use of an improved procedure for training bat agents. The training procedure consists in learning the synaptic weights of an artificial neural network, the type and parameters of the membership function, the architecture of individual elements and the architecture of the artificial neural network as a whole. The method makes it possible to increase the efficiency of data processing at the level of 13–21 % due to the use of additional improved procedures. The proposed method should be used to solve the problems of evaluating complex and dynamic processes in the interests of solving national security problems

Keywords: efficiency of decision-making, decision support systems, complex processes, national security

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1. Introduction

Heuristic and metaheuristic optimization algorithms are algorithms involving a practical method that is not guaranteed to be accurate or optimal, but is sufficient to solve the problem [1, 2]. The correctness of these algorithms in all possible cases has not been proven, but they are known to give a fairly good solution.

These algorithms make it possible to speed up the solution of the problem by 100–1,000 times, which is especially important in problems with a large number of variables. In addition, heuristic algorithms allow you to find a solution even in cases where an exact solution can't be found or the search for it has a high computational complexity [3, 4].

The most well-known representative of heuristic methods is swarm intelligence, describing the collective behavior of a decentralized self-organizing system [5, 6].

There are a large number of swarm algorithms, for example: particle swarm optimization method, ant colony algorithm, cuckoo search algorithm, etc. [7, 8]. One of the most recently developed algorithms of this type is the bat search algorithm.

Using swarm algorithms to search for solutions regarding the state of objects allows you:

– to analyze the stability of the state of heterogeneous objects in the process of combat application (operation);

– to analyze the direct, aggregated and mediated mutual influence of systemic and external factors;

– to assess the reach of target situations of object management;

– to analyze scenarios for various destructive effects;

– to forecast changes in the state of heterogeneous objects under the influence of destabilizing factors during combat application (operation);

– to model and analyze the dynamics of changes in the state of interdependent parameters of heterogeneous objects.

At the same time, the use of the above swarm algorithms in the canonical form does not allow us to obtain an operational assessment of the object state with a given assessment accuracy. The above determines the search for new (improvement of existing) approaches to assessing and forecasting the state of objects by combining already known swarm algorithms with their improvement.

Given this, an urgent scientific problem is to develop a method for the search of solutions in the field of national security using bio-inspired algorithms, which would allow us to increase the efficiency of decisions made regarding the management of the control object parameters with a given reliability.

2. Literature review and problem statement

The work [9] presents a cognitive modeling algorithm. The main advantages of cognitive tools are determined. The shortcomings of this approach include the lack of consideration of the type of uncertainty about the state of the analysis object.

The work [10] reveals the essence of cognitive modeling and scenario planning. A system of complementary principles of building and implementing scenarios is proposed, different approaches to building scenarios are highlighted, the procedure for modeling scenarios based on fuzzy cognitive maps is described. The approach proposed by the authors does not allow us to take into account the type of uncertainty about the state of the analysis object and does not take into account the noise of initial data.

The work [11] analyzes the main approaches to cognitive modeling. Cognitive analysis allows you to: investigate problems with fuzzy factors and relationships; take into account changes in the external environment and use objectively formed trends in the development of the situation to your advantage. At the same time, the issue of describing complex and dynamic processes remains unexplored in this paper.

The work [12] presents a method for analyzing large data sets. This 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 inability to take into account various decision evaluation strategies, the lack of taking into account the type of uncertainty of initial data.

The work [13] presents a mechanism of transformation of information models of construction objects to their equivalent structural models. This mechanism is designed to automate the necessary conversion, modification and addition operations during such information exchange. The shortcomings of this approach include the inability to assess the adequacy and reliability of the information transformation process and make an appropriate correction of the obtained models.

The work [14] developed an analytical web platform to study the geographical and temporal distribution of incidents. The web platform contains several dashboards with statistically significant results by territory. The disadvantages of the specified analytical platform include the inability to assess the adequacy and reliability of the information transformation process, as well as high computational complexity. Also, one of the shortcomings of the mentioned research is that the search for a solution is not unidirectional.

The work [15] developed a method of fuzzy hierarchical assessment of library service quality. This method allows you to evaluate the quality of libraries by a set of input parameters. The disadvantages of the specified method include the inability to assess the adequacy and reliability of assessment and, accordingly, determine the assessment error.

The work [16] carried out an analysis of 30 algorithms for processing large data sets. Their advantages and disadvantages are shown. It was found that the analysis of large data sets should be carried out in layers, take place in real time and have the opportunity for self-learning. The disadvantages of these methods include high computational complexity and the inability to check the adequacy of the obtained estimates.

The work [17] presents an approach for evaluating input data for decision support systems. The essence of the proposed approach consists in clustering the basic set of input data, analyzing them, after which the system is trained based on the analysis. The disadvantage of this approach is a gradual accumulation of assessment and training errors due to the inability to assess the adequacy of decisions made.

The work [18] presents an approach to processing data from various sources of information. This approach allows you to process data from various sources. The disadvantages of this approach include the low accuracy of the obtained estimate and the inability to verify the obtained estimate.

The work [19] carried out a comparative analysis of existing decision support systems, namely: analytic hierarchy process, neural networks, fuzzy set theory, genetic algorithms and neuro-fuzzy modeling. The advantages and disadvantages of these approaches are indicated. The scope of their application is defined. It is shown that the analytic hierarchy process works well with complete initial information, but due to the need for experts to compare alternatives and choose evaluation criteria, it has a high share of subjectivity. For forecasting problems under risk and uncertainty, the use of fuzzy set theory and neural networks is justified.

The work [20] developed a method of structural and objective analysis of the development of weakly structured systems. An approach to the study of conflict situations caused by contradictions in the interests of subjects that affect the development of the studied system and methods of solving poorly structured problems based on the formation of scenarios for the development of the situation. At the same time, the problem is defined as non-compliance of the existing state of the system with the required one, which is set by the management entity. The disadvantages of the proposed method include the problem of the local optimum and the inability to conduct a parallel search.

The work [21] presents a cognitive approach to the simulation of complex systems. The advantages of the specified approach, which allows you to describe the hierarchical components of the system, are shown. The shortcomings of the proposed approach include the lack of consideration of the computing resources of the system.

The work [22] indicates that the most popular evolutionary bio-inspired algorithms are so-called «swarm» procedures (Particle Swarm Optimization – PSO). Among them, there are optimization algorithms based on cat swarms (Cat Swarm Optimization – CSO), which are very promising both in terms of speed and ease of implementation. These algorithms have proven their effectiveness in solving a number of rather complex problems and have already undergone a number of modifications, among which procedures based on harmonic search, fractional derivatives, adaptation of search parameters and, finally, «crazy cats» can be noted. At the same time, these procedures are not without some drawbacks that worsen the properties of the global extremum search process.

The work [23] examines the effectiveness of one of the optimization swarm algorithms – the bat algorithm (BA). This algorithm is inspired by living nature and has many implementations. Moreover, harmonic search and particle swarm algorithm are special cases of BA. With a fairly high relative complexity, BA is very effective in solving global search optimization problems [23]. Bats have a unique means of echolocation. Echolocation is used by bats to detect food and obstacles, and also provides the ability to locate in the dark on a branch or pole [23]. The basic BA is subject to the following rules:

1. All bats use echolocation to determine distance, detect food and obstacles.
2. Each BA is characterized by speed, position in space, frequency, wavelength and amplitude of the emitted sound pulse.
3. The volume of sound pulses varies randomly, but within a fixed range.

At the same time, the basic BA requires a long search for solutions and significant computing costs, which does not allow it to be used in real time.

An analysis of the works [9–23] showed that common shortcomings of the above studies are:

– the lack of possibility to form a hierarchical system of indicators;
– the lack of consideration of computing resources of the system;
– the lack of mechanisms for adjusting the system of indicators during assessment;
– the lack of consideration of the type of uncertainty and noise of data on the state of the analysis object, which creates corresponding errors while assessing its real state;
– the lack of deep learning mechanisms for knowledge bases;
– high computational complexity;
– the lack of consideration of computing (hardware) resources available in the system;
– the lack of search priority in a particular direction.

The problem that needs to be solved in the study is to increase the efficiency of solving the problems of analysis and multidimensional forecasting of the state of objects while ensuring the given reliability.

To this end, it is proposed to develop a method for the search of solutions in the field of national security using bio-inspired algorithms.

3. The aim and objectives of the study

The aim of the study is to develop a method for the search of solutions in the field of national security using bio-inspired algorithms. This will increase the efficiency of assessment and multidimensional forecasting with a given reliability and development of subsequent management decisions. This will make it possible to develop software for intelligent decision support systems in the interests of combat management of the actions of troops (forces).

To achieve the aim, the following objectives were set:

– to determine the algorithm for implementing the method;
– to give an example of using the method in the analysis of the operational situation of a group of troops (forces).

4. Materials and methods

The problem that is solved in the study is to increase the efficiency of decision-making in management problems while ensuring the given reliability regardless of the object hierarchy. The object of research is decision support systems. The subject of research is the decision-making process in management problems using artificial intelligence methods. The hypothesis of research is an increase in the efficiency of decision-making with a given assessment reliability.

Simulation of the proposed method was carried out in the MathCad 14 software environment (USA). The problem to be solved during the simulation was to assess elements of the operational situation of a group of troops (forces). The hardware of the research process is AMD Ryzen 5.

As the object of assessment and management, an operational grouping of troops (forces) was considered. The operational grouping of troops (forces) formed on the basis of an operational command with a typical composition of forces and means according to the wartime staff and with a range of responsibilities under current regulations.

The study is based on the bat algorithm to search for a solution regarding the object state. Evolving artificial neural networks are used to train BA.

5. Development of a method for the search of solutions in the field of national security using bio-inspired algorithms

5. 1. Algorithm for implementing the method for the search of solutions in the field of national security using bio-inspired algorithms

The method for the search of solutions in the field of national security using bio-inspired algorithms consists of the following sequence of actions.

Step 1. Input of initial data. At this stage, available initial data about the object to be analyzed are entered. The existing model of the analysis object is also initialized. A set of analyzed object state functions is specified with the implementation of the corresponding procedures (in this case, two functions are implemented:

$F(x)=\sin(x)$, and $F(x)=-x^2+12x-21$.

Step 2. Processing of initial data taking into account the degree of uncertainty.

At this stage, the type of uncertainty about the object to be analyzed is taken into account, and the basic state model of the object to be analyzed is initialized [2, 19, 21, 24–27]. At the same time, the degree of uncertainty can be: full awareness; partial uncertainty and total uncertainty. This is done using correction factors.

The list of variables used, with their designations inside the algorithm and description of assignments, is presented in Table 1.

Step 3. Numbering of bat agents, i, $i \in [0,S]$.

Step 4. Arrangement of BA taking into account the degree of uncertainty about the state of the analysis object in the search space:

$$x \in (x_{\min}, x_{\max}),\ x_i = (x_1, x_2 \dots x_S), \quad (1)$$

$$x = x_{\min} + (x_{\min} - x_{\max}) * \iota(\ ). \quad (2)$$

where $x_{\min}$, $x_{\max}$ are the minimum and maximum values of the search area, ι is the degree of uncertainty about the state of the analysis object. At the same time, the function $\iota()$ returns a value in the interval [0; 1].

Step 5. Setting the initial BA speed and the echolocation frequency of each BA.

The initial speed v_0 of each BA is determined by the following expression:

$$v_i = (v_1, v_2 \dots v_S),\ v_i = v_0. \quad (3)$$

The initial frequency of BA is determined by the expression:

$$w_i = (w_1, w_2 \dots w_S),\ w_i = w_{\min}. \quad (4)$$

w_i is the value of the BA frequency with the number i, $w_{\min}$ is the minimum BA frequency.

If $i<S$, then we return to Step 4.

Step 6. Search for the best BA.

Substitution of the best BA value x_i into the expression of the analyzed function F(X). The BA value closest to the extremum (in this case, to the maximum) is considered the best, $x_k^* = \max(F(x))$, where k is the number of the best BA. To find the best BA, the improved genetic algorithm developed in [22] is used.

Step 7. BA migration. Migration of agents is performed: agents are moved one step according to the migration procedure, and iterations with n are performed, where $n \in [0\ N]$.

Step 8. Re-numbering of BA, i, $i \in [0, S]$.

Step 9. Changing the search parameters.

New values of position, speed and frequency for BA are calculated – x_i^I, v_i^I and w_i^I [27–37]. The frequency is modified taking into account the degree of data noise according to the following expression:

$$w_i^I = w_{\min} + (w_{\max} - w_{\min}) * \eta(\ ). \quad (5)$$

Step 10. Changing the BA speed.

Speed modification is performed:

$$v_i^I = v_i + w_i (x^* - x_i), \quad (6)$$

where $(x^* - x_i)$ is the approximation of all BA on $\eta \to \max$.

Step 11. BA movement.

BA is moved in accordance with the formula: $x_i^I = x_i + v_i$. Checking the condition $i<S$, if $i<S$, the transition to Step 10 is made.

Step 12. Checking the condition for starting the local search procedure.

If $E_r > \eta(\ )$, then the local search procedure is started (transition to Step 16), otherwise, the transition to Step 19 is performed. The search procedure around the best solution is carried out with the probability E_r. The resulting solution is applied as a new current provision of BA x_i.

Step 13. Checking the number of iterations of searching for a solution n. If the search is not performed for the first time, then the transition to Step 19 is performed. Otherwise, the volume of the BA is calculated by the formula:

$$a_i = (a_1, a_2 \dots a_S);\ a_i^I = a_{\min} + (a_{\max} - a_{\min}) * \eta(\ ), \quad (7)$$

where a_i^I is the new volume value and the transition to Step 18 is performed.

Step 14. The average BA volume is calculated using the following expression:

$$a_{sr} = \left(\sum\nolimits_{i=0}^{S} a\right) / S. \quad (8)$$

Step 15. Changing the current BA position:

$$xx_i^I = x_i + a_{sr} * U[-1,1]. \quad (9)$$

The function $U[-1, 1]$ returns a random value in the interval $[-1; 1]$.

Step 16. The local search procedure is performed until the BA is closer to the search target: $F(xx_i) > F(x_i)$.

Step 17. Restriction of the search area:

$$xx_i = \max\{x_{\min}, x_i\}, xx_i = \min\{x_{\max}, x_i\}. \quad (10)$$

Step 18. Global search for a solution.

With the probability E_a, a global search procedure is performed in the neighborhood of the current solution for all i-th BA, i, $i \in [0, S]$.

Step 19. If $F(xx_i) < F(x_i)$ and $E_a > \eta()$, then a new decision is made: $x_i = xx_i$.

If $i<S$, then the transition to step 20 is performed. The restriction of the search area is performed for all i-th BA, i, $i \in [0, S]$.

Step 20. Checking that a set of conditions is met:

– if $x_i < x_{\min}$, then: $x_i = x_{\min}$, $v_i = v_0$;
– if $x_i > x_{\max}$, then: $x_i = x_{\max}$, $v_i = v_0$;
– if $i<S$, move to Step 10;
– if $n<N$, move to Step 7.

After performing all iterations, the value of x^* is taken relative to the state of the analysis object.

Step 21. Training knowledge bases.

The training method based on evolving artificial neural networks developed in [2] is used for training knowledge bases.

The end of the algorithm.

5. 2. Example of using the proposed method in the analysis of the operational grouping of troops (forces)

The method for the search of solutions in the field of national security using bio-inspired algorithms is proposed. In order to evaluate the effectiveness of the developed method for the search of solutions in the field of national security using bio-inspired algorithms, its comparative evaluation was performed with the results of research presented in [3–6, 23, 24, 36, 38].

Simulation of the solution search processing method was carried out in accordance with expressions (1)–(10). Simulation of the proposed method was performed in the MathCad 14 software environment (USA). The problem to be solved during the simulation was to assess elements of the operational situation of the group of troops (forces).

Initial data for assessing the state of the operational situation using the improved method:

– the number of sources of information about the state of the monitoring object – 3 (radio monitoring means, remote earth sensing tools and unmanned aerial vehicles) to simplify the modeling, the same number of each tool was taken – 4 tools each;

– the number of information signs by which the state of the monitoring object is determined – 12. These parameters include: affiliation, type of organizational and staff formation, priority, minimum width along the front, maximum width along the front. The number of personnel, minimum depth along the flank, maximum depth along the flank, the number of samples of weapons and military equipment (WME), the number of types of WME samples and the number of communication means, the type of operational structure are also taken into account;

– options of organizational and staff formation – company, battalion, brigade.

Tables 1, 2 show the dependence of the algorithm operating time on the number of iterations and population size and the dependence of the absolute error of the algorithm on the number of iterations and population size.

Finally, it should be noted that the presented implementation of the bat algorithm showed good performance and the possibility of adjusting the algorithm parameters to change the quality of the obtained results in solving the search optimization problems of object functions.

Table 3 presents comparative results of evaluating the efficiency of training evolving artificial neural networks.

Before training, the features of observations were normalized to the interval [0, 1].

The study showed that the specified training procedure provides an average of 10–18 % higher training efficiency of artificial neural networks and does not accumulate errors during training (Table 3).

These results can be seen from the results in the last lines of Table 3, as the difference of the Xie-Beni index. At the same time, as already mentioned, known methods accumulate errors in the course of work, which is why the proposed method suggests using evolving artificial neural networks.

The results of the comparative evaluation by the criterion of evaluation efficiency are shown in Table 4.

Table 1

Dependence of the algorithm operating time on the number of iterations and population size

No.	Number of iterations	Function	Population size					
			5	10	15	20	50	100
1	10	$f(x)=\sin(x)$	2.88	3.23	3.82	3.71	2.84	3.03
		$f(x)=-x^2+12x-21$	2.85	3.12	2.98	2.99	3.01	3.00
2	20	$f(x)=\sin(x)$	5.15	5.70	6.32	6.34	5.36	7.43
		$f(x)=-x^2+12x-21$	5.26	5.22	5.12	5.19	5.37	5.09
3	50	$f(x)=\sin(x)$	11.97	12.10	12.38	12.01	12.62	13.58
		$f(x)=-x^2+12x-21$	12.27	12.08	12.22	12.30	12.36	13.50
4	100	$f(x)=\sin(x)$	24.39	42.08	31.72	37.52	118.08	214.38
		$f(x)=-x^2+12x-21$	24.37	28.25	39.53	53.35	77.33	151.18

Table 2

Dependence of the absolute error of the algorithm on the number of iterations and population size

No.	Number of iterations	Function	Population size					
			5	10	15	20	50	100
1	10	$f(x)=\sin(x)$	0.0239	0.0507	0.0017	0.0012	0.00026	0.00018
		$f(x)=-x^2+12x-21$	0.0006	0.1112	0.01111	0.1114	0.00005	0.0008
2	20	$f(x)=\sin(x)$	0.0079	0.0017	0.00063	0.00083	0.00007	0.00019
		$f(x)=-x^2+12x-21$	0.0085	0.01131	0.0011	0.11131	0.00004	0.00001
3	50	$f(x)=\sin(x)$	0.0004	0.00011	0.00058	0.00042	0.00026	0.00002
		$f(x)=-x^2+12x-21$	0.1115	0.01113	0.10111	0.00000	0	0.11111
4	100	$f(x)=\sin(x)$	0.0008	0.00006	0.000041	0.00001	0	0
		$f(x)=-x^2+12x-21$	0.0111	0	0	0.01111	0.00011	0

Table 3

Comparative results of evaluating the efficiency of training evolving artificial neural networks

System	Algorithm parameters	XB (Xie-Beni Index)	Time, sec
FCM (Fuzzy C-Means)	–	0.2004	2.15
EFCM	Dthr=0.30	0.1018	0.155
EFCM	Dthr=0.23	0.1062	0.2
Proposed system (batch mode)	delta=0.1	0.08	0.2
Proposed system (online mode)	delta=0.1	0.078	0.19

Table 4

Results of problem solving

No. of iteration	Branch and bound method [17]	Genetic algorithm [12]	Canonical bat algorithm [23]	Improved bat algorithm
N	T, s	T, s	T, s	T, s
5	1.125	1.125	1.125	1.114
10	0.625	0.625	0.625	0.600
15	48.97	58.20	58.28	57.71
20	106.72	44.29	43.75	46.95
30	–0.1790	–0.0018	–0.0002	–0.0001
40	–0.158	–0.070	–0.069	–0.049
50	97.76	–974.30	–3.72	–334.11
100	–133.28	–195.71	–196.24	–193.04
200	7980.89	7207.49	7198.43	7036.48

As can be seen from Table 4, the gain of the specified solution search method is from 11 to 15 % according to the criterion of data processing efficiency.

6. Discussion of the results of the development of a method for the search of solutions in the field of national security using bio-inspired algorithms

The main advantages of the proposed method are:

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

– unambiguity of the obtained assessment of the analysis object state;

– versatility of application due to adaptation of the system of indicators during operation;

– it does not accumulate learning errors due to the use of the training procedure;

– the possibility of comprehensive training of the architecture and parameters of artificial neural networks;

– taking into account the type of uncertainty of initial data while building models of a heterogeneous analysis object;

– the possibility of searching for a solution in several directions;

– high reliability of the obtained solutions while searching for a solution in several directions;

– no falling into the local optimum trap.

The limitations of the study are the need to have an initial database on the state of the analysis object, the need to take into account the delay time for collecting and communicating information from intelligence sources.

The advantages of the proposed method are the following:

– the type of uncertainty is taken into account while setting the BA (Step 21);

– universality of solving the problem of analyzing the state of BA objects due to the hierarchical nature of their description (expressions (1)–(10));

– the possibility of quick search for solutions due to the simultaneous search for a solution by several individuals (Steps 1–20);

– adequacy of the obtained results (expressions (1)–(10));

– the ability to avoid the local extremum problem (Steps 1–20);

– the possibility of deep learning of BA knowledge bases (Step 21).

The disadvantages of the proposed method include:

– loss of informativeness while assessing the state of the analysis object due to the construction of the membership function;

– lower accuracy of assessment by a single parameter of state assessment of the analysis object;

– 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 you:

– to assess the state of a heterogeneous analysis object;

– to determine effective measures to improve management efficiency;

– to increase the speed of state assessment of a heterogeneous analysis object;

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

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

This study is a further development of research aimed at developing methodological principles for increasing the efficiency of processing various types of data published earlier [2, 4–6, 23].

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

7. Conclusions

1. An algorithm for implementing the method was determined, due to additional and improved procedures, which allows you:

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

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

– to take into account the priority of BA search;

– to carry out the initial exhibition of BA individuals, taking into account the type of uncertainty;

– to carry out accurate training of BA individuals using expressions;

– to determine the best BA individuals using a genetic algorithm;

– to conduct a local and global search taking into account the noise degree of data on the analysis object state;

– to conduct training of knowledge bases, which is carried out by learning the synaptic weights of an artificial neural network, the type and parameters of the membership function, the architecture of individual elements and the architecture of the artificial neural network as a whole;

– to use it as a universal tool for solving the problem of analyzing the state of analysis objects due to the hierarchical description of analysis objects;

– to check the adequacy of the obtained results;

– to avoid the problem of local extremum.

2. An example of using the proposed method is given on the example of assessing and forecasting the state of the operational situation of a group of troops (forces). The specified example showed an increase in the efficiency of data processing at the level of 13–21 % due to the use of additional improved procedures of adding correction factors for uncertainty and noise of data, BA selection, and BA training.

Conflict of interest

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

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Data availability

The manuscript has associated data in the data repository.

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