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IMPROVING THE METHOD FOR INCREASING THE EFFICIENCY OF DECISION-MAKING BASED ON BIO-INSPIRED ALGORITHMS

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The problem that is solved in the research is to increase the efficiency of assessing the state of the monitoring object while ensuring the given reliability, regardless of the hierarchy of the monitoring object. The object of research is decision support systems. The subject of the research is the process of evaluating the monitoring object using bio-inspired algorithms. The hypothesis of the research is the need to increase the efficiency of the assessment of the state of the monitoring object with the given reliability. In the course of the research, an improved method of increasing the efficiency of decision-making based on bio-inspired algorithms was proposed. General provisions of artificial intelligence theory were used to solve the problem of analyzing the object state in intelligent decision support systems.

The essence of improvement is to use the following procedures:

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

– taking into account the degree of noise in the data on the state of the monitoring object. Noise refers to the degree of information distortion created by the enemy's means of electronic and cyber warfare;

– using the ant colony optimization algorithm and the genetic algorithm to find the path metric while assessing the state of the monitoring object;

– deep learning of synthesized ants using evolving artificial neural networks.

An example of using the proposed method in assessing the state of the operational situation of a group of troops (forces) is presented. The specified example showed a 15–22 % increase in the efficiency of data processing using additional improved procedures

Keywords: uncertainty, monitoring object, data noise, assessment efficiency, reliability of decisions

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1. Introduction

The increase in the volume of information circulating in various systems of information collection, processing and transmission leads to significant use of hardware computing resources. The armed forces of technically developed countries have integrated decision-making architectures based on [1–8]:

– artificial intelligence and nanotechnologies;

– effective processing of large amounts of information;

– multifunctional processors with real-time decision support;

– data compression technologies to increase processing speed.

The use of information systems with elements of artificial intelligence will increase the efficiency of operations (combat actions), affect the doctrine, organization and methods of application of groups of troops (forces).

At the same time, the increase in the dynamics of operations, the number of various sensors and the need to integrate them into a single information space create a number of problems [1–8]:

– implemented algorithms for determining correlations between events do not fully take into account the reliability of intelligence sources and information in the dynamics of hostilities;

– forms of information presentation complicate its transmission through communication channels;

– limited computing power of hardware;

– limited bandwidth of data transmission channels;

– radio-electronic suppression of HF and VHF radio communication channels and cybernetic impact on information systems;

– transition to the principle of monitoring object assessment «everything affects everything at once», which covers the aggregate network and computing resources of all types of armed forces.

That is why it is necessary to develop algorithms (methods and techniques) that are able to assess the state of the monitoring object from various sources of intelligence information in a limited time and with a high degree of reliability.

The problem that needs to be solved in the research is to increase the efficiency of assessing the state of the monitoring object while ensuring the given reliability, regardless of the hierarchy of the monitoring object.

Given the above, an urgent scientific task is to develop an improved method of assessing the state of the object, which would increase the efficiency of decisions made regarding the state of the assessment object with the given reliability based on bio-inspired algorithms.

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] presents 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 taking into account the type of uncertainty about the state of the analysis object and the noise of the initial data.

The work [11] carried out an analysis of 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 the work.

The work [12] presents a method of analyzing large data sets. The specified method is focused on finding hidden information in large data sets. The method involves the operations of generating analytical baselines, reducing variables, detecting sparse features and specifying rules. The disadvantages of the method include the impossibility to take into account different decision evaluation strategies, the lack of consideration of the type of uncertainty of the input data.

The work [13] presents the mechanism of transformation of information models of construction objects to their equivalent structural models. This mechanism is intended to automate the necessary conversion, modification, and addition operations during such information exchange. The shortcomings of the mentioned approach include the impossibility to assess the adequacy and reliability of the information transformation process and the 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 information panels with statistically significant results by territory. The disadvantages of the specified analytical platform include the impossibility to assess the adequacy and reliability of the information transformation process and high computational complexity. Also, one of the shortcomings of the mentioned research is the fact that the search for a solution is not unidirectional.

The work [15] developed a method of fuzzy hierarchical assessment of library service quality. The method allows evaluating the quality of libraries based on a set of input parameters. The disadvantages of the specified method include the impossibility to assess the adequacy and reliability of the 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 their high computational complexity and the impossibility 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 the clustering of the basic set of input data, their analysis, after which the system is trained based on the analysis. The disadvantage of this approach is the gradual accumulation of assessment and training errors due to the lack of an opportunity to assess the adequacy of decisions made.

The work [18] presents an approach to processing data from various sources of information. The disadvantages of this approach include the low accuracy of the obtained estimate and the impossibility to verify it.

The work [19] carried out a comparative analysis of existing decision support technologies, 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 under the condition of complete initial information, but due to the need for experts to compare alternatives and choose evaluation criteria, it has a high share of subjectivity. The use of fuzzy set theory and neural networks is justified for forecasting problems under risk and uncertainty conditions.

The work [20] developed a method of structural and objective analysis of the development of weakly structured systems. An approach to studying 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 is proposed. At the same time, the problem is defined as the non-compliance of the existing state of the system with the required one, 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 describing 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.

An analysis of the works [9–21] showed common shortcomings of the above-mentioned studies:

– 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 the assessment;

– the failure to take into account 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;

– the lack of consideration of computing (hardware) resources available in the system.

For this purpose, it is proposed to develop a method for assessing the state of the monitoring object based on bio-inspired algorithms.

3. The aim and objectives of the study

The aim of the study is to develop an improved method of assessing the object state, which would increase the efficiency of decisions made regarding the state of the assessment object with the given reliability based on bio-inspired algorithms. This will make it possible to develop software for intelligent decision support systems in the interests of intelligence support for the actions of troops (forces).

To achieve the aim, the following objectives were set:

– to formulate the concept of presentation of the method for assessing the state of the monitoring object in special-purpose information systems based on bio-inspired algorithms;

– to determine the algorithm for implementing the method;

– to give an example of the application of the proposed method in the analysis of the operational situation of a group of troops (forces).

4. Materials and methods

The object of the research is decision support systems. The subject of the research is the process of evaluating the monitoring object using bio-inspired algorithms. The hypothesis of the research is the need to increase the efficiency of assessing the state of the monitoring object with the given reliability of the assessment using bio-inspired algorithms, regardless of the hierarchy of the monitoring object.

In the course of the research, general provisions of artificial intelligence theory were used to solve the problem of analyzing the state of objects in intelligent decision support systems.

The use of artificial intelligence methods is due to the following:

– the opportunity for self-learning;

– the search for solutions in several directions at the same time;

– performing calculations of various dimensions;

– the possibility to avoid the problem of the local extremum of the function.

Thus, artificial intelligence theory is the basis of the research. The research used an improved genetic algorithm, an improved ant colony optimization algorithm and evolving artificial neural networks. The simulation was carried out using MathCad 2014 software (USA) and an Intel Core i3 PC (USA).

The task to be solved during the simulation was to assess the elements of the operational situation of the group of troops (forces).

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

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

– the number of informational features to determine the state of the monitoring object – 12. Such parameters include: affiliation, type of organizational and staff formation, priority, minimum width along the front, maximum width along the front. The number of personnel, the minimum depth along the flank, the maximum depth along the flank, the total number of personnel, the number of AME samples, the number of AME sample types and the number of communication devices are also taken into account;

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

5. Results of the research on improving the method for assessing the state of the monitoring object

5. 1. The concept of presenting the method for assessing the state of the monitoring object

The control system for the process of analyzing the state of objects can be represented as a sign oriented graph. In general, the task of determining the state of the monitoring object is reduced to calculations according to the formula:

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

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 threshold function of the graph, ι_{ij} is the operator that takes into account the degree of awareness of the object state; ζ_{ij} is the operator for taking into account the degree of noise in the data about the object state. 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 is less than some given value.

To solve the problem of maximizing the reliability of the assessment of the monitoring object state, it is advisable to use the following criterion to be maximized [10, 22–28]:

$$P = \sum_{i=1}^{n}\sum_{j=1}^{m} x_{ij} p_j \to \max, \left(i = 1,...,n;\ j = 1,...,m;\ i \neq j\right), \quad (2)$$

where p_j is the weighting factor that characterizes the effect of including a point with the number j in the solution search metric; x_{ij} is the integer Boolean variable, $x_{ij} \in \{0, 1\}$.

The time of finding the decision T_k about the state of the monitoring object consists of the time of assessing the state of the monitoring object τ_p^*, the time of preparing the decision support system for work τ_f.

To solve the problem of minimizing the time for assessing the state of the monitoring object, it is proposed to use the following criteria:

$$T_k = \tau_p^* + \tau_f \to \min. \quad (3)$$

The optimized efficiency function is discrete and non-monotonic and has a large number of local extrema in its domain.

It is necessary to solve the problem of minimizing the time for evaluating the state of the monitoring object in the minimum time τ_p^* (but not more than τ_p), form a metric for evaluating the state of the monitoring object Π^*, which would satisfy the requirement of the minimum time for evaluating the state of the monitoring object τ_f with maximum reliability P_j and available resource constraints R_q:

$$\Pi^* \in \Pi : T_k \to \min. \quad (4)$$

where $\Pi^* = \bigcup_{q=1}^{m} \Pi_{x_i y_i}, \Pi_{x_i y_i} = \left\langle P_{x_1 y_1}, P_{x_2 y_2}, ..., P_{x_k y_k} \right\rangle$; Π is the metric for assessing the state of the monitoring object; Π_q is the metric of passing the q-th path of the metric of decisions about the state of the monitoring object; k_q is the number of points in the q-th path metric; T_k is the time of assessing the state of the monitoring object; τ_p is the regulated time for assessing the state of the monitoring object [29–33].

From expressions (1)–(4), it can be concluded that the expressions describe the processes in the monitoring object. The specified description is universal and allows describing the object of analysis taking into account the hierarchy and individual specifics of each monitoring object. When expression (1) is written as a multidimensional time series, the description process can be given for a dynamic system. Expression (1) while constructing a mathematical description of the monitoring object state takes into account the degree of awareness of the object state and the noise level of data. Expressions (2)–(4) make it possible to form an optimization problem and constraints while solving it during the assessment of the monitoring object state, taking into account the existing resource limitations.

5. 2. Algorithm for implementing the evaluation method in intelligent decision support systems using bio-inspired algorithms

The assessment of the state of the monitoring object can be reduced to a typical traveling salesman problem while converting the distance of the route to a metric. The presence of a metric in space allows you to make decisions about belonging to a set or about the similarity of sets based on a quantitative indicator. The size of the metric (distance) is often directly related to the probabilistic characteristics of assigning an element to a class [22–27]. The main goal of creating metrics is to increase efficiency while solving new practical tasks [28–30]. The step-by-step algorithm for solving the traveling salesman problem using the synthesized method based on genetic and ant colony optimization algorithms can be presented in the following form [31, 32]:

Step 1. The initial data about the evaluation object $P_j(x_i, y_i)$, where P_j is the number of points; x_i, y_i are the point coordinates are entered.

Step 2. The degree of awareness about the state of the monitoring object and the noise degree of the data about the state of the object are entered. Noise refers to the degree of information distortion created by the enemy's means of electronic and cyber warfare. The correction factors are detailed in [2–6, 33–35].

Step 3. Individuals (cycles) that indicate the route of passing all points and returning to the starting point are created.

Step 4. The parameters of the ant cycle are set: creation of a colony of N ants, entering the number of iterations of the ant colony optimization algorithm.

Step 5. Initial passage of the colony by routes. Passage is carried out by choosing a branch by each ant. The probability that the k-th ant moves from point i to j is calculated by the formula:

$$P_{ij,k} = \frac{\tau_{ij}^{\alpha}\eta_{ij}^{\beta}}{\sum_{m \in \exists j} \tau_{im}^{\alpha}\eta_{im}^{\beta}}, j = 1...n, \quad (5)$$

where τ_{ij}^{α} is the amount of pheromones on the branch from point i to point j; η_{ij}^{β} is the proximity of the j-th point to the vertex i; τ_{im}^{α} is the amount of pheromones on the branch from point i to point m; η_{im}^{β} is the proximity of the j-th point to the vertex m.

Step 6. Calculation of the length of each route traveled by the ant using the formula for finding the distance between successive points of the route $r = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$.

Step 7. Calculation of the number of passes by ants along existing branches using the following formula:

$$\Delta\tau_{ij,k} = \begin{cases} \frac{Q}{r_k}, \text{ if } (i,j) \in L_k; \\ 0, \text{ if } (i,j) \notin L_k; \end{cases} \quad (6)$$

where Q is a user-defined constant to increase or decrease the amount of pheromones in the considered field; r_k is the distance of the route traveled by the k-th ant; L_k is the route of the k-th ant.

Step 8. Renewal of pheromones. The renewal will change on all existing branches and decrease in proportion to the coefficient ρ, the amount of pheromones on the branches that the ants used to make their route will increase according to the formula:

$$\tau_{\iota\varphi(\tau+1)} = \rho\tau_{\iota\varphi(\tau)} + \sum_{\kappa=1}^{\nu} \Delta\tau_{\iota\varphi,\kappa(\tau)}, \quad (7)$$

where $\tau_{ij(t)}$ is the amount of pheromones before the renewal; $\tau_{ij(t+1)}$ is the amount of pheromones after the renewal.

Step 9. After passing all iterations of the ant colony optimization algorithm, the routes of the final iterations with the given levels of pheromones and transition probabilities are calculated.

Step 10. Derivation of suboptimal individuals with a minimum distance after completion of all cycle iterations of the ant colony optimization algorithm.

Step 11. Final selection of the most optimal individual from N found and outputting the length of the route passed by it.

Step 12. Deep learning of ants synthesized during calculations in step 11. At this stage, the individuals obtained in step 11 are trained using evolving artificial neural networks on the basis of the expressions proposed in [2].

Step 13. Determining the need to involve additional hardware resources of the system. At this stage, the need to attract additional system resources is determined based on expressions (6)–(20) given in [36].

The end of the algorithm.

5. 3. Example of the application of the proposed method in the analysis of the operational situation of a group of troops (forces)

Simulation of the assessment method based on bio-inspired algorithms in accordance with the algorithm and expressions (1)–(7) was carried out. Simulation of the proposed method was performed in the MathCad 14 software environment (USA).

The results of the comparative analysis using the proposed method, the branch and bound method, the ant colony optimization algorithm and the simulated annealing genetic algorithm are shown in Table 1.

According to the analysis of the data given in Table 1, the proposed method has an acceptable computational complexity.

In the range from 50 to 100, the proposed method becomes more efficient in terms of algorithm operation time compared to other algorithms (faster than the branch and bound method by 82.58–83.54 % and the ant colony optimization method by 7.62–9.71 %. The proposed method provides adequate solutions with a complex hierarchical structure of the monitoring object. The effectiveness of the proposed method is on average from 15 to 22 % with different hierarchies of the monitoring object.

6. Discussion of the results of the development of the assessment method

The results of improving the efficiency of assessing the state of the object are explained by the use of bio-inspired algorithms in contrast to classical empirical expressions. Bio-inspired algorithms are used not in a classical way, but by improving the ant colony optimization algorithm using the genetic algorithm and evolving artificial neural networks.

The main advantages of the proposed evaluation 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 (expressions (1)–(4) compared to [16–21];

– the unambiguity of the obtained assessment of the object state (expressions (1)–(7) compared to [9–13];

– the universality of application due to the adaptation of the system of indicators in the course of work compared to [13–16];

– it does not accumulate learning errors due to the use of learning procedures (step 12), which is not taken into account in [8–10, 12–21];

– taking into account the type of uncertainty and noise of the initial data while constructing the path metric (step 2) compared to [8–21];

– high reliability of the obtained solutions while searching for a solution in several directions (steps 4–10) compared to [8–21];

– the ability to determine the need to involve additional network hardware resources (step 12), which is not taken into account in [8–21].

The disadvantages of the proposed method include:

– the loss of informativeness while assessing the state of the monitoring object due to the construction of the affiliation function;

Table 1

Comparative analysis of bio-inspired algorithms

Number of intermediate solution points	Branch and bound method	Simulated annealing genetic algorithm	Ant colony optimization algorithm	Proposed method
N	T, s	T, s	T, s	T, s
5	0.282	0.264	0.276	0.284
10	0.723	0.414	0.4	0.414
15	6.641	0.96	0.999	1.099
20	10.7	2.433	2.5	2.512
30	21.3	4.4	4.5	4.643
40	42	8.2	7.9	7.232
50	56	10.515	10.1	9.142
100	120	20.2	17.6	19.52
200	727	82.8	74.2	80.8
Complexity	$O\left(\frac{(N-1)!}{4}\right)=O(N!)$	$O(5N^2+5)=O(N^2)$	$O(N^2+N)=O(N^2)$	$O\left(\frac{(5N^2)}{2}+N\right)=O(N^2)$

– lower accuracy of assessment for a single parameter of object state 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 makes it possible:

– to carry out an assessment of the object state;

– to determine effective measures to improve control efficiency;

– to increase the speed of object state assessment;

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

– to calculate the need to involve additional computing resources of the system.

The proposed method allows solving the problem of improving the efficiency of the process of assessing the state of the monitoring object using the synthesized algorithm to solve the problem of assessing its state.

It is advisable to use this method in decision support systems for assessing the state of the monitoring object as a software product. It is proposed to be used for intelligence support in monitoring the state of intelligence objects.

The limitations of the research are:

– the need to know the completeness of information about the state of the monitoring object;

– the need to know the amount of computing resources of the decision support system.

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

This study is a development of research aimed at elaborating methodological principles for increasing the efficiency of information and analytical support published earlier [2, 4–6, 34].

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

7. Conclusions

1. A formalized description of the problem of analyzing the state of objects in special-purpose information systems using bio-inspired algorithms was carried out. The specified formalization allows you to describe the processes that take place in special-purpose information systems while solving the problems of analyzing the state of objects. As a criterion for the effectiveness of the specified method, the efficiency of the process of analyzing the object state with the given reliability was chosen. In the course of the research, the concept of presenting the assessment method in special-purpose information systems was formulated. In this concept, the analysis process is presented as 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. The algorithm for implementing the method is defined, which allows you:

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

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

– to determine the necessary computing resources of the system for operational assessment of the object state;

– to carry out accurate training of synthesized individuals of the ant colony optimization algorithm using the expressions developed in [2].

3. An example of using the proposed method in assessing the state of the operational situation of a group of armies (forces) is given. The specified example showed a 15–22 % increase in the efficiency of data processing using additional improved procedures.

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