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THE DEVELOPMENT OF A METHOD FOR INCREASING THE RELIABILITY OF THE ASSESSMENT OF THE STATE OF THE OBJECT

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The object of the research is assessment of object with different degrees of embeddedness. The subject of the research is the process of assessing the state of objects using the apparatus of neuro-fuzzy expert systems, the apparatus of relational analysis and bio-inspired algorithms. The problem that is solved in the research is to increase the reliability of the assessment of the objects state, regardless of the number of attachments. The originality of the research is that:

– possibility of increasing the reliability of the object state assessment due to the parallel use of two bio-inspired algorithms;

– taking into account the degree of awareness of the object state, due to the application of correction coefficients for the degree of awareness;

– construction of both object and relational models, which allows to increase the reliability of assessment of the objects state;

– possibility of combining the results of the work of bio-inspired algorithms, which makes it possible to mutually verify the correctness of the work of each of the algorithms;

– universality of solving the task of assessing the state of objects with different degrees due to the hierarchical nature of their description;

– possibility of simultaneously searching for a solution in different directions;

– adequacy of the obtained results.

An example of the use of the proposed method is presented on the example of solving the task of determining the composition of an operational group of troops (forces) and elements of its operational construction. The specified example showed an increase in the reliability of the assessment of the objects state by an average of 20 % due to the use of additional improved procedures.

It is advisable to use the proposed method to solve the problems of assessing the state of multidimensional objects in conditions of uncertainty and risks, which are characterized by high requirements for the reliability of the information obtained

Keywords: neuro-fuzzy expert systems, relational model, object model, swarm algorithms, hierarchy

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1. Introduction

The process of evaluating objects is a complex process of determining a set of possible states for a wide range of tasks, including for making management decisions [1–3]. Object evaluations are discontinuous, undifferentiated and multimodal. Considering the above, it is impractical to use classic gradient deterministic algorithms [4–6] to solve this type of problem.

The most common approaches to assessing the state of objects are swarm intelligence algorithms (swarm algorithms).

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The most famous swarm algorithms are particle swarm optimization algorithm, artificial bee colony algorithm, firefly swarm algorithm, ant colony optimization algorithm, wolf swarm optimization algorithm, and sparrow swarm algorithm [6–8].

However, most of the basic bio-inspired algorithms mentioned above are not able to achieve a high degree of reliability in data processing.

This prompts the search for new solutions for combining the work of bio-inspired algorithms with other approaches to increase the reliability of the assessment of the state of the object.

Therefore, research devoted to the development of new approaches to increasing the reliability of the assessment of the condition of objects is relevant.

2. Literature review and problem statement

The main advantages and disadvantages of cognitive algorithms are defined in works [9–11]. In work [9], an algorithm for determining hidden information in large data samples is given. In work [10], an algorithm for building information models for coordination of joint activities is presented. In work [11], a data processing algorithm for emergency and security management systems is presented. The disadvantages of these approaches include the lack of consideration of the type of uncertainty, the inability to search in different directions by several agents.

The work [12] presents an approach focused on the search for hidden information in large data sets. The method is based on analytical baselines, variable reduction, sparse feature detection and rule formation. The disadvantages of the specified method include the impossibility of taking into account different decision-making strategies, the lack of consideration of the type of uncertainty of the initial data,

The works [13, 14] present an approach to the transformation of information models of 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 of assessing the adequacy and reliability of the information transformation process, as well as the appropriate correction of the obtained models.

The work [15] proposed a method of fuzzy hierarchical evaluation, which allows to evaluate the quality of library services. The disadvantages of the specified method include the impossibility of assessing the adequacy and reliability of the assessment and, accordingly, determining the assessment error,

The work [16] analyzed 30 of the most common Big-data algorithms. It has been established 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, finding a solution in different directions and taking into account the noisy nature of the data.

The works [17, 18] present approaches to the evaluation of various types of data for decision making support systems, based on the clustering of the basic set of input data, after which the system is trained based on the analysis. However, taking into account the static nature of the architecture of artificial neural networks, there is an accumulation of errors.

The work [19] carried out a comparative analysis of existing decision-making support technologies, namely: the method of analyzing hierarchies, neural networks, the theory of fuzzy sets, genetic algorithms, and neuro-fuzzy modeling. The advantages and disadvantages of these approaches are indicated. For tasks of assessing the state of hierarchical systems in conditions of risk and uncertainty, the use of the theory of artificial neural networks and gradient algorithms is justified.

A canonical algorithm of ant lions is proposed in work [20] for classification problems of filters with infinite impulse response. The way it works depends on cooperation between ants and ant lions, which use a traditional selection scheme called a roulette wheel selection scheme to test the ant lions for catching ants. During the optimization processes, the performance of the regular antlion is compared to the best antlion at each round of the process, guaranteeing an excellent solution. The performance of the simulation is evaluated using the root mean square error between the identified and actual model achievements, the root mean square deviation between the identified and actual different infinite values of the impulse filter, and the rate of convergence. The proposed algorithm gives the smallest standard deviations, showing the best solutions. In addition, in the research of the t-test, large positive values of t again showed the significance of the advantage of the proposed algorithm over the comparative ones for the infinite impulse response in the simulation of filters.

An analysis of works [9–20] showed that the common shortcomings of the above-mentioned researches are:

– no possibility of hierarchical processing of various types of data;

– the lack of possibility of additional involvement of necessary computing resources of the system;

– a failure to take into account the type of uncertainty and noisy data about the information circulating in the system;

– the lack of deep learning mechanisms of knowledge bases;

– the lack of search priority in a certain direction.

3. The aim and objectives of the study

The aim of the study is development of methods of increasing the reliability of the object state assessment. This will make it possible to increase the reliability of the assessment of the state of objects with the specified efficiency and the development of subsequent management decisions. This will make it possible to develop software for intelligent decision-making support systems.

To achieve the aim, the following objectives were set:

– to determine the procedures for the implementation of the method of increasing the reliability of the assessment of objects;

– to give an example of assessing the objects state while analyzing the operational situation of a group of troops (forces).

4. Research materials and methods

The object of the research is the assessment object with different degrees of embeddedness. The subject of the research is the process of assessing the state of objects using the apparatus of neuro-fuzzy expert systems, the apparatus of relational analysis, and bio-inspired algorithms. The problem that is solved in the research is to increase the reliability of the assessment of the objects state, regardless of the number of attachments.

Research hypothesis is a possibility of increasing the reliability of the assessment of the objects state at the level of at least 0.9.

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

The operational grouping of troops (forces) was considered as an object of assessment. An operational grouping of troops (forces) formed on the basis of an operational command with a typical composition of forces and devices according to the wartime staff, as well as with a range of responsibility in accordance with current regulations.

Initial data for determining the composition of the operational grouping of troops (forces) and the elements of its operational construction using a method approach:

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

– the number of informational signs by which the state of the hierarchical system is determined – 12. Such parameters include: affiliation, type of organizational and staff formation, priority, minimum width along the front, maximum width along the front. It also takes into account the number of personnel, the minimum depth along the flank, the 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 means of communication), the type of operational construction;

– the variants of organizational and staff formations are battalion, brigade, operational grouping of troops (forces).

Parameters of the method:

– the number of iterations is 100;

– the number of individuals in the flock is 50;

– the range of feature space is [–1000, 1000].

The research is based on the apparatus of neuro-fuzzy expert systems – to build an object model of the object's state, to build a relational model of the object's state assessment – Gray's method of relational analysis. The bat swarm optimizer, the jumping frog swarm algorithm was chosen due to the possibility of using different search strategies depending on the available computing resources of the system.

5. The results of the development of the method of increasing the reliability of the object state assessment

5. 1. Basic procedures of the method of increasing the reliability of the object state assessment

The Rete II method [5, 10, 11] was chosen as the basis for the development of the method of increasing the reliability of the object state assessment. Despite the advantages of the Rete II method, including the increased performance of processing various types of data, the presence of a reverse inference algorithm, the main disadvantages of this method are:

– work only with clear products;

– low efficiency of setting up databases;

– compared to other methods, the assessment's reliability is low, which does not allow it to be used in the processing of various types of data, which require a high degree of reliability of decision making.

The essence of the proposed method is the following:

– construction of an object model for the object state assessment;

– adjustment of the neuro-fuzzy knowledge base by several bio-inspired algorithms and combining the results of parallel work of bio-inspired algorithms using the Merge function;

– the construction of a relational model of object state assessment.

Due to this set of procedures, an increase in the reliability of the object state assessment is achieved.

The algorithm for the implementation of the proposed method of increasing the reliability of the object state assessment consists of the following sequence of actions:

Step 1. Input of initial data.

At this stage, the initial data about the object to be evaluated is entered. The starting point for the degree of uncertainty about the object state is determined. The initial data for the work of bio-inspired algorithms are determined, the reliability parameters of the research object are introduced.

Step 2. Formation of the object model.

A formal object model using neuro-fuzzy expert systems has the following form:

$$\{P_o\} = \{\mathrm{Rule}_o\}, \tag{1}$$

where Rule is a set of rules characterizing the object model of the specified object of analysis.

Each Rule is described as follows:

$$\mathrm{Rule}_o = < C \rightarrow S >, \tag{2}$$

where C is the condition of each rule of the object model, S is the consequence for each rule of the object model.

For this type of object model, it is necessary to correctly present the grammatical structure of the rules with various types of nested conditions. For this purpose, it is proposed to use a recursive mechanism for describing the nodes and terminal vertices of the rule condition tree. In expression (2), C is described as:

$$C = < C_l, R, C_r >, \tag{3}$$

where C_l is the left node of the condition of each rule of the object model, R is the relationship between the nodes of each rule of the object model, C_r is the right node conditions of each object model rule.

Then, further parameters are considered:

$$C_l = FC_l \,\|\mathrm{Null}\|\, C, \tag{4}$$

$$C_r = FC_r \,\|\mathrm{Null}\|\, C, \tag{5}$$

where FC_l is the left terminal triple of the condition of each rule of the object model, FC_r is the right final triple of the condition of each rule of the object model. The expressions (4) and (5) allow to describe the conditions of each rule of the object model with a different degree of hierarchy:

$$FC_l = < L, Z, W >, \tag{6}$$

$$FC_r = < L, Z, W >, \tag{7}$$

where L is a linguistic variable of the object model, Z is a condition sign Z={<,>,<=,>=,=,!=}; W is the condition value of the object model, which is determined as follows (8):

$$W = L \| V, \tag{8}$$

where L is a linguistic variable of the object model, V is some fixed value (9):

$$V = T_i \| \mathrm{const}, \tag{9}$$

where T_i is the value of the fuzzy variable from the term-sets of the linguistic variable, const is a constant. The given set of mathematical expressions (1)–(9) allows the use of not only linguistic variables, but also classical variables.

Similarly to parameter C of the object model, parameter S is determined – a consequence of the rule of the object model:

$$S = < S_l, R, S_r >, \tag{10}$$

where S_l is the left node of the consequence of the rule of the object model, R is the relationship between the nodes of the consequence of the rule, S_r is the right node of the consequence of the rule of the object model:

$$S_l = FS_l \| \text{Null} \| S, \tag{11}$$

$$S_r = FS_r \| \text{Null} \| S, \tag{12}$$

where FS_l is the left terminal triplet of the consequence of the rule of the object model, FS_r is the right final triple of the consequence of the rule of the object model. Formulas (11), (12) allow to describe the consequences with different degrees of hierarchy:

$$FS_l = < L, \text{Op}, W >, \tag{13}$$

$$FS_r = < L, \text{Op}, W >, \tag{14}$$

where L is a linguistic variable of the object model, Op is the type of operation, Op={:=}, W is the value of the consequence of the object model.

Step 3. Setting up the neuro-fuzzy knowledge base and combining the results of their work.

At this stage, the results of parallel work of bio-inspired algorithms are combined using the Merge function.

The function element-by-element compares two binary vectors from the outputs of two bio-inspired algorithms – the bat swarm algorithm and the frog swarm algorithm.

Under the condition that the value of the element at the same position coincides, the given value will be written to this position in the resulting vector. Otherwise, a random number is generated from the interval from 0 to 1 [14–20].

If the value is less than or equal to 0.5, then the corresponding position of the new vector is written by the element from the worst vector. Otherwise, an element from a better vector will be displayed at this location.

Thus, the merge function can be given as follows:

$$merge\left(S_w, S_b\right) = \begin{cases} s_i^* = s_{wi} = s_{bi}, \text{ if } s_{wi} = s_{bi}, \\ s_i^* = s_{wi}, \text{ if } s_{wi} \neq s_{bi} \text{ and } rand \leq 0.5, \\ s_i^* = s_{bi}, \text{ if } s_{wi} \neq s_{bi} \text{ and } rand > 0.5, \end{cases} \tag{15}$$

where *rand* is a random, uniformly distributed number, $rand \in [0;1]$.

Step 4. Construction of a relational model of object state assessment.

The construction of the relational model of object state assessment in this research is based on the Gray relational analysis (GRA) method. This approach is one of the approaches to multi-criteria analysis, which is used to evaluate alternatives based on a number of different criteria. This method is used to measure the level of relationship between existing alternatives by calculating the Gray correlation coefficient (Grey's relational coefficient). The stages of completion by the GRA method are as follows.

Step 4. 1. Normalization of relational model data.

Normalization is used to transform data into a single scale that allows better comparison of different variables. The normalization equation in GRA is as follows:

$$X_{norm} = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}}. \tag{16}$$

Step 4. 2. Formation of the matrix of relational analysis of Gray.

After data normalization, the result of the normalization matrix is the relational analysis of the Gray matrix, namely:

$$G = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}, \tag{17}$$

where G is the result of the data normalization matrix; m is an existing alternative; n is the existing criterion; x_{ij} is normalization in the measurement of alternatives.

Step 4. 3. Multiplying the GRA matrix by weights.

The next step is to determine the relative weight for each variable. This weight reflects the level of importance of each variable in the GRA analysis. In addition, the GRA method is to give each criterion a weighting that relates to the level of importance of the criterion. Below is the formula for calculations:

$$V_{ij} = g_{i,j} \cdot w_j. \tag{18}$$

Thus, the following results of the weighted normalization matrix can be formed:

$$V = \begin{bmatrix} v_{1,1} & \cdots & v_{1,n} \\ \vdots & \ddots & \vdots \\ v_{m,1} & \cdots & x_{m,n} \end{bmatrix}. \tag{19}$$

Step 4. 4. Calculating the value of Gray's relational analysis.

In this step, the Gray ratio value is calculated for each variable based on the Gray ratio matrix and the relative weights that were determined using the following equation:

$$GRG_i = \frac{1}{n} \sum_{j=1}^{n} V_{ij}, \tag{20}$$

GRG_i is the value of the Gray ratio (VGR) of the i-th variable to the reference variable.

The end of algorithm.

5. 2. An application example of the method of increasing the reliability of the object state assessment

To determine the effectiveness of the proposed method of increasing the reliability of the assessment of the object's condition, a simulation of its operation was carried out. To solve the task of determining the composition of the operational grouping of troops (forces) and the elements of its operational construction in order to determine the expediency of regrouping troops (forces).

The following linguistic variables were used to solve the problem:

1. The types of radio emitting devices (RED): the range of permissible values: radio communication devices, radio relay devices, satellite communication devices, air monitoring devices (radar detection devices); radio-electronic countermeasures devices:

RED="Types of radio emitting devices"=
={"brigade tactical group", "operational grouping of troops (forces)", "strategic grouping of troops (forces)"}.

2. The types of organizational and staff formations: the range of permissible values: 0÷1:

OSF="The types of organizational and staff formations"=
={"brigade tactical groups", "operational groupings of troops (forces)", "strategic groupings of troops (forces)"}.

3. The types of control points: range of permissible values: 0÷1:

CP="Types of control points"=
={"control points of brigade tactical groups", "control points of operational groups of troops (forces)", "control points of strategic groups of troops (forces)"}.

4. Availability of fortifications: range of permissible values: 0÷1:

F="Availability of fortifications"=
={"Fortifications of the first tier", "Fortifications of the first and second tiers", "Fortifications of the first to third tiers"}.

5. Availability of reserves: range of permissible values: 0÷1:

AR="Availability of reserves"=
={"reserve brigade tactical group", "two reserve brigade tactical groups", "reserve operational group"}.

6. The type of operation: range of permissible values: 0÷1:

TO="Type of operation"=
={"defensive", "offensive", "counter-offensive"}.

7. Activity of actions in the specified direction: range of permissible values: 0÷1:

AA="Activity of actions in the specified direction"=
={"low", "medium", "high"}.

8. Uncertainty of the operational situation: Range of permissible values: complete uncertainty÷complete awareness:

UN="Uncertainty of operational situation"={"Complete uncertainty", "partial uncertainty", "full awareness"}.

To simplify further writing, let's denote the vague variables "zero" – "Z", "low" – "L", "normal" – "N", "high" – "H".

The membership functions given in the example for the analysis of the operational situation are presented in the specified form according to the formula:

1) (CP="H") and (OSF="H") and (UN="H") and (AR="L")→(REZ="H");
...
81) (CP="L") and (OSF="L") and (UN="L") and (AR="H")→(REZ="L");
82) (F="L") and (AA="L") and (UN="H") and (AR="H")→(REZ="N");
...
108) (SC="L") and (OSF="L") and (UN="H") and (CP="L")→(REZ="N").

In this example, only a separate part of the rule base of the neuro-fuzzy expert system is given. In the main base of rules there are rules not only with connections of conditions with the help of T-norms, but also with the help of T-conorms and with negations of conditions.

In the worst case, to find a solution, the system should check all the rules contained in the rule base. Thus, it is necessary to check 617 conditions and calculate 315 T-norm operations.

The credibility assessment for rule bases (RB*i*) is given in Table 1.

The classic Rete II, Treat and Leaps method and the proposed method [10–12] were used to compare the reliability of the assessment.

Table 1 clearly shows that the application of the modified Rete II method is justified for rule bases containing a large number of rules and a relatively small number of linguistic variables. In this case, the modified Rete method allows the reliability of information processing to be almost twice that of a fuzzy expert system, and by 20–25 % compared to the classic Rete method.

Table 1

The value of reliability estimates

–	n	m_{av}	k	t_{av}	s	Ξ_{ReteII}	Ξ_{Treat}	Ξ_{Leaps}	$\Xi_{mod\ ReteII}$
RB1	20	9	12	5	6	0.7	0.68	0.77	0.89
RB2	200	9	12	5	6	0.76	0.67	0.75	0.85
RB3	400	9	12	5	6	0.65	0.67	0.77	0.88
RB4	600	9	12	5	6	0.66	0.69	0.8	0.87
RB5	20	9	12	5	6	0.69	0.7	0.76	0.87
RB6	200	9	12	5	6	0.68	0.71	0.72	0.88
RB7	400	9	12	5	6	0.69	0.67	0.74	0.89
RB8	600	9	12	5	6	0.7	0.66	0.77	0.95
RB9	20	9	12	5	6	0.66	0.7	0.75	0.92
RB10	200	9	12	5	6	0.67	0.72	0.78	0.93
RB11	400	9	12	5	6	0.64	0.71	0.73	0.97
RB12	600	9	12	5	6	0.67	0.73	0.76	0.98
RB13	20	9	12	5	6	0.6	0.69	0.74	0.92
RB14	200	9	12	5	6	0.74	0.73	0.75	0.94
RB15	400	9	12	5	6	0.69	0.7	0.76	0.96
RB15	600	9	12	5	6	0. 7	0.69	0.78	0.97

The research of the developed method showed that the specified method provides an average of 20 % higher reliability of obtaining an estimate (Table 1).

6. Discussion of the results of the development of the method of increasing the reliability of the object state assessment

The advantages of the proposed method are due to the following:

– the possibility of increasing the reliability of the object state assessment due to the parallel use of two bio-inspired algorithms, in comparison with works [9, 12, 19];

– taking into account the degree of awareness of the object state, due to the application of correction coefficients for the degree of awareness, in comparison with works [10, 12, 15];

– construction of both object and relational models, which makes it possible to increase the reliability of the assessment of the objects state, in comparison with works [12, 14, 15];

– the possibility of combining the results of the work of bio-inspired algorithms, which makes it possible to mutually check the correctness of the work of each of the algorithms in comparison with works [14, 16, 17];

– universality of solving the task of assessing the objects state with different degrees due to the hierarchical nature of their description (Steps 1–4, Table 1), in comparison with works [9, 12, 18];

– the possibility of simultaneously searching for a solution in different directions (Steps 1–4, Table 1), due to the use of a multi-agent approach implemented in bio-inspired algorithms;

– the adequacy of the obtained results (Steps 1–4), in comparison with works [9–11];

The disadvantages of the proposed method of approach should include:

– increased computational complexity due to the construction of two types of models – object and relational, as well as the operation of two bio-inspired algorithms.

This method will allow:

– to carry out an assessment of the objects state with a given degree of reliability;

– to determine effective measures to increase the reliability of the assessment of the objects state, while maintaining the specified efficiency.

The limitations of the research are the need to have an initial database on the objects state, the need to take into account the delay time for collection and proving information from intelligence sources.

The proposed method should be used to solve the problems of assessing the state of multidimensional objects in conditions of uncertainty and risks, which are characterized by high requirements for the reliability of the obtained data.

This research is a further development of research aimed at developing method principles for increasing the efficiency of processing various types of data, which were published earlier [2, 4–6, 20].

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 procedures of methods for increasing the reliability of object state assessment are defined, the originality of which is the use of several types of object state models and the parallel application of two bio-inspired algorithms, which allows:

– to increase the reliability of the object state assessment due to the parallel use of two bio-inspired algorithms;

– to take into account the degree of awareness of the object state, due to the application of correction coefficients for the degree of awareness;

– to build both object and relational models, which allows to increase the reliability of the assessment of the objects state;

– to combine the results of the work of bio-inspired algorithms, thus achieving the possibility of mutual verification of the correctness of the work of each of the algorithms;

– to obtain a universal solution to the task of assessing the objects state with different degrees due to the hierarchical nature of their description;

– to carry out a simultaneous search for a solution in different directions, due to the use of a multi-agent approach.

2. An example of the use of the proposed method was provided, on the example of solving the task of determining the composition of an operational group of troops (forces) and elements of its operational construction. The specified example showed an increase in the reliability of the assessment of the objects state by an average of 20 % due to the use of additional improved procedures.

Conflict of interest

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

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Data availability

The manuscript has associated data in the data repository.

The use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies while creating the presented work.

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