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DEVELOPMENT OF A SOLUTION SEARCH METHOD USING THE IMPROVED EMPEROR PENGUIN ALGORITHM

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The objects of the study are decision support systems. The subject of the study is the decision-making process in management problems using the Emperor Penguin Algorithm (EPA), an advanced genetic algorithm and evolving artificial neural networks.

A solution search method using the improved EPA is proposed. The study is based on the EPA algorithm for finding a solution regarding the object state. Evolving artificial neural networks are used to train EPA, and an advanced genetic algorithm is used to select the best EPA. The method has the following sequence of actions:

- ***input of initial data;***
- ***setting agents on the search plane;***
- ***numbering EPA in the flock;***
- ***setting the initial velocity of the EPA and thermal radiation of each EPA;***
- ***calculation of the position of each EPA on the total search area and its cost;***
- ***approach (attraction) of the EPA to another EPA;***
- ***changing in the trajectory of EPA movement;***
- ***selection of the best individuals from the EPA flock;***
- ***ranking the obtained solutions and sorting them;***
- ***training EPA knowledge bases;***
- ***determining the amount of necessary computing resources for an intelligent decision support system.***

The originality of the proposed method lies in setting EPA taking into account the uncertainty of the initial data, improved global and local search procedures taking into account the noise degree of data on the state of the analysis object. The method makes it possible to increase the efficiency of data processing at the level of 13–17 % 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: multi-extremal functions, decision support systems, emperor penguin algorithm, optimization

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1. Introduction

Heuristic and metaheuristic optimization algorithms are algorithms that include a practical method that is not guaranteed to be accurate or optimal, but is sufficient for solving the problem [1, 2]. The correctness of these algorithms for all possible cases has not been proven, but they are known to provide a fairly good solution [3, 4].

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

There are a large number of swarm algorithms, for example: particle swarm method, ant algorithm, cuckoo algorithm, bat algorithm, etc. [7, 8]. Using swarm algorithms to find solutions regarding the state of objects allows you to perform:

– an analysis of the stability of the state of heterogeneous objects in the process of combat use (operation);

– an analysis of the direct, aggregated and indirect mutual influence of systemic and external factors;

– an assessment of the reach of target situations of object management;

– scenario analysis for various destructive effects;

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

– the modeling and analysis of the dynamics of changes in the state of interrelated parameters of heterogeneous objects.

At the same time, using the above-mentioned swarm algorithms in the canonical form does not allow you to obtain an operational assessment of the object state with a given reliability. This leads to the search for new (improvement of existing) approaches to assessing and forecasting the state of objects by combining already known swarm algorithms with their further improvement.

Given the above, an urgent scientific task is to develop a solution search method using the improved emperor penguin algorithm, which would increase the efficiency of decisions 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] disclosed the essence of cognitive modeling and scenario planning. A system of complementary principles for building and implementing scenarios is proposed, different approaches to building scenarios are highlighted, and the procedure for modeling scenarios based on fuzzy cognitive maps is described. The approach proposed by the authors does not take into account the type of uncertainty about the state of the analysis object and the noise of the 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 aimed at 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 consideration of the type of uncertainty of the input 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 disadvantages of the 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 this analytical platform include the inability 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 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 based on a set of input parameters. The disadvantages of the method include the inability to assess the adequacy and reliability of the evaluation and, accordingly, determine the evaluation 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 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 disadvantages of this approach are the 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 reliability of the obtained estimate.

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 if the initial information is complete, 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 the non-compliance of the existing system state with the required one, which is set by the management subject. 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 simulation modeling of complex systems. The advantages of this 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] indicated that the most popular evolutionary bio-inspired algorithms are the so-called «swarm» procedures (Particle Swarm Optimization – PSO). Among them, optimization algorithms based on cat swarms (Cat Swarm Optimization – CSO) 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 tasks and have already undergone a number of modifications. Among the modifications, 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] investigated the emperor penguin colony algorithm (EPA) – an algorithm based on simulating the movement pattern of emperor penguins. In nature, the temperature of an adult penguin in a flock can reach 35 °C, to maintain the body temperature necessary for survival, the birds gather in dense flocks (clusters). The heat exchange of the flock ensures that each penguin stays warm enough. Thus, emperor penguins, snuggled up to each other, create the most favorable conditions for life and egg hatching. There is much more heat in the center of the cluster, so all the birds tend to get to the center of the crowd, and in order to use the heat of other birds in the colony, they make spiral movements towards the center.

The basic EPA is subject to the following rules:

– all EPA in the initial population have thermal radiation and are attracted to each other due to the absorption coefficient;

– the body surface area of all EPA is considered equal to each other;

– EPA completely absorbs thermal radiation and the influence of the earth’s surface and atmosphere is not considered;

– thermal radiation of EPA is considered linear;

– EPA attraction is carried out according to the amount of heat at the distance between two EPA. The greater the distance, the less heat is received, the smaller the distance, the more heat;

– the spiral movement of EPA in the process of absorption is not monotonous and has deviations with the uniform distribution.

At the same time, the basic EPA 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 the common shortcomings of the above-mentioned studies are:

– the lack of possibility of forming 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 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 certain 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 solution search method using the improved emperor penguin algorithm.

3. The aim and objectives of the study

The aim of the study is to develop a solution search method using the improved emperor penguin algorithm. This will allow you to 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.

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 of the study is to increase the efficiency of decision-making in management problems while ensuring the given reliability. The objects of the study are decision support systems. The subject of the study is the decision-making process in management problems using improved bio-inspired algorithms.

The hypothesis of the study is the possibility of increasing the efficiency of decision-making with a given assessment reliability.

To simulate the operation of the proposed method, MathCad 14 software environment (USA) was used. The problem solved during the simulation was to assess the elements of the operational situation of a group of troops (forces). An operational group of troops (forces) formed on the basis of an operational command with a standard composition of forces and means according to the wartime state and with a range of responsibilities in accordance with current regulations.

For the hardware support of the research process, a personal computer based on an AMD Ryzen 5 processor was used.

The research is based on the emperor penguin algorithm for finding a solution regarding the object state, taking into account the analysis of literature sources. For training EPA, evolving artificial neural networks developed in [2] are used. This approach is characterized by a high degree of adaptability to input data due to the possibility of adapting the architecture of evolving artificial neural networks to input data. To select the best EPA, an improved genetic algorithm developed in [24, 25] is used, which is characterized by high efficiency of data processing and improved mutation and selection procedures.

5. Development of a solution search method using the improved emperor penguin algorithm

5. 1. Algorithm for implementing the solution search method using the improved emperor penguin algorithm

The proposed algorithm is the improved emperor penguin algorithm and consists of the following sequence of actions.

Step 1. Input of initial data. At this stage, the available initial data on the object to be analyzed are entered. The existing model of the analysis object is also initialized, the decision matrix D is filled: each column is filled with a subset F_k.

Step 2. Setting up agents on the search plane.

At this stage, the EPA is set up taking into account the type of uncertainty about the object to be analyzed, and the basic model of the object's state is initialized [2, 19, 21, 24, 25]. At the same time, the degree of uncertainty can be: full awareness; partial uncertainty and total uncertainty. This is done using the appropriate correction coefficients, which are set at the analysis stage.

Step 3. Numbering EPA in the flock, i, $i \in [0, S]$.

Since penguins are social animals, each member of the flock participates in the general heat exchange: all EPA emit heat, which attracts other members of the EPA colony [26–29].

Step 4. Setting the initial velocity of the EPA and thermal radiation of each EPA.

The initial velocity v_0 of each EPA is determined by the following expression:

$$v_i = (v_1, v_2 \ldots v_S),\ v_i = v_0. \tag{1}$$

The initial thermal radiation of each EPA is determined by the expression:

$$T_i = (T_1, T_2 \ldots T_S),\ T_i = T_{\max}, \tag{2}$$

where T_i is the value of the thermal radiation of the EPA with number i; $T_{\max}$ is the maximum thermal radiation of the EPA.

Step 5. Calculation of the position of each EPA on the total search area and its cost.

The cost of each EPA is calculated according to the formula:

$$Q = A\varepsilon\sigma T_s^4 e^{\mu x}, \tag{3}$$

where A is the total surface area of the EPA; ε is the emissivity of the EPA bird plumage; σ is the Boltzmann's constant; T_i is the EPA body temperature; μ is the coefficient of attenuation of thermal radiation of each EPA, which is calculated taking into account the degree of noise of the initial data about the analysis object, based on the method developed in [22, 24]; x is the distance to the nearest penguin in meters.

Also at this stage, the cost of each EPA is compared with each other. EPA always move towards an agent that has a low cost (high heat intensity) of absorption. The cost of the agent is determined according to the desired function, which takes the coordinates of the given agent as arguments. In other words, the penguin with the closest position to the global optimum of the function will have the lowest cost, and therefore others will move towards it [30–34].

Step 6. Approach (attraction) of the EPA to another EPA.

Thus, penguins gather in clusters. However, the agents do not move linearly, but spirally. The spiral movement of EPA is described by the formula:

$$\begin{cases} x_k = ae^{b\frac{1}{b}\ln\left\{(1-Q)e^{b\tan^{-1}\frac{y_i}{x_i}} + Qe^{b\tan^{-1}\frac{y_i}{x_i}}\right\}} \cos\left\{\frac{1}{b}\ln\left\{(1-Q)e^{b\tan^{-1}\frac{y_i}{x_i}} + Qe^{b\tan^{-1}\frac{y_i}{x_i}}\right\}\right\}; \\ y_k = ae^{b\frac{1}{b}\ln\left\{(1-Q)e^{b\tan^{-1}\frac{y_i}{x_i}} + Qe^{b\tan^{-1}\frac{y_i}{x_i}}\right\}} \sin\left\{\frac{1}{b}\ln\left\{(1-Q)e^{b\tan^{-1}\frac{y_i}{x_i}} + Qe^{b\tan^{-1}\frac{y_i}{x_i}}\right\}\right\}, \end{cases} \tag{4}$$

where a is the height penguin; b is the penguin thickness; Q is the penguin attractiveness (calculated from expression (3)).

Step 7. Changing the trajectory of EPA movement.

In order not to be limited to a uniform spiral path, a random component is needed, which we introduce using formula (4), as follows:

$$\begin{cases} x_k = ae^{b\frac{1}{b}\ln\left\{(1-Q)e^{b\tan^{-1}\frac{y_i}{x_i}} + Qe^{b\tan^{-1}\frac{y_i}{x_i}}\right\}} \times \\ \times\cos\left\{\frac{1}{b}\ln\left\{(1-Q)e^{b\tan^{-1}\frac{y_i}{x_i}} + Qe^{b\tan^{-1}\frac{y_i}{x_i}}\right\}\right\} + \varphi\varepsilon_i; \\ y_k = ae^{b\frac{1}{b}\ln\left\{(1-Q)e^{b\tan^{-1}\frac{y_i}{x_i}} + Qe^{b\tan^{-1}\frac{y_i}{x_i}}\right\}} \times \\ \times\sin\left\{\frac{1}{b}\ln\left\{(1-Q)e^{b\tan^{-1}\frac{y_i}{x_i}} + Qe^{b\tan^{-1}\frac{y_i}{x_i}}\right\}\right\} + \varphi\varepsilon_i, \end{cases} \tag{5}$$

where φ is the mutation coefficient; ε is the uncertainty vector of information about the state of the analysis object.

Step 8. Selection of the best individuals from the EPA flock.

At this stage, using an improved genetic algorithm proposed by the authors in [25], the best EPA in the flock are selected based on the indicators of the reduction in the heat radiation power of each EPA, the mutation coefficient and the attenuation coefficient [35, 36].

Step 9. Ranking the obtained solutions and sorting them.

After recalculating the EPA position, according to (4), the mutation coefficient is added, as shown in (5). The cost of EPA is compared again, the best result is selected. After each iteration, it is necessary to sort the best solutions and reduce the amount of thermal radiation, mutation and attenuation coefficients.

Step 10. Training EPA knowledge bases.

To train the knowledge bases of each EPA, the training method based on evolving artificial neural networks developed in [2] is used. This method is used to change the movement pattern of each EPA for more accurate analysis results in the future.

Step 11. Determining the amount of necessary computing resources for an intelligent decision support system.

In order to prevent looping of calculations on Steps 1–10 of this method and increase the efficiency of calculations, the system load is additionally determined. If the defined threshold of computational complexity is exceeded, the amount of software and hardware resources that must be additionally involved is determined using the method proposed in [36].

The end of the algorithm.

5. 2. Example of applying the proposed method in the analysis of an operational group of troops (forces)

A solution search method using the improved emperor penguin algorithm is proposed. To evaluate the effectiveness of the developed method, its comparative evaluation was performed by the results of research presented in [3–6, 23, 24, 36].

Simulation of the solution search processing method was carried out in accordance with Steps 1–11. Simulation of the proposed method was carried out in the MathCad 14 software environment (USA). The task to be solved during the simulation was to assess the elements of the operational situation of a 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 tools, earth remote sensing tools and unmanned aerial vehicles). To simplify the modeling, the same amount of each tool was taken – 4 tools each;

– the number of informational 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;

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

To evaluate the effectiveness of the studied method, simulation was carried out using some global optimization functions from the example of a number of test functions, in particular, multi-extreme functions with a complex landscape. As a result of the simulation, sets of input parameters were obtained that ensure the optimal operation of the algorithm under the given conditions (Table 1).

Table 1

Results of the EPA algorithm for test functions

Function	Dimensionality of the function	Number of AIP	Number of iterations	Result	Average time, sec.
De Jong (global optimum: 0)	2	4	4	0	0
	5	14	18	0	0.1
	10	28	35	0.001	3.17
	30	30	80	0.007	30.42
Rastrigin (global optimum: 0)	2	6	8	0	0
	5	64	40	0	18.23
	10	50	100	0.03	62.5
	30	50	300	0.97	528.4
Griewank (global optimum: 0)	2	6	4	0	0
	5	16	15	0.002	0.17
	10	30	40	0.004	4.77
	30	43	46	0.028	89.38
Ackley (global optimum: 0)	2	6	4	0	0
	5	24	16	0.001	0.15
	10	42	32	0.013	3.24
	30	50	50	0.021	66.73
Bukina (global optimum: 0)	2	8	4	0	0
	5	20	15	0.002	2.08
	10	40	35	0.03	4.16
	30	50	42	0.85	70.4

Analyzing the results of the improved algorithm shown in Table 1, it can be seen that the algorithm demonstrates the greatest efficiency for functions with a small number of parameters. However, when the dimension of multi-extremal functions with a complex landscape (such as the Rastrigin, Griewank, Bukin functions) increases, there is a small deviation from the global optimum. This deviation can be smoothed out by increasing the number of iterations and agents that affect the duration of the method.

The Rosenbrock function should be noted separately: when the number of parameters increases to more than 10, the EPA shows a rather noticeable discrepancy from the optimal solution. To achieve the required accuracy, a serious increase in time costs is needed, which makes the method ineffective in this particular case.

Based on the conducted research, it can be said that EPA is more effective for working with functions with a small number of parameters. One of the ways to improve the accuracy of the solutions found for multiparameter multimodal functions is to modify or hybridize the method with other algorithms.

The results of the comparative evaluation by the criterion of evaluation efficiency with known scientific studies are shown in Table 2.

Table 2

Results of solving the problem

No. of iteration	Branch and bound method [17]	Genetic algorithm [12]	Canonical EPA algorithm [23]	Improved EPA algorithm
N	T, sec	T, sec	T, sec	T, sec
5	1.125	1.125	1.1	1.05
10	0.625	0.625	0.611	0.450
15	48.97	58.20	56.2	55.41
20	106.72	44.29	42.75	40.21
30	–0.1790	–0.0018	–0.0003	–0.00007
40	–0.158	–0.070	–0.041	–0.06
50	97.76	–974.30	–3.83	–331.19
100	–133.28	–195.71	–195.15	–198.12
200	7980.89	7207.49	7222.16	7022.85

As can be seen from Table 1, the gain of the specified method of finding solutions is from 13 to 17 % by the criterion of data processing efficiency.

6. Discussion of the results of developing a solution search method using the improved emperor penguin algorithm

The advantages of the proposed method are as follows:

– while setting the EPA, the type of uncertainty is taken into account, compared to [9–13] (Step 2);

– universality of solving the problem of analyzing the state of EPA objects due to the hierarchical nature of their description, compared to [12–14] (Steps 1–11);

– the ability to quickly find solutions due to the simultaneous search for a solution by several individuals, compared to [11–16] (Steps 1–11, Tables 1, 2);

– adequacy of the obtained results, compared to [16–21] (Steps 1–11);

– the ability to avoid the local extremum problem, compared to [11–16] (Steps 1–11);

– the possibility of deep learning of EPA knowledge bases, compared to works [16–20] (action 10).

The disadvantages of the proposed method include:

– the 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 assessment parameter for the state of the analysis object;

– 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 mehod 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 assessing the state of a heterogeneous analysis object;

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

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

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 is 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 the available computing resources of the object state analysis system;

– to take into account the priority of the EPA search;

– to carry out the initial setting of EPA individuals taking into account the type of uncertainty;

– to conduct accurate training of EPA individuals;

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

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

– to conduct training of knowledge bases, which is carried out by training the synaptic weights of the 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 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 using 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 13–17 % due to the use of additional improved procedures of adding correction coefficients for uncertainty and noise of data, selection and training of EPA.

Conflict of interest

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.

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Data availability

The work has associated data in the data repository.

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