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DEVELOPMENT OF A SOLUTION SEARCH METHOD USING AN IMPROVED MONKEY ALGORITHM

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The object of the research is decision support systems. The subject of the research is the decision-making process in management problems using the monkey algorithm and evolving artificial neural networks.

A solution search method using an improved monkey algorithm is proposed. The research is based on the monkey algorithm – for finding a solution regarding the state of an object. For training monkey agents (MA), evolving artificial neural networks are used. The method has the following sequence of steps:

– input of initial data;
– processing of initial data taking into account the degree of uncertainty;
– a search vector is generated for each MA, taking into account the degree of uncertainty;
– determination of the initial speed of MA movement;
– calculation of the fitness function of the MA solution;
– calculation of the height of MA movement;
– verification of fulfillment of local jump conditions;
– generation of local search plane coordinates;
– calculation of the fitness function of the MA solution;
– generation of global search plane coordinates;
– search distribution among the MA flock;
– changing the speed of MA movement;
– checking the permissible value of the obtained solution regarding the object state;
– training of MA knowledge bases.

The originality of the proposed method lies in the arrangement of MA taking into account the uncertainty of the initial data, improved procedures of global and local search taking into account the degree of noise of data about the state of the analysis object. A feature of the proposed method is the use of an improved MA training procedure. The training procedure consists in learning the parameters and 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 23–28 % due to the use of additional improved procedures

Keywords: swarm intelligence, decision support systems, hierarchical systems, monkey algorithm

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1. Introduction

The increase in the amounts of information and the sources of their receipt makes it necessary to increase the requirements for the efficiency of collection, processing and generalization of information flows [1, 2]. One of the ways to increase the efficiency of information processing is heuristic and meta-heuristic optimization algorithms [3, 4].

The most famous representative of heuristic methods is swarm intelligence, which describes the collective behavior of a decentralized, self-organizing system [5, 6]. The main advantage of this class of algorithms is the ability to conduct a multidirectional search, which significantly increases decision-making efficiency.

Researchers have developed and further improved swarm algorithms, for example: particle swarm method, ant algorithm, cuckoo algorithm, bat algorithm, fish algorithm, etc. [7, 8]. The use of swarm algorithms to find solutions regarding the objects state allows you to make:

– an analysis of the structure of complex hierarchical systems;

– an analysis of the direct, aggregated and mediated interaction of systemic and external factors;

– an assessment of the achievement of the given target functions for managing complex (hierarchical) objects;

– a comprehensive analysis and forecasting of the development of various destructive effects on the analysis object;

– the modeling and analysis of the dynamics of changes in the state of interdependent parameters of complex and 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's state with a given reliability. This determines the search for new (improvement of existing) approaches to the assessment and forecasting of 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 an improved monkey algorithm, which would increase the efficiency of decisions made to manage the parameters of the control object 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] revealed 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 take into account the type of uncertainty about the state of the analysis object and the noise of the initial data.

The work [11] analyzed 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 work.

The work [12] presents a method of analyzing large data sets. This 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 this method include the impossibility of taking 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 impossibility of assessing the adequacy and reliability of the information transformation process and making 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 information panels with statistically significant results by territory. The disadvantages of the specified analytical platform include the impossibility of assessing 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 us to evaluate the quality of libraries based on a set of input parameters. 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] 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 of checking 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 disadvantages of this approach are 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. This approach allows us to process data from various sources. The disadvantages of the approach include the low accuracy of the obtained estimate and the impossibility of verifying 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 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 the non-compliance of the existing state of the system with the required one, which is set by the management subject. At the same time, 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 the specified approach, which allows us 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, 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 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.

In [23], the monkey algorithm is investigated. Like other metaheuristic algorithms, this algorithm belongs to evolutionary ones and is able to solve a number of optimization problems, including nonlinearity, non-differentiability, high dimensionality of the search space with a high speed of convergence. Another advantage of the monkey algorithm is that it is regulated by a small number of parameters, making it quite easy to implement.

The basic MA is subject to the following rules:

1. Randomly distribute monkeys in the search space.
2. Measure the height of the monkey's position.
3. Make local jumps a fixed number of times.
4. If the new vertex is higher than the one obtained in point 3, then make local jumps from this place.
5. If the limit of the number of local jumps is exhausted and a new vertex is not found, make a global jump.
6. After point 5, repeat point 3.
7. Repeat from point 2 until the stop criterion is met. At the same time, the basic KR requires a long search for solutions and significant computing costs, which does not allow it to be used in real time.

From its current position, each of the monkeys moves upwards until it reaches the top of the mountain. Then, the monkey makes a series of local jumps in a random direction in the hope of finding a higher mountain and the movement is repeated.

After performing a certain number of climbs and local jumps, the monkey believes that it has sufficiently explored the landscape around its initial position. To explore a new search area, the monkey performs a long global jump.

The above steps are repeated a given number of times. The solution to the problem is declared to be the highest of the vertices found by this population of monkeys.

An analysis of the works [9–23] showed that the 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 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.

For this purpose, it is proposed to develop a solution search method using an improved monkey algorithm.

3. The aim and objectives of the study

The aim of the study is to develop a solution search method using an improved monkey algorithm. This will allow increasing the efficiency of assessment and multidimensional forecasting with a given reliability and developing 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 verify the method when analyzing the operational situation of a group of troops (forces).

4. Materials and methods

The problem to be solved in this study is to increase decision-making efficiency while ensuring the given reliability. The object of research is decision support systems. The subject of research is decision-making in management problems using the monkey algorithm and evolving artificial neural networks.

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

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

An operational group of troops (forces) was considered as an object of assessment and management. The 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.

The study is based on the monkey algorithm – to find a solution regarding the state of an object. For MA training, evolving artificial neural networks are used.

5. Development of a solution search method using an improved monkey algorithm

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

The proposed algorithm is an improved monkey algorithm and consists of the following sequence of steps:

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.

At this stage, the decision matrix D is filled: each column is filled with a subset ω_i.

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 analyzed object is initialized [2, 19, 21]. At the same time, the degree of uncertainty can be: full awareness; partial uncertainty and total uncertainty. This is done using correction factors.

Step 3. For each MA, a search vector is generated taking into account the degree of uncertainty:

$$\omega_i = \left((\omega_{i1} \times \eta_{i1}), (\omega_{i2} \times \eta_{i2}), ..., (\omega_{in} \times \eta_{in})\right). \quad (1)$$

To start the motion process, the MA motion direction vector is generated:

$$\Delta\omega_i = \left(\Delta\omega_{i1}, \Delta\omega_{i2}, ..., \Delta\omega_{in}\right), \quad (2)$$

$$\Delta\omega_{ij} = \begin{cases} a, & \text{if } t = rand(0,1) > 1/2; \\ -a, & \text{if } t \le 1/2, \end{cases} \quad (3)$$

where $j=1, 2, ... n$, a ($a>0$) is the step length selected depending on the studied area.

Step 4. Determination of the initial speed of MA movement.

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

$$v_i = (v_1, v_2 ... v_S), v_i = v_0. \quad (4)$$

Step 5. Calculation of the fitness function of the MA solution:

$$f'_{ij}(\omega_i) = \frac{E(\omega_i + \Delta\omega_i) - E((\omega_i - \Delta\omega_i))}{2\Delta\omega_{ij}}, \quad (5)$$

where E is the fitness function of the MA solution, $j=1, 2, ...n$.

Step 6. Calculation of the height of MA movement:

$$y_j = \omega_{ij} + a * sign\left(f'_{ij}(\omega_i)\right), \ j = 1, 2, ..., n. \quad (6)$$

Step 7. Checking the fulfillment of local jump conditions.

If the resulting vector **y** is valid, the positions of the vector ω_i are replaced by the positions of the vector **y**. Otherwise, ω_i remains unchanged. Steps 1–6 are repeated until the number of possible iterations is exhausted or the search termination condition is met [29–32].

Step 8. Generation of local search plane coordinates. The numbers y_j are generated from the range $(\omega_{ij}-b)\times\iota$, $(\omega_{ij}+b)\times\iota$, taking into account the degree of noise of the initial data ι. They form the vector $y=(y_1, y_2,..., y_n)$.

Step 9. If the value $E(y)>E(\omega_{ij})$ and the value of the vector **y** is valid, then the positions of the vector ω_i are replaced by the positions of the vector **y**. Otherwise, Steps 6–8 are repeated until a better value is found or until the number of possible iterations is exhausted and a decision is made regarding the feasibility of performing a global MA jump [33–36].

Step 10. Generation of global search area coordinates.

A uniformly distributed real number α is generated from the range $[c, d]$ (global jump range), taking into account the degree of noise of the output data, where c, d are the algorithm parameters.

Step 11. The global search vector $y_j=\omega_{ij}+a*(p_j-\omega_{ij})$, $j=1$, 2, ... n is specified.

Step 12. Search distribution among the MA flock.

Each formula must be typed separately:

$$p_j = \frac{1}{M}\sum_{i=1}^{M}\omega_{ij}, j = 1, 2, ... n, \quad (7)$$

M is the number of monkeys in the population, and the point $p=(p_1, p_2,..., p_n)$ is the current center of gravity.

Step 13. Changing the speed of MA movement.

Speed modification is performed:

$$v_i^I = v_i + w_i\left(x^* - x_i\right), \quad (8)$$

where (x^*-x_i) is the approximation of all MA by $\eta\rightarrow$max.

Step 14. If the obtained vector **y** is acceptable and the value $E(y)>E(\omega_{ij})$, then the positions of the vector ω_i are replaced by the positions of the vector **y**. Otherwise, ω_i remains unchanged. Steps 10–14 are repeated until a better value is found or the number of possible iterations is exhausted.

Step 15. Training of MA knowledge bases.

In this study, the training method based on evolving artificial neural networks developed in [2] is used to train the knowledge bases of each MA.

End of the algorithm.

5. 2. Verification of the method when analyzing the operational group of troops (forces)

A solution search method using an improved monkey algorithm is proposed.

Simulation of the solution search processing method was carried out in accordance with Steps 1–10. 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 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, remote earth 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;

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

Table 1 shows a comparative evaluation of the effectiveness of the proposed algorithm for some evaluation functions for 20 runs of the algorithm. It is well known that some of these comparison functions have many local minima, which are complex enough to evaluate the performance. The convergence behavior of MA is governed by the choice of parameters in the climb process, the observation jump process and the somersault process.

Table 1

Results of comparative analysis with 20 runs of the algorithm

Function name	Search area	Number of elements in the structure (n)	Evaluation error
$f_1(\omega)=\sum_{i=1}^{n}\left(-\omega_i \sin\left(\sqrt{\lvert\omega_i\rvert}\right)\right)$	$[-500, 500]^n$	30	$-418.986\, n$
$f_2(\omega)=\sum_{i=1}^{n}\left(\omega_i^2-10\cos(2\pi\omega_i)+10\right)$	$[-5.12, 5.12]^n$	30	0
$f_3(\omega)=-20\exp\left(-0.2\sqrt{\frac{1}{n}\sum_{i=1}^{n}\omega_i^2}\right)-$ $-\exp\left(\frac{1}{n}\sum_{i=1}^{n}\cos(2\pi\omega_i)\right)+20+\exp(1)$	$[-32, 32]^n$	30	0
$f_4(\omega)=\frac{1}{4000}\sum_{i=1}^{n}\omega_i^2-\prod_{i=1}^{n}\cos\left(\frac{\omega_i}{\sqrt{i}}\right)+1$	$[-600, 600]^n$	30	0
$f_5(\omega)=\sum_{i=1}^{n-1}\left[100\left(\omega_i^2-x_{i+1}\right)^2+\left(\omega_i-1\right)^2\right]$	$[-5, 10]^n$	30	0
$f_6(\omega)=\sum_{i=1}^{n-1}\omega_i^2$	$[-100, 100]^n$	30	0
$f_7(\omega)=\sum_{i=1}^{n-1}\omega_i^4+\text{random}[0,1)$	$[-1.28, 1.28]^n$	30	0
$f_8(\omega)=\sum_{i=1}^{n-1}\lvert\omega_i\rvert+\prod_{i=1}^{n}\lvert\omega_i\rvert$	$[-10, 10]^n$	30	0
$f_9(\omega)=\sum_{i=1}^{n}\left(\sum_{j=1}^{i}\omega_i\right)$	$[-100, 100]^n$	30	0
$f_9(\omega)=\max\left\{\lvert\omega_i\rvert, i=1,2,\ldots,n\right\}$	$[-100, 100]^n$	30	0

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

Table 2

Results of problem solving

No. of iteration	Branch and bound method [17]	Genetic algo-rithm [12]	Canonical monkey al-gorithm [23]	Improved monkey algorithm
N	T, s	T, s	T, s	T, s
5	1.125	1.125	1.125	0.95
10	0.625	0.625	0.625	0.420
15	48.97	58.20	58.28	53.71
20	106.72	44.29	43.75	37.33
30	–0.1790	–0.0018	–0.0002	–0.00007
40	–0.158	–0.070	–0.069	–0.07
50	97.76	–974.30	–3.72	–325.18
100	–133.28	–195.71	–196.24	–180.12
200	**7980.89**	**7207.49**	**7198.43**	**6816.85**

As can be seen from Table 2, the gain of the specified solution search method is from 23 to 28 % by the criterion of data processing efficiency.

6. Discussion of the results of developing a solution search method using an improved monkey algorithm

The features of the proposed method are as follows:

– when setting the MA, the type of uncertainty is taken into account (Step 2);

– universality of solving the problem of analyzing the state of MA objects due to the hierarchical nature of their description (Steps 1–15);

– the possibility to quickly find solutions due to the simultaneous search for a solution by several individuals (Steps 1–15, Table 1);

– the adequacy of the obtained results (Steps 1–15);

– the ability to avoid the local extremum problem (Steps 1–15);

– the possibility of deep learning of MA knowledge bases (Step 15).

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 for assessing the state 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 object of analysis;

– 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 time of delay for collecting and communicating 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 system for analyzing the state of the analysis object;

– to take into account the priority of MA search;

– to conduct an initial display of MA individuals taking into account the type of uncertainty;

– to carry out accurate training of MA individuals;

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

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

– to use as a universal tool to solve 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. Verification of the proposed method was performed on the example of assessment and forecasting of the state of the operational situation of a group of troops (forces). Verification of the proposed method showed an increase in the efficiency of data processing at the level of 23–28 % due to the use of additional improved procedures of adding correction factors for uncertainty and noise of data and MA 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 work has associated data in the data repository.

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