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DEVELOPMENT OF A METHOD FOR ASSESSING THE STATE OF DYNAMIC OBJECTS USING A POPULATION ALGORITHM

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The object of the study is complex dynamic objects with a hierarchical structure. A method for assessing the state of dynamic objects using a population algorithm is proposed. The study is based on the snake optimization algorithm for finding a solution to the state of dynamic objects with a hierarchical structure. For training snake agents (SA), evolving artificial neural networks are used. The originality of the method lies in using additional advanced procedures that allow you:

– to determine the initial position of SA, taking into account the type of uncertainty by using a correction factor for the degree of awareness of the state of the initial situation in relation to the object of analysis;

– to take into account the initial velocity of each SA, which allows studying complex functions;

– to ensure the universality of SA food location search strategies, which allows classifying the type of data to be processed;

– to adjust the SA velocity by adjusting the ambient temperature, which allows priorizing the search for a solution in a certain plane;

– to explore the solution spaces of functions described by non-typical functions, using exploitation mode procedures;

– to flexibly adjust the transition from the SA fighting mode to the mating mode using the food saturation coefficient;

– to replace individuals unsuitable for search using the SA fertility rate;

– to conduct a simultaneous search for a solution in different directions, by changing the ambient temperature and adjusting the food saturation coefficient.

Modeling showed a 13–19 % increase in data processing efficiency by using additional improved procedures

Keywords: complex processes, unimodal functions, multimodal functions, complex and dynamic objects

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1. Introduction

Optimization is a complex process of defining a set of solutions for a variety of functions. Many calculation problems today refer specifically to optimization problems [1–3].

When solving optimization problems, the solution variables are defined so that complex dynamic objects work in their best point (mode) according to a certain optimization criterion.

One type of stochastic optimization algorithms for complex dynamic objects is swarm intelligence algorithms (swarm algorithms) [4–6]. Swarm intelligence algorithms are based on swarm movement and simulate the interaction between the swarm and its environment to improve knowledge about the environment, such as new food sources [7, 8]. The most well-known swarm algorithms are the particle swarm optimization algorithm, artificial bee colony algorithm, ant colony optimization algorithm, wolf optimization algorithm and sparrow search algorithm.

Metaheuristic algorithms have found practical application for solving practical problems both in everyday life (engineering calculations, processing large amounts of data) and purely special problems, such as assessing the operational situation.

However, most of the basic metaheuristic algorithms mentioned above are unable to balance exploration and exploitation, resulting in poor performance for real-world complex optimization problems.

This prompts the implementation of various strategies to improve the convergence rate and accuracy of basic metaheuristic algorithms. One option to increase decision-making efficiency using metaheuristic algorithms is to combine them, that is, add the basic procedures of one algorithm to another.

2. Literature review and problem statement

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

The work [10] reveals the essence of cognitive modeling and scenario planning. A system of complementary principles of building and implementing scenarios is proposed, various 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] 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 work.

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

The work [13] presents a mechanism of transforming 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 mentioned approach include the inability to assess the adequacy and reliability of the information transformation process and make appropriate correction of the resulting 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, as well as high computational complexity. Also, the disadvantage of this study is that the search for a solution is not unidirectional.

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

The work [16] analyzes 30 algorithms for processing large amounts of data. 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 verify the adequacy of the estimates obtained.

The work [17] presents an approach for evaluating input data for decision support systems. The essence of the proposed approach is to cluster the basic set of input data, analyze 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 different sources of information. This approach allows you to process data from different 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, using 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 for solving poorly structured problems based on the formation of situation development scenarios. 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 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 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 system computing resources.

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 cat swarm optimization algorithms (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.

An analysis of the works [9–22] showed that the common shortcomings of the above studies are:

– the lack of possibility of forming a hierarchical system of indicators for assessing the state of complex dynamic objects;

– the lack of consideration of computing resources of the system that evaluates the state of complex dynamic objects;

– the lack of mechanisms for adjusting the system of indicators for assessing the state of complex dynamic objects;

– the lack of consideration of the type of uncertainty and noise of data on the state of complex dynamic objects, which creates corresponding errors when assessing their 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.

3. The aim and objectives of the study

The aim of the study is to develop a method for assessing the state of dynamic objects using a population algorithm. This will increase the efficiency of assessing the state of dynamic objects 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 method implementation algorithm;

– to give an example of using the method in analyzing the operational situation of a group of troops (forces).

4. Materials and methods

The object of the study is complex dynamic objects with a hierarchical structure. The problem solved in the study is to increase decision-making efficiency in the problems of assessing the state of dynamic objects while ensuring a given reliability, regardless of its hierarchy. The subject of the study is the decision-making process in management problems using:

– an advanced snake population algorithm – which allows studying objects described by complex multimodal functions;

– evolving artificial neural networks – for deep learning of multi-agent system knowledge bases, by learning both the parameters and architecture of artificial neural networks.

The hypothesis of the study is the possibility of increasing the efficiency of decision-making with a given assessment reliability using an improved snake population algorithm.

The proposed method was simulated in the MathCad 14 software environment (USA). The problem solved during the simulation 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.

The object of assessment was the operational group of troops (forces). 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 staff, as well as with a range of responsibilities under current regulations.

Initial data for determining the composition of the operational group of troops (forces) and elements of its operational structure using the method:

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

– the number of informational features for determining the state of the monitoring object – 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, the minimum depth along the flank, the maximum depth along the flank, the number of weapons and military equipment (WME) samples, the number of types of WME samples and the number of communication means, the type of operational structure are also taken into account;

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

Parameters of swarm algorithms:

– the number of iterations – 100;

– the number of individuals in the flock – 50 (for the advanced method 25/25);

– the feature space range – [–300, 300].

5. Development of a method for assessing the state of dynamic objects using a population algorithm

5. 1. Algorithm of the method for assessing the state of dynamic objects using a population algorithm

The proposed approach is a population swarm algorithm based on simulating the mating behavior of snakes, which can provide solutions to optimization problems in a multiple iterative process based on search capabilities in the problem-solving space.

The method for assessing the state of dynamic objects using a population algorithm consists of the following sequence of actions:

Step 1. Input of initial data.

At this stage, the available initial data on the dynamic object to be evaluated are entered. Snakes enter the mating season when it's cold outside and they can find food.

Step 2. Initial setting of agents on the search plane.

The snake optimization algorithm (SOA) is initialized by generating a random population according to equation (1). The snake agent (SA) population is then divided into two groups, male and female (2):

$$x_{i,j} = Lb_j + r\cdot\left(Ub_j - Lb_j\right),\ i = 1,2,\ldots,N,\ j = 1,2,\ldots,m, \quad (1)$$

$$N_{female} \cong \frac{N}{2},\ N_{male} = N - N_{female}, \quad (2)$$

where x_{ij} is the j-th dimension of the i-th SA, m is the number of measurements, N is the size of the SA population, r is the uncertainty degree of information about the object state, Ub and Lb are the upper and lower bounds of the j-th dimension, respectively, N_{female} is the number of female SA in the population, N_{male} is the number of male SA in the population.

The best value obtained for the objective function corresponds to the best member of the swarm (the best possible solution), and the worst value obtained for the objective function corresponds to the worst member of the population (the worst possible solution). Since at each iteration, the position of the population SA in the problem-solving space is updated, the best SA of the population must also be updated based on a comparison of the updated values for the objective function. At the end of the algorithm, the position of the best population SA obtained during the algorithm iterations is presented as a solution to the problem of finding a solution to the state of the dynamic object [23–30].

Step 3. Numbering SA in the population, i, $i\in[0, S]$.

At this stage, each SA of the population is assigned a serial number.

Step 4. Determining the initial velocity of population SA.

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

$$v_i=\left(v_1,v_2...v_S\right), v_i=v_0. \qquad (3)$$

In planning the proposed approach, the position of the population SA in the problem-solving space is updated based on simulating exploitation, fighting and mating strategies.

Step 5. Preliminary assessment of the SA search area.

In this procedure, the search area in natural language is determined precisely by the SA existence halo. Given that SA food sources are diverse, we will sort out the quality of food.

Step 6. Classification of food sources for SA.

The attractiveness of food significantly depends on the temperature parameters (T) of the environment, and the quality of food is calculated by equations (4), (5):

$$T=\exp\left(\frac{-t}{t_{\max}}\right), \qquad (4)$$

$$FQ=c_1\exp\left(\frac{t-t_{\max}}{t_{\max}}\right), \qquad (5)$$

where t is the number of the current iteration, $t_{\max}$ is the total number of iterations, c_1 is the food attractiveness coefficient for each temperature range.

In this algorithm, SA select a food search area, according to c_1, then SA update the position. The exploration behavior of male and female SA is expressed mathematically in equations (6), (7), respectively:

$$x_{i,j}(t+1)=x_{k,j}(t)\mp c_2\times A_{i,male}\left(\left(Ub-Lb\right)r_1+Lb\right), \qquad (6)$$

where

$$A_{i,male}=\exp\left(\frac{-F_{r,male}}{F_{i,male}}\right),$$

$$x_{i,j}(t+1)=x_{k,j}(t+1)\mp c_2\times A_{i,female}\left(\left(Ub-Lb\right)r_1+r_2+Lb\right), \quad (7)$$

where

$$A_{i,female}=\exp\left(\frac{-F_{r,female}}{F_{i,female}}\right),$$

where k is a random integer in the range $(1, N/2)$, $x_{k,j}$ is a random value of the number of males/females in the SA population, r_1 and r_2 are random numbers in the range (0, 1). $A_{i,female}$ and $A_{i,male}$ are the ability of male and female SA to find food, $F_{r,male}$ is the fitness of a pre-selected random male SA, $F_{r,female}$ is the fitness of a pre-selected random female SA. $F_{i,male}$ and $F_{i,female}$ are the i-th indicator of the male and female SA, respectively. The direction operator (±) scans all possible directions randomly in a given search space.

Step 7. Verifying that the condition is met.

If $FQ>T$ – go to the exploitation mode. If $FQ<T$ – return to the exploration mode (Step 6).

Step 8. Exploitation mode.

Step 8. 1. Verifying that the condition is met.

If $T>0.6$ (hot), SA will move towards food according to equation (8):

$$x_{i,j}(t+1)=x_f\mp c_3\times T\times r_3\left(x_f-x_{i,j}(t)\right), \qquad (8)$$

where $x_{i,j}$ are the locations of male and female SA, x_f are the best SA, c_3 is a constant equal to 2, r_3 is a random number in the range (0, 1).

Step 8. 2. Verifying that the condition is met.

If $FQ<T$ ($T<0.6$) (cold), SA fight or mate.

Step 8. 3. SA fighting.

The fighting abilities of male SA F_{male} and female SA F_{female} can be written in equations (9) and (10):

$$x_{i,j}(t+1)=x_{i,j}(t)\pm c_4\times F_{i,male}r_4\times\left(x_{best,female}-x_{i,male}(t)\right),$$

$$F_{i,male}=\exp\left(\frac{-F_{best,f}}{F_i}\right), \qquad (9)$$

$$x_{i,j}(t+1)=x_{i,j}(t)\pm c_4F_{i,female}r_5\left(x_{best,male}-x_{i,female}(t+1)\right),$$

$$F_{i,female}=\exp\left(\frac{-F_{best,male}}{F_i}\right), \qquad (10)$$

where $x_{i,j}$ is the position of male and female SA, $x_{best,female}$ and $x_{best,male}$ are the positions of the best SA in female and male groups, respectively, $F_{i,male}$ is the fighting of SA in males, and $F_{i,female}$ is the fighting of SA in females. In addition, c_4 is the SA food saturation coefficient, r_4 and r_4 are random numbers in the range (0, 1).

Step 8. 4. Verifying that the condition is met.

If $c_4\leq c_{4neces}$ – go to Step 8. 3, if $c_4\geq c_{4neces}$ – go to Step 8. 5 – mating.

Step 8. 5. SA mating.

During mating, male and female SA update their positions, according to equations (10) and (11):

$$x_{i,male}(t+1)=x_{i,m}(t)\pm c_5\times$$
$$\times M_{i,male}r_6\times\left(FQx_{i,female}-x_{i,male}(t)\right),$$

$$M_{i,male}=\exp\left(\frac{-f_{i,female}}{f_{i,male}}\right), \qquad (11)$$

$$x_{i,female}(t+1)=x_{i,f}(t)\pm c_5\times$$
$$\times M_{i,female}r_7\left(FQ\,x_{i,male}-x_{i,female}(t+1)\right),$$

$$M_{i,female}=\exp\left(\frac{-f_{i,male}}{f_{i,female}}\right), \qquad (12)$$

where $x_{i,m}$ and $x_{i,f}$ are the positions of the i-th male and female SA, $M_{i,male}$ and $M_{i,female}$ are the mating abilities of the male and female SA, c_5 is the fertility rate of a new SA, r_6 and r_7 are random numbers in the range (0, 1).

Step 8. 6. Verifying that the condition is met.

If $c_5 \leq c_{5neces}$ – go to Step 8. 5, if $c_5 \geq c_{5neces}$ – go to Step 8. 7 – replacement of SA in the population.

Step 8. 7. Replacement of SA in the population.

In this step, SA that do not meet the SA fertility requirements are replaced, according to expressions (13), (14):

$$x_{w,male} = Lb + r_8 (Ub - Lb), \quad (13)$$

$$x_{w,female} = Lb + r_8 (Ub - Lb), \quad (14)$$

where $x_{w,\ male}$ is the worst male SA, while $x_{w,\ female}$ is the worst female SA, r_8 is a random number in the range (0,1).

Step 9. Checking the stop criterion.

The algorithm terminates if the maximum number of iterations is completed. Otherwise, the behavior of generating new locations and checking conditions is repeated.

Step 10. Training SA knowledge bases.

This study uses the training method based on evolving artificial neural networks developed in [2] for training the knowledge bases of each SA. The method is used to change the movement nature of each SA, for more accurate analysis results in the future.

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

In order to prevent looping of calculations on Steps 1–10 of this method and increase the calculation efficiency, the system load is additionally determined. When the specified 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 [31].

The end of the algorithm.

5. 2. Example of using the proposed method in analyzing the operational group of troops (forces)

A method for assessing the state of dynamic objects using a population algorithm is proposed. To determine the effectiveness of the proposed method, it was simulated to solve the problem of determining the composition of the operational group of troops (forces) and elements of its operational structure.

The effectiveness of the method for assessing the state of dynamic objects using a population algorithm is compared using the functions shown in Tables 1, 2.

From the analysis of Tables 1, 2, it can be concluded that the proposed method ensures stable operation of the algorithm for the main test functions of unimodal and multimodal type.

Table 1

Unimodal functions and their parameters used for the simulation

Function	Range	$f_{\min}$	Dim
$f1(x) = \sum_{i=2}^{n} x_i^2$	[–300, 300]	0	26
$f2(x) = \sum_{i=1}^{n} \lvert x_i \rvert + \prod_{i=1}^{n} \lvert x_i \rvert$		0	26
$f3(x) = \sum_{i=1}^{n} \left(\sum_{j=1}^{i} x_j \right)^2$		0	26
$f4(x) = \max_i \{\lvert x_i \rvert, 1 \leq i \leq n\}$		0	26
$f5(x) = \sum_{i=1}^{n-1} \left[100 (x_{i+1} - x_i^2)^2 + (x_i - 1^2) \right]$		0	26
$f6(x) = \sum_{i=1}^{n} ([x_i + 0.5])^2$		0	26
$f7(x) = \sum_{i=1}^{n} i x_i^4 + rand[0,1)$		0	26
$f8 = \sum_{i=1}^{d} -x_i \sin\left(\sqrt{\lvert x_i \rvert}\right)$		$-306{,}194 \times \dim$	26

Table 2

Multimodal functions and their parameters used for the simulation

Function	Range	$f_{\min}$	Dim
$f9 = \sum_{i=1}^{d} \left[x_i^2 - 10 \cos(2\pi x_i) + 10 \right]$	[–300, 300]	0	26
$f10(x) = \sum_{i=1}^{n} -20 \exp\left(-0.2 \sqrt{\frac{1}{n} \sum_{i=1}^{n} x_i^2} \right) - \exp\left(\frac{1}{n} \sum_{i=1}^{n} \cos(2\pi x_i) \right) + 20 + e$		0	26
$f11(x) = \frac{1}{4} \times 10^{-3} \sum_{i=1}^{n} x_i^2 - \prod_{i=1}^{n} \cos\left(\frac{x_i}{\sqrt{i}} + 1 \right)$		0	26
$f12(x) = \frac{\pi}{n} \left\{ \begin{array}{l} 10 \sin(\pi y_1) + \\ + \sum_{i=1}^{n-1} (y_i - 1)^2 \left[1 + 10 \sin^2(\pi y_{i+1}) \right] + (y_n - 1)^2 \end{array} \right\} + \sum_{i=1}^{n} u(x_i, 10, 100, 4);$ $y_i = \frac{x_i + 5}{4} u(x_i, a, k, m) = \left\{ \begin{array}{ll} k(x_i - a)^m, & Eger\ x_i > a; \\ k(-x_i - a)^m, & Eger\ x_i < a; \\ 0, & diger \end{array} \right\}$		0	26

In order to obtain a comparative estimate by the criterion of information processing efficiency at a given assessment reliability, a comparative assessment of the proposed method with swarm algorithms was carried out (Tables 3, 4).

Table 3

Comparative assessment of the proposed method with swarm algorithms by the criterion of information processing efficiency

Test function number	Grey wolf optimization algorithm	Walrus optimization algorithm	Particle swarm optimization algorithm	Proposed method
F1	3.56E-195	2.40E-195	1.10E-195	2.24E-196
F2	2.57E-97	2.45E-98	2.07E-98	2.01E-98
F3	2.54E-128	1.14E-127	1.63E-123	1.51E-127
F4	7.00E-87	7.01E-87	4.24E-87	5.38E-87
F5	1.57E+01	1.52E+01	1.50E+01	1.57E+01
F6	2.61E-02	1.31E-03	1.45E-03	2.25E-03
F7	1.03E-04	9.17E-05	1.09E-04	1.04E-04
F8	–1.25E+04	–1.26E+04	–1.26E+04	–1.25E+04
F9	4.73E-01	1.28E-01	9.09E-02	5.62E-01
F10	4.09E-15	3.97E-15	3.97E-15	3.97E-15
F11	8.10E-03	3.42E-03	1.21E-03	2.73E-03
F12	2.09E-02	3.56E-02	2.15E-02	2.1E-02

Table 4

Comparative assessment of the proposed method with swarm algorithms by the criterion of information processing efficiency

Test function number	Monkey algorithm	Hawk optimization algorithm	Bat algorithm	Coot optimization algorithm	Proposed method
F1	5.78E-194	2.16E-196	1.40E-195	3.67E-196	2.12E-196
F2	1.26E-98	1.37E-98	3.45E-98	2.28E-98	1.01E-98
F3	2.22E-128	1.05E-124	5.98E-125	1.06E-125	1.00E-127
F4	1.23E-86	5.58E-87	2.23E-87	6.91E-87	2.31E-87
F5	1.52E+01	1.43E+01	1.69E+01	1.46E+01	1.30E+01
F6	2.00E-02	1.91E-03	5.65E-03	2.22E-03	1.10E-03
F7	9.53E-05	1.21E-04	1.14E-04	1.04E-04	2.15E-05
F8	–1.26E+04	–1.26E+04	–1.25E+04	–1.25E+04	–1.26E+04
F9	9.05E-01	5.98E-01	1.15E+00	4.62E-01	2.70E-01
F10	4.09E-15	3.85E-15	3.85E-15	3.97E-15	3.61E-15
F11	1.13E-02	1.34E-03	4.22E-03	3.71E-03	1.50E-03
F12	3.67E-04	9.56E-03	4.30E-03	9.35E-03	3.22E-02

As can be seen from Tables 1–4, a 13–19 % increase in decision-making efficiency is achieved by using additional procedures.

It can be seen that the method for assessing the state of dynamic objects using a population algorithm is able to converge to the true value. This is achieved for most unimodal and multimodal functions with the fastest convergence rate and highest accuracy. Whereas the convergence results of the monkey algorithm and the grey wolf optimization algorithm are not satisfactory for multimodal functions.

6. Discussion of the results of developing a method for assessing the state of dynamic objects using a population algorithm

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

– the initial setting of SA is carried out taking into account the type of uncertainty (1) using appropriate correction factors, compared to [9, 14, 21];

– the initial velocity of each SA is taken into account (3), which allows prioritizing the search in the appropriate direction, compared to [9–15];

– the fitness of the SA search area is determined, which reduces the solution search time (Step 5), compared to [14, 16, 17];

– universality of SA food location search strategies, which allows classifying the type of data to be processed (Step 6), compared to [14, 16, 17];

– the possibility of adjusting the SA velocity by adjusting the ambient temperature (4), which allows prioritizing solution search in a certain plane, compared to [11, 13, 17–19];

– the possibility to explore the solution spaces of functions described by non-typical functions using exploitation mode procedures (Step 8), compared to [9, 12–18];

– the possibility to flexibly adjust the transition from the SA fighting mode to the mating mode using the food saturation coefficient (12), compared to [9–23];

– the possibility to replace individuals unsuitable for search using the SA fertility rate (Step 8. 7), compared to [9, 12, 13–18];

– the possibility of simultaneous search for a solution in different directions (Steps 1–11, Tables 1–4);

– the possibility of deep learning of SA knowledge bases (Step 10), compared to [9–23];

– the possibility of calculating the necessary amount of computing resources, which must be involved if calculations cannot be performed with available computing resources (Step 11), compared to [9–23].

The disadvantages of the proposed method include:

– the loss of informativeness when assessing the state of complex dynamic objects due to the construction of the membership function;

– lower accuracy of assessment by a single parameter for the state of complex dynamic objects;

– the loss of credibility of the obtained solutions when searching for a solution in several directions simultaneously;

– lower assessment accuracy compared to other assessment methods.

This method will allow you:

– to assess the state of complex dynamic objects;

– to determine effective measures to improve the management of complex dynamic objects;

– to increase the speed of assessing the state of complex dynamic objects;

– 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 a complex dynamic object, the need to take into account the delay time for collecting and communicating information from intelligence sources.

The proposed approach should be used to solve problems of assessing 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, 21–23].

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

7. Conclusions

1. The algorithm for implementing the method was defined, using additional and improved procedures, which allows you:

– to determine the initial position of SA, taking into account the type of uncertainty using a correction factor for the degree of awareness of the state of the initial situation in relation to the object of analysis;

– to take into account the initial velocity of each SA, which allows studying complex functions;

– to ensure the universality of SA food location search strategies, which allows classifying the type of data to be processed;

– to adjust the SA velocity by adjusting the ambient temperature, which allows prioritizing solution search in a certain plane;

– to explore the solution spaces of functions described by non-typical functions, using exploitation mode procedures;

– to flexibly adjust the transition from the SA fighting mode to the mating mode using the food saturation coefficient;

– to replace individuals unsuitable for search using the SA fertility rate;

– to conduct a simultaneous search for a solution in different directions, by changing the ambient temperature and adjusting the food saturation coefficient;

– to conduct deep learning of SA knowledge bases, using the proposed training method.

2. An example of using the proposed method when solving the problem of determining the composition of the operational group of troops (forces) and elements of its operational structure is given. This example showed a 13–19 % increase in data processing efficiency by using additional improved procedures.

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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The study was conducted without financial support.

Data availability

The manuscript has associated data in the data repository.

Use of artificial intelligence

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

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