UDC 004.81
DOI: 10.15587/1729-4061.2024.298205

DEVELOPMENT OF A SOLUTION SEARCH METHOD USING A COMBINED BIO-INSPIRED ALGORITHM

Khudhair Abed Thamer
PhD, Assosiate Professor, Head of Department
Department of Computer Engineering
Al-Maarif University College
Karrada str., 3, Karbala, Iraq, 31001

Oleg Sova
Correspondin author
Doctor of Technical Sciences, Professor, Deputy Head of Scientific Center
Scientific Center for Building Integrity and Preventing Corruption in the Security and Defense Sector
The National University of Defense of Ukraine
Povitroflotskyi ave., 28, Kyiv, Ukraine, 03049
E-mail: soy135@ukr.net

Olena Shaposhnikova
PhD, Associate Professor
Department of Computer Systems
Kharkiv National Automobile and Highway University
Yaroslava Mudroho str., 25, Kharkiv, Ukraine, 61002

Volodymyr Yashchenok
PhD, Associate Professor, Head of Department
Department of Design and Durability of Aircraft and Engines
Ivan Kozhedub Kharkiv National Air Force University
Sumska str., 77/79, Kharkiv, Ukraine, 61023

Iraida Stanovska
Doctor of Technical Sciences, Professor
Department of Advanced Mathematics and Systems Modelling
Odesa Polytechnic National University
Shevchenka ave., 1, Odesa, Ukraine, 65044

Serhii Shostak
PhD, Associate Professor
Department of Higher and Applied Mathematics
National University of Life and Environmental Sciences of Ukraine
Heroiv Oborony str., 15, Kyiv, Ukraine, 03041

Oleksandr Rudenko
PhD, Associate Professor
Department of Computer and Information Technologies and Systems
National University «Yuri Kondratyuk Poltava Polytechnic»
Pershotravnevyi ave., 24, Poltava, Ukraine, 36011

Serhii Petruk
PhD, Senior Researcher, Deputy Head of Scientifically-Research Department
Central Scientifically-Research Institute of Armaments and Military Equipment of the Armed Forces of Ukraine
Povitrofloski ave., 28, Kyiv, Ukraine, 03049

Olha Matsyi
PhD
Department of Artificial Intelligence and Software
V. N. Karazin Kharkiv National University
Svobody sq., 4, Kharkiv, Ukraine, 61022

Svitlana Kashkevich
Seniour Lecturer
Department of Computerized Control Systems
National Aviation University
Lubomyra Huzara ave., 1, Kyiv, Ukraine, 03058

The object of the study is decision support systems. The subject of the study is the decision-making process in management problems using a combined bio-inspired algorithm, consisting of:

– the improved wolf optimization algorithm and the improved sparrow search algorithm – for solving optimization problems regarding the object state;

– an advanced genetic algorithm – for selecting the best agents in flocks;

– an advanced training method – for deep training of agents to improve the optimization characteristics of agents.

A solution search method using an improved bio-inspired algorithm is proposed. The method has the following sequence of actions:

– input of initial data;

– initialization of the search for a flock of sparrows and its parameters;

– ranking and selection of sparrow agents using an advanced genetic algorithm;

– updating the sparrow location for the discoverer;

– checking the conditions for updating the position of sparrows;

– initialization of additional search parameters;

– running the gray wolf optimization algorithm;

– training agents' knowledge bases;

– determining the amount of necessary computing resources of the intelligent decision support system.

The originality of the proposed method lies in the combined use of bio-inspired algorithms, setting agents taking into account the uncertainty of the initial data, advanced global and local search procedures. The method makes it possible to increase the efficiency of data processing at the level of 19 % using additional improved procedures. The proposed method should be used to solve the problems of evaluating complex and dynamic processes in the interest of solving national security problems

Keywords: optimization, complex technical systems, sparrow search algorithm, wolf optimization algorithm

Received date 15.11.2023
Accepted date 30.01.2024
Published date 28.02.2024

How to Cite: *Tamer, K. A., Sova, O., Shaposhnikova, O., Yashchenok, V., Stanovska, I., Shostak, S., Rudenko, O., Petruk, S., Matsyi, O., Kashkevich, S. (2024). Development of a solution search method using a combined bio-inspired algorithm. Eastern-European Journal of Enterprise Technologies, 1 (4 (127)), 6–13. doi: https://doi.org/10.15587/1729-4061.2024.298205*

1. Introduction

Optimization is a complex process of identifying a set of solutions for a variety of functions. Many calculation problems today relate specifically to optimization problems [1–3]. While solving optimization problems, the solution variables are determined in such a way that the system works at its best point (mode) according to the optimization criterion determined.

Optimization problems are discontinuous, nondifferentiable and also multimodal. Thus, it is impractical to use classical gradient deterministic algorithms [4–6] to solve optimization problems.

To overcome the shortcomings of classical optimization algorithms, a significant number of stochastic optimization algorithms, known as metaheuristic algorithms, have been created [7–9].

One of the types of stochastic optimization algorithms are swarm intelligence algorithms (swarm algorithms). Swarm intelligence algorithms are based on swarm movement and simulate interactions between the swarm and its environment to improve knowledge of the environment, such as new food sources. 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 [10–14].

However, most of the basic metaheuristic algorithms mentioned above are not able to balance exploration and exploitation, resulting in poor performance for real-world complex optimization problems.

This fact prompts the implementation of various strategies to improve the convergence rate and accuracy of the basic metaheuristic algorithms. One of the options for increasing the efficiency of decision-making using metaheuristic algorithms is to combine them, adding the basic procedures of one algorithm to another.

The use of metaheuristic algorithms for finding solutions regarding objects state allows you to:

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

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

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

– make a scenario analysis for various destructive effects;

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

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

At the same time, the use of the above swarm algorithms in the canonical form does not allow obtaining 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 objects state 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 a combined bio-inspired algorithm, which would increase the efficiency of decisions made regarding the management of 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] disclosed 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] carried out an analysis of the main approaches to cognitive modeling. Cognitive analysis allows: to investigate problems with fuzzy factors and relationships; to 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. The specified 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 impossibility of taking into account different 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 mentioned 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 should be attributed to the fact that the search for a solution is not unidirectional.

The work [15] developed a method of fuzzy hierarchical assessment of library service quality. The specified method allows you 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 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 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 you to process data from various sources. The disadvantages of this 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: the 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 provided 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 research 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. 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 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, 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.

The work [23] considered the gray wolf optimization algorithm. The algorithm is based on search and optimization by simulating the tracking, encirclement and hunting process, which is based on the predatory behavior of the gray wolf population. Gray wolves hunt in packs and cooperate to catch prey.

An analysis of the works [9–23] showed that the common shortcomings of the above 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 to be solved in the study is to increase the efficiency of solving the problems of analysis and multidimensional forecasting of the objects state while ensuring the given reliability.

3. The aim and objectives of the study

The aim of the study is to develop a solution search method using a combined bio-inspired algorithm. This will increase 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 give an example of using the method in analyzing the operational situation of a group of troops (forces).

4. Materials and methods

The problem solved in the study is to increase the efficiency of decision-making in management problems while ensuring the given reliability, regardless of the hierarchical nature of the object. The object of the study is decision support systems. The subject of the study is the decision-making process in management problems using a combined bio-inspired algorithm, an improved genetic algorithm and evolving artificial neural networks.

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

The simulation of the proposed method was carried out 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 operational group of troops (forces) was considered as an object of assessment and management. The operational group of troops (forces) is 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 under current regulations.

The study is based on the gray wolf optimization algorithms and sparrow search algorithm for finding a solution regarding the object state. These optimization methods have shown stable performance for various types of functions to be solved. Evolving artificial neural networks are used to train agents. When solving optimization problems, there is an urgent problem of accumulating solution errors. Numerous training methods are used to solve this problem. The most common is the reverse descent method. However, training methods usually use only learning of synaptic weights, not including the adjustment of the architecture and type and parameters of the membership function in the learning process.

An advanced genetic algorithm is used to select the best agents. The genetic algorithm is the most common method of selecting the best individuals for metaheuristic algorithms. However, its use in the canonical form is limited by:

– the complexity of formalizing the initial problem at the level of genes and chromosomes, as well as selection, crossover and mutation operators;

– a priori uncertainty of external parameters of the algorithm;

– a relatively large amount of calculations (each individual in the population is, in fact, a separate course of problem optimization);

– some individuals in the population can quickly occupy the local optimum and drag the entire population with them (they will be duplicated by the selection operator many times, and the population will consist mainly of their descendants), as a result of others, the global optimum may not be detected, etc.

These research methods were chosen based on the literature review [1–23]. The given methods are not used in the canonical form due to the identified shortcomings.

5. Development of a solution search method using a combined bio-inspired algorithm

5. 1. Development of an algorithm for the solution search method using a combined bio-inspired algorithm

The essence of improving the method is that in this method, calculations are performed in parallel using two advanced metaheuristic algorithms: an advanced wolf optimization algorithm and an advanced sparrow search algorithm. After performing parallel calculations, the results are checked among themselves and the best solution is chosen. This combination allows you to avoid the local optimum while improving convergence rate and accuracy.

The proposed advanced procedure is based on the advanced sparrow search algorithm and has three types of individual behavior: discoverer, follower and explorer. That is, sparrows update their location according to their own rules.

The discoverer searches for food and directs the rest of the flock [23]. Having identified the location of the discoverer, they search for food around that place. The location of the follower is updated according to equation (1) [23]:

$$X_i^{t+1} = \begin{Bmatrix} Q \cdot \exp\left(\dfrac{X_{worst} - X_i^t}{i^2}\right), i > \dfrac{n}{2} \\ X_{best}^{t+1} + \left|X_i^t - X_{best}^{t+1}\right| \cdot A \cdot L, i \le \dfrac{n}{2} \end{Bmatrix}, \quad (1)$$

where X_{best} is the best individual position, meaning the best current position; X_{worst} is the current worst global location; A – $d \times d_{matrix}$ containing each factor randomly assigned 1 or –1; n is the number of sparrows; when $i<n/2$, it means that the i-th participant searches for food near the best location, if $i>n/2$, it means that the i-th participant needs to fly to another location for food.

When predators attack, they send signals that make sparrows flee to safety [23]. The mutation strategy in the sparrow search algorithm directly affects the accuracy and rate of convergence. The sparrow search algorithm works better while solving complex optimization problems, but has disadvantages related to reduced flock diversity and insufficient convergence accuracy. It may have a chance to get into the local optimum without reaching the optimal solution to the problems.

The advanced sparrow search algorithm consists of the following sequence of actions:

Step 1. 1. Initialization of the search for a flock of sparrows and its parameters (n is the total number of sparrows, $T_{\max}$ is the maximum iteration, d is the number of variables). While initializing the search, the type of uncertainty about the state of the analysis object is taken into account in the following gradation: complete uncertainty, partial uncertainty and complete awareness.

Step 1. 2. Ranking and selection of sparrow agents using an advanced genetic algorithm. While ($t<T_{\max}$), sparrows are ranked according to their physical form values using the genetic algorithm developed in [24]. The current best value, which is the minimum fitness value and the current worst value, which is the maximum fitness value, are found.

Step 1. 3. Updating the sparrow location for the discoverer using equation (2):

$$X_i^{t+1} = \begin{Bmatrix} X_i^t \times \exp\left(\dfrac{-i}{\alpha \cdot T_{\max}}\right), R_2 < STh \\ X_i^t + Q \cdot L, R_2 \ge X_i^t \end{Bmatrix} \quad (2)$$

if:

$$X = \left[X_1, X_2, X_3, \dots X_i \dots X_n\right]^T, \; X_i = \left[X_{i,1}, X_{i,2}, X_{i,3} \; \dots X_{i,d}\right],$$

where t is the current iteration; X_i^t is the location of the i-th sparrow at iteration t; α is a random number from 0 to 1; R_2 is the alarm value, which is $0<R_2<1$; the safety threshold is STh and it is estimated as $0.5<STh<1$; L is $1\times d_{matrix}$; d_{matrix} is a matrix containing 1 in each factor; Q is a random value with zero mean and unit variance corresponding to a normal distribution. If $R_2<STh$ – the foraging environment is safe, while $R_2>STh$ means that some individuals have already encountered dangerous animals and that all sparrows should flee to other safe places as soon as possible.

Step 1. 4. Checking the conditions for updating the position of sparrows. If the number of individuals in the current iteration is less than or equal to half of the sparrow population, then the follower's position is updated.

Step 1. 5. Initialization of additional search parameters. Initialization of the a, A and C values.

Step 1. 6. Running the gray wolf optimization algorithm.

Step 1. 6. 1. Input of initial data.

At this step, the initial data available in the system are entered to solve the optimization problem.

Step 1. 6. 2. Setting gray wolves to initial positions taking into account uncertainty.

A pack of gray wolves is created as a set of Euclidean vectors distributed over a set of valid argument values, taking into account the degree χ of awareness of the object state. The awareness is divided into: complete uncertainty – setting randomly, partial uncertainty – setting taking into account the correction factor of the position of gray wolves $\chi=0.01\div0.99$.

Step 1. 6. 3. Determining leaders in the pack of gray wolves.

In the classical gray wolf optimization algorithm, the «wolf» with the best objective function value at this iteration is the leader. If at the next iteration another «individual» is found with a better value of the objective function than the leader, then, accordingly, the pack «finds» a new leader. In this procedure, it is proposed to determine the number of leaders that will maximize the search efficiency with limitations on the available computing resources.

Step 1. 6. 4. Search for prey by other wolves in the pack.

Other wolves explore the area for prey. Moreover, the function $f(x_i)$ characterizes how strongly the victim's smell is felt by the i-th «wolf». Then the value of G_{best} characterizes how strongly the victim's smell is felt by the pack leader.

Step 1. 6. 5. Changing the leader in the pack.

If $f(x_i) > G_{Best}$, then the i-th wolf is closer to the victim than the pack leader, so the i-th wolf becomes the leader at this stage $f(x_i) = G_{Best}$. If $f(x_i) < G_{Best}$, then the «wolf» moves in space with some predetermined step.

The pack leader(s) «inform» the other «wolves» in the pack about their location as the closest point to the victim now, so that they move in its direction.

Step 1. 6. 6. Approaching the pack leaders.

At this stage, the «leader» is considered almost the same as the victim – the target to be approached. Then the «wolves» of the pack move in the direction of the leader with a predetermined step *step*, and the coordinate d of the i-th «wolf» on the $(k+1)$-th iteration is calculated by the formula:

$$x_{iD}^{(k+1)} = x_{iD}^{(k)} + step\frac{G_{Best}^{(k)} - x_{iD}^{(k)}}{\left\| G_{Best}^{(k)} - x_{iD}^{(k)} \right\|}. \quad (3)$$

It can be seen from formula (3) and the description of the algorithm that in the «wolf pack» search method, only the coordinates of «wolves» are updated without taking into account the speed of their movement in space. Four parameters must be selected for the swarm algorithm (learning coefficients, inertial weight, population size). However, for the wolf optimization method, it is enough to select only two parameters – population size N and Step *step*, from which the «wolves» move in the direction of the leader and victim.

It should be noted that formula (3) cannot be applied to the traveling salesman problem in a standard way. In this case, only its main principle is taken, namely: other «wolves» must be sufficiently «similar» to their leader(s), which in the current iteration is closer to the victim (by the value of the objective function). At this stage, the advanced genetic algorithm proposed by the authors in [24] is used.

All subsequent iterations are performed in a similar way: the best «wolf» is found and a new population is generated based on it.

End of the algorithm.

Comparison with the values obtained from the sparrow search algorithm.

Step 1. 7. Updating the follower's position using equation (2). Then updating the explorer's location using equation (4):

$$X_i^{t+1} = \begin{Bmatrix} X_{best}^{t} + \beta_e \left| X_i^t - X_{best}^t \right|, f_i > f_b \\ X_{best}^{t+1} + K\dfrac{\left| X_i^t - X_{best}^{t+1} \right|}{(f_i - f_\omega) + \varepsilon}, f_i = f_b \end{Bmatrix}, \quad (4)$$

where β_e is the random step length control factor, which has a variance of 1 and an average value of 0 and corresponds to a normal distribution; K is a random number from –1 to 1; f_i is the fitness value of individual i; f_b is the current best physical fitness; f_ω is the worst physical fitness.

Step 1. 8. If the probability factor is a positive value, the matching value is calculated and its value is compared with the best matching solution to get the minimum optimal value.

Step 2. Learning agents' 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 agent. It is used to change the movement pattern of each agent, for more accurate analysis results in the future.

Step 3. Determining the amount of necessary computing resources of the intelligent decision support system.

In order to prevent looping of calculations on Steps 1–2 of this method and increase the efficiency of calculations, the system load is additionally determined. When 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 [25].

End of the algorithm.

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

A solution search method using a combined bio-inspired algorithm is proposed. To assess the effectiveness of the developed method, its comparative evaluation was performed based on the results of research presented in [3–31].

Simulation of the solution search processing method was carried out in accordance with Steps 1–3. The problem 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 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;

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

The comparison was made by the criterion of information processing efficiency for various functions, namely: unimodal, highly multimodal and fixed multimodal functions. The comparison results are given in Table 1.

An analysis of the data given in Table 1 shows that the proposed method demonstrates stable efficiency by the criterion of information processing efficiency for all types of functions that describe the analysis object. We will analyze the efficiency of the proposed method by the criterion of solution accuracy for various algorithms. The results of a comparative analysis of the algorithms by the criterion of the accuracy of the obtained solutions are shown in Table 2.

An analysis of the simulation results given in Tables 1, 2 shows that the improved technique provides an average of 19 % less compared to other algorithms.

Table 1

Comparison of the efficiency of algorithms by the criterion of information processing efficiency

Name of the optimization algorithm	Function type		
	Unimodal	Highly multimodal	Fixed multimodal functions
Walrus optimization algorithm	1.01E–24	6.25E–18	1.44E–34
Particle swarm optimization algorithm	1.01E–24	2.29E–12	2.09E–26
Flying squirrel search optimization algorithm	1.01E–24	5.98E–20	1.44E–34
Artificial bee colony algorithm	1.01E–24	0.044967	1.13E–05
Ant colony optimization algorithm	1.01E–24	3.17E–18	1.44E–34
Proposed method	1.01E–24	1.17E–16	1.44E–34
Monkey search algorithm	1.01E–24	2.37E–13	1.44E–34
Bat algorithm	1.01E–24	1.97E–21	3.22E–13
Locust swarm optimization algorithm	1.01E–24	1.97E–21	5.35E–17
Genetic algorithm	1.01E–24	1.49E–11	1.44E–34

Table 2

Comparison of the obtained solutions by the criterion of the accuracy of the obtained solutions

Name of the optimization algorithm	Best value	Average value	Worst value	Standard deviation	Median value
Walrus optimization algorithm	0.012672	0.012701	0.012706	0.001106	0.012700
Particle swarm optimization algorithm	0.012722	0.012754	0.012766	0.007391	0.012744
Flying squirrel search optimization algorithm	0.01317	0.013848	0.015774	0.006119	0.013727
Artificial bee colony algorithm	0.012782	0.012799	0.01283	0.00567	0.012802
Ant colony optimization algorithm	0.012786	0.012812	0.012836	0.004191	0.012815
Proposed method	0.012305	0.014151	0.013023	0.002103	0.013112
Monkey search algorithm	0.012926	0.014594	0.018	0.001636	0.014147
Bat algorithm	0.012818	0.012956	0.013116	0.007828	0.012961
Locust swarm optimization algorithm	0.012983	0.01356	0.01434	0.000289	0.013488
Genetic algorithm	0.013147	0.014162	0.016398	0.002092	0.013119

6. Discussion of the results of developing a solution search method using a combined bio-inspired algorithm

The advantages of the proposed method are the following:

– in the initial setting of agents on the search plane of the object to be analyzed, the type of uncertainty about the state of the specified analysis object is taken into account (Steps 1. 1 and 1. 6. 2), compared to [9, 11, 14, 18];

– the availability of variable search (exploration) strategies for determining fitness, which reduces the solution search time (Step 1, 2), compared to [9–16];

– taking into account the presence of predators during exploration, which allows avoiding local optima (Step 1. 3), compared to [14–23];

– the universality of solving the problem of analyzing the objects state by agents due to the hierarchical nature of their description (Steps 1–3), compared to [18–24];

– the possibility of quick search for solutions due to the simultaneous search for a solution by several agents on the search plane (Steps 1–3, Tables 1, 2), compared to [19–24, 26–28];

– the adequacy of the obtained results (Steps 1–3), compared to [8, 15, 23, 28, 31];

– the possibility of mutual verification of the obtained results due to the combined use of several algorithms (Steps 1, 2), compared to [5, 8, 19, 24, 28, 31];

– the possibility of deep learning of agents' knowledge bases (Step 2), compared to [3, 5, 6, 12, 14, 15, 17, 24, 25, 28, 31];

– the possibility of additional involvement of computing resources of the object state analysis system (Step 3), compared to [9–24, 26–31].

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 parameter for assessing 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;

– greater computational complexity compared to using a single optimization algorithm;

– lower assessment accuracy compared to other assessment methods.

This method will allow you:

– to assess the state of the heterogeneous analysis object;

– to determine effective measures to improve management efficiency;

– to increase the speed of assessing the state of the 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 analysis object state, 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 the 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 was determined, due to additional and improved procedures, which allows you:

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

– to implement adaptive strategies for finding food sources;

– combined use of intelligence strategies due to the joint use of two optimization algorithms;

– to implement the possibility of mutual verification of optimization results;

– to take into account the presence of a predator while choosing food sources;

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

– to take into account the search priority of agents;

– to carry out the initial setting of agents, taking into account the type of uncertainty;

– to carry out accurate training of agents;

– to determine the best individuals of agents using a genetic algorithm;

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

– 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 be used 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 in assessing and forecasting the state of the operational situation of a group of troops (forces) is given. The specified example showed a 19 % increase in the efficiency of data processing due to the combined use of several optimization algorithms. Also, the effectiveness of the algorithm is achieved by using additional advanced procedures, the possibility of checking the results of a separate optimization algorithm, adding correction factors for data uncertainty, selecting and training agents.

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.

Financing

The research 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.

References

1. Bashkyrov, O. M., Kostyna, O. M., Shyshatskyi, A. V. (2015). Rozvytok intehrovanykh system zviazku ta peredachi danykh dlia potreb Zbroinykh Syl. Ozbroiennia ta viyskova tekhnika, 1, 35–39. Available at: http://nbuv.gov.ua/UJRN/ovt_2015_1_7
2. Dudnyk, V., Sinenko, Y., Matsyk, M., Demchenko, Y., Zhyvotovskyi, R., Repilo, I. et al. (2020). Development of a method for training artificial neural networks for intelligent decision support systems. Eastern-European Journal of Enterprise Technologies, 3 (2 (105)), 37–47. https://doi.org/10.15587/1729-4061.2020.203301
3. Sova, O., Shyshatskyi, A., Salnikova, O., Zhuk, O., Trotsko, O., Hrokholskyi, Y. (2021). Development of a method for assessment and forecasting of the radio electronic environment. EUREKA: Physics and Engineering, 4, 30–40. https://doi.org/10.21303/2461-4262.2021.001940
4. Pievtsov, H., Turinskyi, O., Zhyvotovskyi, R., Sova, O., Zvieriev, O., Lanetskii, B., Shyshatskyi, A. (2020). Development of an advanced method of finding solutions for neuro-fuzzy expert systems of analysis of the radioelectronic situation. EUREKA: Physics and Engineering, 4, 78–89. https://doi.org/10.21303/2461-4262.2020.001353
5. Zuiev, P., Zhyvotovskyi, R., Zvieriev, O., Hatsenko, S., Kuprii, V., Nakonechnyi, O. et al. (2020). Development of complex methodology of processing heterogeneous data in intelligent decision support systems. Eastern-European Journal of Enterprise Technologies, 4 (9 (106)), 14–23. https://doi.org/10.15587/1729-4061.2020.208554
6. Shyshatskyi, A. (2020). Complex Methods of Processing Different Data in Intellectual Systems for Decision Support System. International Journal of Advanced Trends in Computer Science and Engineering, 9 (4), 5583–5590. https://doi.org/10.30534/ijatcse/2020/206942020
7. Yeromina, N., Kurban, V., Mykus, S., Peredrii, O., Voloshchenko, O., Kosenko, V. et al. (2021). The Creation of the Database for Mobile Robots Navigation under the Conditions of Flexible Change of Flight Assignment. International Journal of Emerging Technology and Advanced Engineering, 11 (5), 37–44. https://doi.org/10.46338/ijetae0521_05
8. Rotshteyn, A. P. (1999). Intellektual'nye tekhnologii identifikatsii: nechetkie mnozhestva, geneticheskie algoritmy, neyronnye seti. Vinnitsa: «UNIVERSUM», 320.

9. Ko, Y.-C., Fujita, H. (2019). An evidential analytics for buried information in big data samples: Case study of semiconductor manufacturing. Information Sciences, 486, 190–203. https://doi.org/10.1016/j.ins.2019.01.079
10. Ramaji, I. J., Memari, A. M. (2018). Interpretation of structural analytical models from the coordination view in building information models. Automation in Construction, 90, 117–133. https://doi.org/10.1016/j.autcon.2018.02.025
11. Pérez-González, C. J., Colebrook, M., Roda-García, J. L., Rosa-Remedios, C. B. (2019). Developing a data analytics platform to support decision making in emergency and security management. Expert Systems with Applications, 120, 167–184. https://doi.org/10.1016/j.eswa.2018.11.023
12. Chen, H. (2018). Evaluation of Personalized Service Level for Library Information Management Based on Fuzzy Analytic Hierarchy Process. Procedia Computer Science, 131, 952–958. https://doi.org/10.1016/j.procs.2018.04.233
13. Chan, H. K., Sun, X., Chung, S.-H. (2019). When should fuzzy analytic hierarchy process be used instead of analytic hierarchy process? Decision Support Systems, 125, 113114. https://doi.org/10.1016/j.dss.2019.113114
14. Osman, A. M. S. (2019). A novel big data analytics framework for smart cities. Future Generation Computer Systems, 91, 620–633. https://doi.org/10.1016/j.future.2018.06.046
15. Gödri, I., Kardos, C., Pfeiffer, A., Váncza, J. (2019). Data analytics-based decision support workflow for high-mix low-volume production systems. CIRP Annals, 68 (1), 471–474. https://doi.org/10.1016/j.cirp.2019.04.001
16. Harding, J. L. (2013). Data quality in the integration and analysis of data from multiple sources: some research challenges. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-2/W1, 59–63. https://doi.org/10.5194/isprsarchives-xl-2-w1-59-2013
17. Kosko, B. (1986). Fuzzy cognitive maps. International Journal of Man-Machine Studies, 24 (1), 65–75. https://doi.org/10.1016/s0020-7373(86)80040-2
18. Koval, M., Sova, O., Shyshatskyi, A., Artabaiev, Y., Garashchuk, N., Yivzhenko, Y. et al. (2022). Improving the method for increasing the efficiency of decision-making based on bio-inspired algorithms. Eastern-European Journal of Enterprise Technologies, 6 (4 (120)), 6–13. https://doi.org/10.15587/1729-4061.2022.268621
19. Maccarone, A. D., Brzorad, J. N., Stone, H. M. (2008). Characteristics and Energetics of Great Egret and Snowy Egret Foraging Flights. Waterbirds, 31 (4), 541–549. https://doi.org/10.1675/1524-4695-31.4.541
20. Koshlan, A., Salnikova, O., Chekhovska, M., Zhyvotovskyi, R., Prokopenko, Y., Hurskyi, T. et al. (2019). Development of an algorithm for complex processing of geospatial data in the special-purpose geoinformation system in conditions of diversity and uncertainty of data. Eastern-European Journal of Enterprise Technologies, 5 (9 (101)), 35–45. https://doi.org/10.15587/1729-4061.2019.180197
21. Mahdi, Q. A., Shyshatskyi, A., Prokopenko, Y., Ivakhnenko, T., Kupriyenko, D., Golian, V. et al. (2021). Development of estimation and forecasting method in intelligent decision support systems. Eastern-European Journal of Enterprise Technologies, 3 (9 (111)), 51–62. https://doi.org/10.15587/1729-4061.2021.232718
22. Gorokhovatsky, V., Stiahlyk, N., Tsarevska, V. (2021). Combination method of accelerated metric data search in image classification problems. Advanced Information Systems, 5 (3), 5–12. https://doi.org/10.20998/2522-9052.2021.3.01
23. Trotsko, O., Protas, N., Odarushchenko, E., Vakulenko, Y., Degtyareva, L., Parzhnytskyi, V. et al. (2023). Improvement of the optimization method based on the wolf flock algorithm. Eastern-European Journal of Enterprise Technologies, 1 (4 (121)), 26–33. https://doi.org/10.15587/1729-4061.2023.273784
24. Meleshko, Y., Drieiev, O., Drieieva, H. (2020). Method of identification bot profiles based on neural networks in recommendation systems. Advanced Information Systems, 4 (2), 24–28. https://doi.org/10.20998/2522-9052.2020.2.05
25. Koval, M., Sova, O., Orlov, O., Shyshatskyi, A., Artabaiev, Y., Shknai, O. et al. (2022). Improvement of complex resource management of special-purpose communication systems. Eastern-European Journal of Enterprise Technologies, 5 (9 (119)), 34–44. https://doi.org/10.15587/1729-4061.2022.266009
26. Kuchuk, N., Merlak, V., Skorodelov, V. (2020). A method of reducing access time to poorly structured data. Advanced Information Systems, 4 (1), 97–102. https://doi.org/10.20998/2522-9052.2020.1.14
27. Shyshatskyi, A., Tiurnikov, M., Suhak, S., Bondar, O., Melnyk, A., Bokhno, T., Lyashenko, A. (2020). Method of assessment of the efficiency of the communication of operational troop grouping system. Advanced Information Systems, 4 (1), 107–112. https://doi.org/10.20998/2522-9052.2020.1.16
28. Raskin, L., Sira, O. (2016). Method of solving fuzzy problems of mathematical programming. Eastern-European Journal of Enterprise Technologies, 5 (4 (83)), 23–28. https://doi.org/10.15587/1729-4061.2016.81292
29. Lytvyn, V., Vysotska, V., Pukach, P., Brodyak, O., Ugryn, D. (2017). Development of a method for determining the keywords in the slavic language texts based on the technology of web mining. Eastern-European Journal of Enterprise Technologies, 2 (2 (86)), 14–23. https://doi.org/10.15587/1729-4061.2017.98750
30. Stepanenko, A., Oliinyk, A., Deineha, L., Zaiko, T. (2018). Development of the method for decomposition of superpositions of unknown pulsed signals using the secondorder adaptive spectral analysis. Eastern-European Journal of Enterprise Technologies, 2 (9 (92)), 48–54. https://doi.org/10.15587/1729-4061.2018.126578
31. Gorbenko, I., Ponomar, V. (2017). Examining a possibility to use and the benefits of post-quantum algorithms dependent on the conditions of their application. Eastern-European Journal of Enterprise Technologies, 2 (9 (86)), 21–32. https://doi.org/10.15587/1729-4061.2017.96321