UDC 004.81
DOI: 10.15587/1729-4061.2023.284315

DEVELOPMENT OF A SOLUTION SEARCH METHOD USING AN IMPROVED FISH SCHOOL ALGORITHM

Aqeel Bahr Tarkhan
PhD, Lecturer of Department
Department of Computer Technologies Engineering
Al-Taff University College
Karrada str., 3, Karbala, Iraq, 31001

Yurii Zhuravskyi
Doctor of Technical Sciences, Senior Researcher, Head of Department
Department of Electrical Engineering and Electronics
Zhytomyr Military Institute named after S. P. Korolyov
Myru ave., 22, Zhytomyr, Ukraine, 10004

Andrii Shyshatskyi
Corresponding author
PhD, Senior Researcher, Associate Professor*
E-mail: ierikon13@gmail.com

Tetiana Pluhina
PhD, Associate Professor
Department of Automation and Computer-Aided Technologies**

Volodymyr Dudnyk
PhD, Associate Professor
Department of Management of Troops (Forces) in Peace
The National Defence University of Ukraine named after Ivan Cherniakhovskyi
Povitroflotski ave., 28, Kyiv, Ukraine, 03049

Ihor Kiris
Senior Researcher
Scientific-Research Institute of Military Intelligence
Yuriy Illenka str., 81, Kyiv, Ukraine, 04050

Oleksii Nalapko
PhD, Senior Researcher
Scientific-Research Laboratory of Automation of Scientific Researches
Central Scientifically-Research Institute of Armaments and Military Equipment of the Armed Forces of Ukraine
Povitrofloski ave., 28, Kyiv, Ukraine, 03049

Nadiia Protas
PhD, Associate Professor
Department of Information Systems and Technologies
Poltava State Agrarian University
Skovorody str., 1/3, Poltava, Ukraine, 36003

Serhii Neronov
Senior Lecturer
Department of Computer Technologies and Mechatronics**

Vitaliy Nechyporuk
PhD, Associate Professor*
*Department of Computerized Management Systems
National Aviation University
Lubomyra Huzara ave., 1, Kyiv, Ukraine, 03058
**Kharkiv National Automobile and Highway University
Yaroslava Mudroho str., 25, Kharkiv, Ukraine, 61002

The object of research is decision support systems. The subject of research is the decision-making process in management problems using the fish school (FSH) algorithm, an advanced genetic algorithm and evolving artificial neural networks.

A solution search method using an improved FSH algorithm is proposed. The study is based on the FSH algorithm for finding a solution on the object state. For training FSH, evolving artificial neural networks are used. The method has the following sequence of actions:

– input of initial data;

– processing of initial data taking into account the degree of uncertainty;

– checking the fitness function of the solution found;

– procedure of feeding fish agents (FA);

– instinctive-collective FA swimming;

– calculation of the center of school gravity;

– collective voluntary FA swimming;

– changing the FA swimming parameters;

– training of FA knowledge bases.

The originality of the proposed method lies in the arrangement of FA taking into account the uncertainty of the initial data, improved global and local search procedures taking into account the degree of noise of data about the state of the analysis object. The peculiarity of the proposed method is the use of an improved FA training procedure. The training procedure consists in learning 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. The use of the method makes it possible to increase the efficiency of data processing at the level of 18–25 % due to the use of additional improved procedures. The proposed method should be used to solve the problems of evaluating complex and dynamic processes in the interest of solving national security problems

Keywords: multi-agent systems, decision support systems, complex processes, fish school algorithm

Received date 02.05.2023
Accepted date 06.07.2023
Published date 31.08.2023

How to Cite: *Tarkhan, A. B., Zhuravskyi, Y., Shyshatskyi, A., Pluhina, T., Dudnyk, V., Kiris, I., Nalapko, O., Protas, N., Neronov, S., Nechyporuk, V. (2023). Development of a solution search method using an improved fish school algorithm. Eastern-European Journal of Enterprise Technologies, 4 (4 (124)), 27–33. doi: https://doi.org/10.15587/1729-4061.2023.284315*

1. Introduction

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

There are a large number of swarm algorithms, for example, particle swarm method, ant algorithm, cuckoo algorithm, bat algorithm, etc. [7, 8]. The use of swarm algorithms to find solutions on the object state allows you to:

– analyze the stability of the heterogeneous object state in the process of combat use (operation);

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

– assess the reach of target situations of object management;

– analyze scenarios under various destructive effects;

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

– model and analyze the dynamics of changes in the state of interdependent parameters of heterogeneous objects.

At the same time, the use of the above swarm algorithms in the canonical form does not allow you to obtain an operational assessment of the object state with a given reliability. This leads to the search for new (improvement of existing) approaches to 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 fish school algorithm, which would allow you to 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 defined. 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, a procedure for modeling scenarios based on fuzzy cognitive maps is described. The approach proposed by the authors does not allow us to take into account the type of uncertainty about the state of the analysis object and does not take into account the noise of the initial data.

The work [11] analyzes the main approaches to cognitive modeling. Cognitive analysis allows us: 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 in one's interests. 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 includes the operations of generating analytical baselines, reducing variables, detecting sparse features and specifying rules. The disadvantages of this method include the impossibility to take into account various decision evaluation strategies, the lack of consideration of the type of uncertainty of initial data.

The work [13] presents the mechanism of transformation of information models of construction objects into their equivalent structural models. This mechanism is designed to automate the necessary conversion, modification and addition operations during such information exchange. The shortcomings of the approach include the impossibility to assess the adequacy and reliability of the information transformation process and make an appropriate correction of the obtained models.

The work [14] developed an analytical web platform to study the geographical and temporal distribution of incidents. The web platform contains several information panels with statistically significant results by territory. The disadvantages of this analytical platform include the impossibility to assess the adequacy and reliability of the information transformation process and high computational complexity. Also, one of the shortcomings of the study is 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. This method allows you to evaluate the quality of libraries based on a set of input parameters. The disadvantages of the method include the impossibility to assess the adequacy and reliability of assessment and, accordingly, determine 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 to check 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 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 to verify the reliability of the obtained estimate.

The work [19] carried out a comparative analysis of existing decision support systems, 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 spheres of their application are 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 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 situation development. In this case, the problem is defined as a discrepancy between the existing state of the system and the required one set by the management entity. The disadvantages of the proposed method include the problem of the local optimum and the inability to conduct a parallel search.

The work [21] presents a cognitive approach to simulation modeling of complex systems. The advantages of this approach, which allows 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, we can note procedures based on harmonic search, fractional derivatives, adaptation of search parameters and, finally, «crazy cats». At the same time, these procedures have shortcomings that worsen the properties of the global extremum search process.

The work [23] investigates the fish school (FSH) algorithm, which is a multi-agent system in which each agent (fish) is located in the solution search area, which is an aquarium. It is known that fish move in schools in search of food. Thus, the algorithm is the movement of a fish school to the point with the largest amount of food, while not going beyond the boundaries of the aquarium – the solution space. Each fish has a weight that characterizes how successful the agent is in the process of searching for food.

The basic FSH is subject to the following rules:

1. Initialization of the population.
2. Individual swimming stage of agents.
3. Feeding stage.
4. Instinctive collective swimming.
5. Calculation of the center of school gravity.
6. Collective voluntary swimming.
7. Changing the swimming parameters.

At the same time, the basic FSH requires a long search for solutions and significant computing costs, which does not allow it to be used in real time.

An analysis of the works [9–23] showed that the common shortcomings of the above-mentioned studies are:

– the lack of possibility 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 when 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 state of objects while ensuring the given reliability. To this end, it is proposed to develop a solution search method using an improved fish school algorithm.

3. The aim and objectives of the study

The aim of the study is to develop a solution search method using an improved fish school algorithm. This will allow us to increase the efficiency of assessment and multidimensional forecasting with a given reliability and development of subsequent management decisions. This will make it possible to develop software for intelligent decision support systems.

To achieve the aim, the following objectives were set:

– to determine the algorithm for implementing the method;

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

4. Materials and methods

The problem that is solved in the study is to increase the efficiency of decision-making in management problems while ensuring the given reliability, regardless of the hierarchy of the object. The object of research is decision support systems. The subject of research is the decision-making process in management problems using the fish school algorithm, advanced genetic algorithm, and evolving artificial neural networks.

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

Modeling 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). 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. An operational group of troops (forces) formed on the basis of an operational command with a standard composition of forces and means according to the wartime state and with a range of responsibility under current regulations.

The study is based on the fish school algorithm to find a solution regarding the object state. For training FSH, evolving artificial neural networks are used.

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

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

The proposed algorithm is an improved fish school algorithm and consists of the following sequence of steps.

Step 1. Input of initial data. At this stage, 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 F_k.

Step 2. Processing of the 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 object to be analyzed 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 with the help of correction factors.

Step 3. Individual swimming stage of agents. For each agent, the search for the best solution is performed in the neighborhood of the given solution. Since it is impossible to define the concept of a solution neighborhood for this type of problem, let's consider this procedure. When choosing a feeding source, the degree of noise about the state of the assessment object is taken into account. The degree of noise is defined as total noise, partial noise and reliability.

Step 3. 1. At the first stage, each column of the decision matrix D is considered. In each column, the elements d_{ik} and d_{ik+1} are interchanged, where i is the column number, k is an odd number.

Step 3. 2. The second stage is similar to the first, with the difference that k is an even number.

Step 4. Checking the fitness function of the solution found. If the fitness function has improved, we consider that movement has occurred. If the FA went outside the aquarium, we consider that there was no movement.

Step 5. FA feeding procedure. At this stage, it is necessary to fix the improvement of the current FA solution with respect to other FA in the school using the genetic algorithm developed in [22]. For this, such a property of FA as its weight is used: $W = \Delta f_i / \max \Delta f_i$, where Δf_i is the value of the improvement in the fitness function for the i-th FA.

Step 6. Instinctive-collective FA swimming. Each FA is affected by the entire population as a whole, and the influence of an individual FA is proportional to its success in the individual swimming stage. After that, the entire population shifts by the size of the migration step, which characterizes the movement of the entire FA school.

To calculate the migration step, it is necessary to consider the process of movement of one FA in the direction of another [24–30]. Let the current solution for this FA be D_1. In order to make a move to the FA that has a solution D_0, it is necessary to sequentially view the columns of the matrix D_0 from left to right. In each column, it is necessary to find out the relative location of the elements d_{ik} and d_{ik+1}, where i is the column number, k is an odd number. If the location of the elements d_{ik} and d_{ik+1} in the matrix D_1 does not coincide with the position D_0, then the places of these elements are exchanged. If one of the elements is zero, then the replacement of the elements in D_1 will be carried out if the modulus of the difference between the number of zeros over the nonzero element in the matrix D_0 and the number of zeros over the nonzero element in the matrix D_1 becomes smaller [31–36]. A move with a given probability α is a move in which the comparison and interchange of the elements d_{ik} and d_{ik+1} in the matrices D_0 and D_1 are carried out with the probability α. To calculate the migration step, it is necessary to make a move with a given probability α for each fish. For this purpose, the sum $Sum = \sum_{1}^{N} \Delta f_i$ is calculated – the sum of improvements in the fitness function for each FA in the population. Then each FA in the school will move to other FA with the probability $\alpha = \Delta f_i / Sum$.

Step 7. Calculation of the center of school gravity. This stage is preparatory for the next stage of the algorithm and consists in calculating a weighted solution regarding the total weight of the entire school. In this case, the calculation of the barycenter is performed as follows: the agents are arranged as the weight decreases; starting with the FA of the smallest weight, a movement with a given probability ρ to the heaviest FA takes place. The result of such a movement is the barycenter. The probability ρ is a controlled parameter.

Step 8. Collective voluntary FA swimming. At this stage of the algorithm, it is determined how the weight of the fish school has changed compared to the previous iteration. If it has increased, then the population has approached the area of the function maximum, therefore it is necessary to narrow the circle of its search, thereby revealing the intensification properties. And vice versa: if the weight of the school has decreased, then the agents search for the maximum in the wrong place, so it is necessary to change the direction of the trajectory and identify diversification properties.

For this stage, it is necessary to determine the distance between two FA. The distance is determined in two stages.

Step 8. 1. At the first stage, it is necessary to sequentially view the columns of matrix D from left to right. In each column, it is necessary to find out the relative location of the elements d_{ik} and d_{ik+1}, where i is the column number, k is an odd number. If the location of the elements d_{ik} and d_{ik+1} does not coincide in the matrix $D_{barycenter}$ – the matrix of the agent's decision corresponding to the previously calculated barycenter, then the degree of difference increases by 1, otherwise, it does not increase.

Step 8. 2. The second stage is carried out when k is an even number. The degree of difference is the distance between the two agents.

Collective voluntary swimming occurs with the help of moving in the direction of the FA barycenter with the probability $\beta = collStep * rand(0;1) * dist / \max(dist)$, where $dist$ is the distance between the current agent and the barycenter, max($dist$) is the maximum distance between the FA in the school and the barycenter, $collStep$ is the free displacement step, $rand$ (0,1) is a random number from 0 to 1.

Step 9. Changing the FA swimming parameters. At this stage, the step of individual movement of each FA changes depending on the iteration number. This procedure is used to increase the efficiency of the algorithm and speed up convergence.

Step 10. Training FA 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 FA.

The 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 an improved fish school algorithm is proposed. In order to assess the effectiveness of the developed method, its comparative evaluation was performed based on the results of research presented in [3–6, 23, 24, 36].

Simulation of the solution search processing method was carried out in accordance with steps 1–10. 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 number of each tool was taken – 4 tools each;

– the number of informational signs by which the state of the monitoring object is determined – 12. These parameters include: affiliation, type of organizational and staff formation, priority, minimum width along the front, maximum width along the front. The number of personnel, minimum depth along the flank, maximum depth along the flank, the number of samples of weapons and military equipment (WME), the number of types of WME samples and the number of communication means), the type of operational structure are also taken into account;

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

The results of the comparative evaluation by the criterion of evaluation efficiency with known scientific studies are shown in Table 1.

Table 1

Results of problem solving

No. of iteration	Branch and bound method [17]	Genetic algorithm [12]	Canonical fish algorithm [23]	Improved fish algorithm
N	T, s	T, s	T, s	T, s
5	1.125	1.125	1.125	1.05
10	0.625	0.625	0.625	0.450
15	48.97	58.20	58.28	55.71
20	106.72	44.29	43.75	41.33
30	–0.1790	–0.0018	–0.0002	–0.00008
40	–0.158	–0.070	–0.069	–0.08
50	97.76	–974.30	–3.72	–331.18
100	–133.28	–195.71	–196.24	–198.12
200	7980.89	7207.49	7198.43	7022.85

As can be seen from Table 1, the gain of the specified solution search method is from 11 to 15 % by the criterion of data processing efficiency.

6. Discussion of the results of the development of a solution search method using an improved fish school algorithm

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

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

– the universality of solving the problem of analyzing the state of FA objects due to the hierarchical nature of their description (Steps 1–10);

– the possibility of quick search for solutions due to the simultaneous search for a solution by several individuals (Steps 1–10, Table 1);

– the adequacy of the obtained results (Steps 1–10);

– the ability to avoid the local extremum problem (Steps 1–10);

– the possibility of deep learning of FA knowledge bases (Step 10).

The disadvantages of the proposed method include:

– the loss of informativeness when 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 when searching for a solution in several directions at the same time;

– lower assessment accuracy compared to other assessment methods.

This method allows you:

– to assess the state of a heterogeneous analysis object;

– to determine effective measures to improve management efficiency;

– to increase the speed of assessing the state of a heterogeneous analysis object;

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

The limitations of the study are the need for an initial database on the state of the analysis object, the need to take into account the delay time for collecting and providing 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 when 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 the FA search;

– to carry out an initial display of FA individuals taking into account the type of uncertainty;

– to carry out accurate training of FA individuals;

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

– 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, which is carried out by training the synaptic weights of the artificial neural network, the type and parameters of the membership function, the architecture of individual elements and the architecture of the artificial neural network as a whole;

– to use as a universal tool for solving the problem of analyzing the state of analysis objects due to the hierarchical description of analysis objects;

– to check the adequacy of the obtained results;

– to avoid the problem of local extremum.

2. An example of using the proposed method is given on the example of assessing and forecasting the state of the operational situation of a group of troops (forces). This example showed an increase in the efficiency of data processing at the level of 18–25 % due to the use of additional improved procedures of adding correction factors for uncertainty and noise of data, FA selection, and FA training.

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.

Acknowledgments

The author team expresses gratitude for providing assistance in the preparation of the paper:

– Shovkovska Nataliya – a teacher of the secondary school of grades I-III No. 2 in the city of Svitlovodsk, Kirovohrad region;

– Doctor of technical sciences, professor Kuvshinov Oleksiy – deputy head of the Educational and Scientific Institute of the National Defense University of Ukraine named after Ivan Chernyakhovsky;

– Doctor of technical sciences, professor Rotshtein Oleksandr – professor of the Mahon Lev Polytechnic Institute of Jerusalem;

– PhD, associate professor Bashkyrov Oleksandr – leading researcher of the Central Research Institute of Armament and Military Equipment of the Armed Forces of Ukraine.

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