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A METHOD FOR CHOOSING A STRATEGY FOR THE BEHAVIOR OF A CELLULAR AUTOMATON WHEN SOLVING THE PROBLEM OF FINDING TARGETS BY A GROUP OF MOVING OBJECTS

Abstract. Currently, a large number of different mathematical models and methods aimed at solving problems of multidimensional optimization and modeling of complex behavioral systems have been developed. One of the areas of search for solutions is the search for solutions in conditions of incomplete information and the need to take into account changing external factors. Often such problems are solved by the method of complete search. In some conditions, the method of complete search can be significantly improved through the implementation and use of behavioral models of natural formations. Examples of such formations can be group behavior of insects, birds, fish, various flocks, etc. The idea of copying group activity of a shoal of fishes at the decision of problems of joint activity on extraction of food is used in work. The reasoning based on the simulation of the behavior of such a natural object allowed to justify the choice as a mathematical model - cellular automata. The paper examines the key features of such a model. Modeling of his work is carried out, strategies of behavior of group of mobile objects at search of the purposes are developed, key characteristics are investigated and the method of adaptive choice of strategy and change of rules of behavior taking into account features of the solved problem is developed. The search strategy is implemented in the work, which takes into account the need to solve the optimization problem on two parameters. The obtained results testify to the high descriptive possibility of such an approach, the possibility of finding the optimal strategy for the behavior of the cellular automaton and the formalization of the process of selecting the parameters of its operation. A further improvement of this approach can be the implementation of simulation to study the properties of the developed model, the formation of the optimal set of rules and parameters of the machine for the whole set of tasks.

Keywords: cellular automaton; path search; optimization problem; random search; model.

Introduction

Solving real problems using some kind of mathematical apparatus often takes a lot of time to select the optimal parameters. In addition, difficulties arise in assessing the influence of various factors on the effectiveness of solving each specific problem. In [16], an approach to solving the problem of searching for targets by a group of moving objects was proposed. It was based on a mathematical model of a cellular automaton. However, in [16], the issues of optimization of the solution time and selection of the optimal parameters of the cellular automaton operation for solving the problem of finding targets were not investigated.

This makes a more detailed consideration of the proposed model, the study of its properties and the search for ways to improve to expand the range of tasks to be solved, urgent. It is also important to formalize the process of choosing a strategy for the behavior of a cellular automaton when solving the problem of searching for a group of moving objects.

Analysis of recent research and publications. A significant amount of work has been devoted to the study of the motion of objects and their interaction. The author of [2] divides the existing methods of searching for routes of moving objects into three classes: exact, classical heuristic and metaheuristic methods.

Exact methods are of interest in the development and testing of optimal algorithms. But to solve practical problems are not used due to the rapid growth of computational complexity with increasing dimension of the problem.

Heuristic methods are to search in a relatively limited space of solutions and ensure finding close to optimal solutions in a reasonable time. Metaheuristic methods are based on a careful study of the most promising parts of the solution space [3] on some grounds. However, they contain a large number of parameters that must be configured for each specific task [4]. Therefore, metaheuristic methods form the basis of modern research in the field of approximate methods of solution [2]. Metaheuristic methods based on mechanisms found in wildlife are especially often used to solve optimization problems, which include the problem of finding routes. Such methods and models are called bioalgorithms. Among them are cellular automata, which due to natural parallelism, simplicity and universality allow to model the behavior of various systems, objects and phenomena of any nature [5].

The operation of the apparatus of cellular automata is described in detail in [5, 7, 8]. Examples of their use to solve optimization problems prove their effectiveness. Thus, in the article [9] on the basis of cellular automata the behavior of the crowd is modeled taking into account the mental characteristics of pedestrians. In [10] a cellular-automatic approach to modeling the behavior of transport and pedestrians is described.

The search for optimal routes of movement using the apparatus of cellular automata is also carried out in the article [11]. However, this paper considers the motion of objects in two-dimensional space for homogeneous single objects. This does not allow their use and requires refinement of the developed model. It is necessary to take into account the limitations and features of the tasks of forming a search in a given area.

Substantiation of the possibility of applying the cellular-automatic approach to solving the problem of the salesman is given in [5].

In [13], an example of successful use of cellular automata to solve the problem of finding routes for moving cars from wholesale bases to outlets is given. However, this approach can be applied only in the presence of a road network and a clearly defined task of a salesman for these conditions. This does not allow to use such an approach to solving the problem of determining the route of movement, for example, search groups.

In [14], the use of routing algorithms for determining the optimal routes of strike aircraft flights is proposed. However, this approach is characterized by high computational complexity and rough partition of space with different properties.

The analysis shows the successful use of cellular automata to solve the problem of finding objects in the area. In [our article], a method for studying the behavior of a group of moving objects using a cellular automaton is proposed. However, the article does not consider its characteristics, does not identify ways to optimize it and possible sets of rules (strategies) of its behavior. This requires further research.

The purpose of the article is to develop a method for selecting a strategy for the behavior of the cellular automaton in solving the problem of finding targets by a group of moving objects.

Presenting main material

In continuation of the idea presented in [16], we will consider as the initial model of a group of moving objects - a shoal of fish with appropriate properties [15].

In works [11-13] for problems of the considered class it is offered to use the cellular automaton on the plane corresponding to the solved problem. Then, a two-dimensional cellular automaton can be defined as a set of finite automata on a plane with coordinates that can be in one of the possible states [7, 8, 11, 13]:

$$\theta_{i,j} \in S \equiv \{0,1,2,3,...k\}. \quad (1)$$

At each step of the automaton changes the state of the automaton in accordance with the rule:

$$\theta_{i,j}(\mathrm{t+1}) = \phi(\theta_{k,l}(\mathrm{t}) | (\mathrm{k,l}) \in \mathrm{N(i,j)}), \quad (2)$$

where N(i, j) - automaton environment (i, j).

In this paper we use the definition of the environment of the automaton as Moore's environment [11]:

$$\mathrm{N}_M(\mathrm{i,j}) = \{k,l \| i-k| \le 1, \ |j-l| \le 1\}. \quad (3)$$

The number of possible transition rules is determined by the number of possible states θ and the number of neighbors under consideration m. Theoretically, the number of such rules can be equal to $\Psi = \theta^{\theta^m}$. This allows you to build different sets of rules for constructing different behavioral strategies of the cellular automaton.

Analysis of formulas (2), (3) shows that with the help of rules can be described quite complex cell behavior. A large number of possible states can also be considered. Consider the given formal descriptions in practice.

Define a homogeneous two-dimensional grid with coordinates on the plane (Fig. 2). This grid is usually folded into a sphere, ie the "lower" edge of the grid joins the "upper" and the "left" edge with the "right". This convolution is usually used for ease of calculation and to avoid the associated problems [8]. However, in this example, it is proposed to use a limited lattice with boundaries (an example is shown in Figure 1).

Given the rules of development of the cellular automaton, we will use two types of automata for the search task: search objects and search group (Fig. 3a and 3b, respectively).

As a basis for finding the rules of behavior of the cellular automaton, we use the strategy of joint movement of the group to the goal.

We use the simplest model of behavior: the machine moves to the goal - the object that is closest to the group.

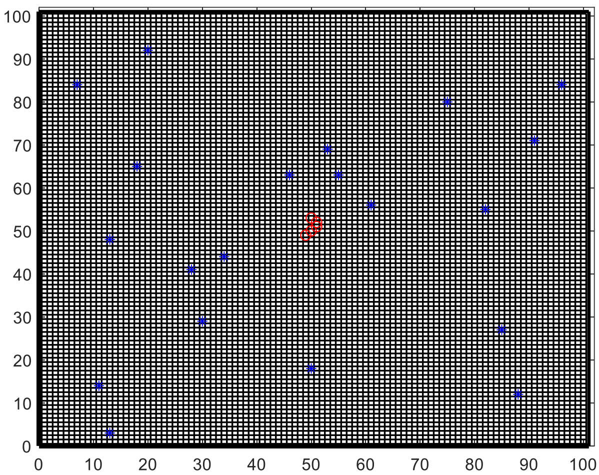

Fig. 1. Two-dimensional homogeneous grid for the operation of the cellular automaton Source: developed by the authors using the developed model

In Fig. 1, asterisks indicate objects - search targets, and circles - the composition of a group of search objects.

Based on the strategy of behavior "movement to the nearest goal", we can formulate the following rules of behavior of the cellular automaton:

Strategy 1.

1. Search objects do not move. Objects are defined by a set $C = \{c_1, \mathrm{c}_2, ..., \mathrm{c}_k\}$, each object has coordinates $c_k(x_i, y_j)$.

2. The search team

$$O = \{o_1, o_2, ..., o_g\}, o_g(x_i, y_j)$$

moves in unison, without changing its structure.

3. At each step of the cellular automaton, the automaton of the search group changes its position.

4. All calculations are performed relative to the center of gravity of the group, determined by the formula:

$$O_{CG}(x, y) = \left(\frac{1}{L}\sum_{l=1}^{L} x_l , \frac{1}{L}\sum_{l=1}^{L} y_l \right), \qquad (4)$$

where (x_l, y_l) - the coordinates of cellular automata belonging to the search group.

5. Search group machines can determine the distance to targets relative to the center of gravity of the group.

6. The search group machine moves to the nearest object.

Using this strategy for the operation of the cellular automaton, the following results were obtained (Fig. 2).

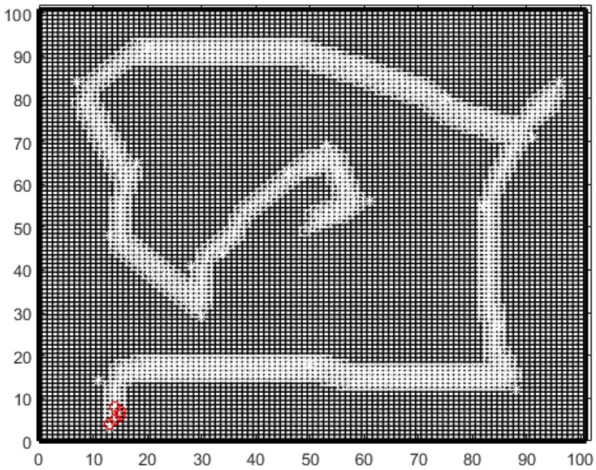

Fig. 2. The results of the cellular automaton operation according to the strategy of movement to the nearest purpose.
Source: developed by the authors using the developed model

Analysis of the results of the machine showed that the machine coped with the specified work in 342 steps of the machine.

However, this is not the only possible strategy for the machine.

As the next strategy we will consider movement to the most massive (important) purpose. In this case, it is assumed that for each purpose is assigned a value of mass or weight. This is a conditional concept and for a practical task, this concept may have the necessary meaning and semantic description, characteristic of the task.

In this case, the system of rules will look like this.

Strategy 2.

Items 1-5 are equivalent to the strategy points of the machine above.

6. The search engine has information about the "importance" of the object.

7. The search engine moves to the most "important" goal.

The implementation of this strategy allowed to obtain the results shown in Fig. 3.

The machine allowed to get this result in 514 steps.

As you can see from Fig. 3, this machine finds unsuccessful solutions. They implement an energy-intensive path with a large number of re-visits to the same areas.

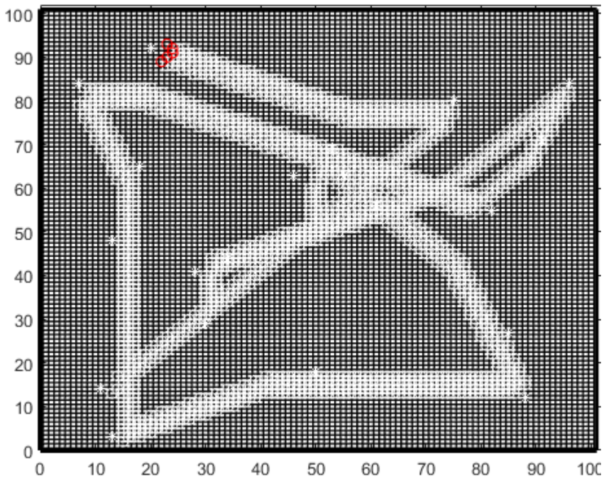

Fig. 3. The results of the cellular automaton operation according to the strategy of movement towards the most "important" purpose.
Source: developed by the authors using the developed model

Then we can conclude that the use of such a strategy is possible on a limited number of objects or in the absence of other alternatives.

Consider the following strategy - mixed. It is based on the idea of moving to the closest and "important" object.

Formally, this machine can be set by such a system of rules.

Strategy 3.

Rules 1-5 will be identical to the rules for the first machine.

6. The function of significance of the object is calculated, which connects the distance from the object to the center of the search group and its mass.

Formally, this function can be set as follows:

$$f(c_{ij}, O_{CG}) = \left(1 - \frac{L_{c_{ij}}}{L_{\max}} \right) + \frac{m_{c_{ij}}}{m_{\max}},$$

where $L_{c_{ij}}$ - distance from the target c_{ij} to the center of the search group O_{CG};

$L_{\max}$ - the maximum distance from all targets $C = \{c_1, c_2, ..., c_k\}$ to the center of the search group O_{CG};

$m_{c_{ij}}$ - the "importance" of the target c_{ij};

$m_{\max}$ - maximum "importance" of targets $C = \{c_1, c_2, ..., c_k\}$.

7. The machine moves to the target, which has the maximum value of the function $f(c_{ij}, O_{CG})$.

This system of rules allowed to obtain the following results of the machine (Fig. 4).

To the surprise of the authors, this machine has completed its work in 555 steps. Analysis of the results suggests that the end result is little different from the machine, which took into account only the "importance".

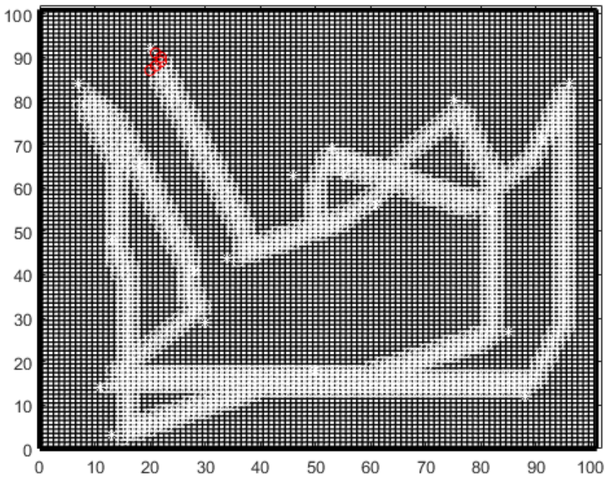

Fig. 4. The results of the cellular automaton operation according to the strategy of movement towards the closest and "important" purpose.
Source: developed by the authors using the developed model

The path seems less chaotic. However, the machine often moved in the same areas many times.

Thus, this machine can not be applied to a large number of purposes and has a limited scope.

Analysis of all the results shows that very often the machines pass close to the target. But they do not visit it because of certain behavioral strategies. Expanding the "vision" of the machine does not significantly improve the results.

However, field analysis showed that it would be interesting to visit nearby objects in a limited area of space and then move to the next area.

This approach can be a dynamic clustering of the search space associated with the center of the search group.

Under the cluster we mean the area of space around the center of mass of the search group radius R.

Then it is possible to imagine a model of this machine with such a set of rules.

Strategy 4.

Rules 1-5, as in other machines.

6. Define objects that fall into the cluster of radius R.

7. The function of significance of the object is calculated, which connects the distance to the object to the center of the search group and its mass.

8. The machine moves to the target, which has the maximum value of the function $f(c_{ij}, O_{CG})$.

9. If there are no targets in the cluster, there is a movement to the next cluster.

Then we obtain the following results of this machine (Fig. 5).

This result was obtained for $R = 25$. The number of implemented steps of the machine was 355. This number of steps can be compared with the machine in Fig. 1.

However, instead of one parameter - range, it takes into account 2 interrelated parameters - distance and "importance".

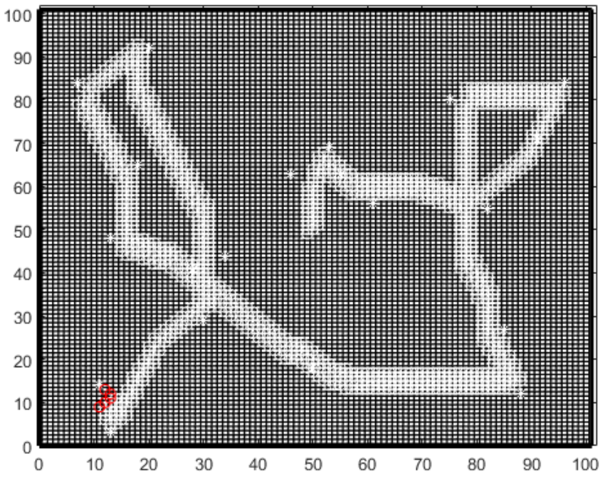

Fig. 5. The results of the cellular automaton operation according to the strategy of movement to the closest and "important" purpose in the cluster.
Source: developed by the authors using the developed model

Fig. 6 shows the machine with $R = 50$. The number of implementation steps was 355.

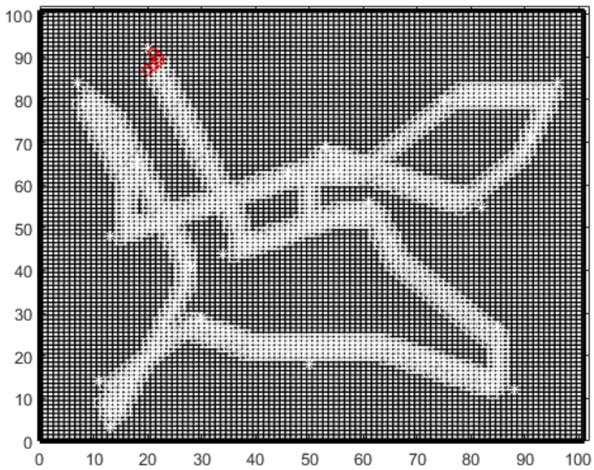

Fig. 6. The results of the cellular automaton operation on clusters.
Source: developed by the authors using the developed model

As a result of setting the parameters of the machine, namely the change and selection of values R. It was possible to reduce the number of steps of the machine to 338. At the same time $R = 20$. The results of the machine are presented in Fig. 7.

The results obtained are almost identical to those shown in Fig. 1. However, formally the number of steps of the machine was 342 in the first case and 338 in the latter. The optimization was carried out on two components - "importance" and distance.

The obtained results indicate the prospects of this area of research and the great potential. However, the question of the method of selecting a cellular automaton that implements a certain strategy remains unresolved. Studies of the properties of the developed cellular automaton indicate the need for large-scale statistical modeling of this automaton. Its purpose is an unambiguous choice of parameters of its work. However, the impact on the results of the number of goals, their characteristics, search tasks, time and resource constraints.

Based on these considerations, we can propose an adaptive method for selecting parameters and behavioral strategies of the cellular automaton in solving the problem of finding targets by a group of moving objects, shown in Fig. 8.

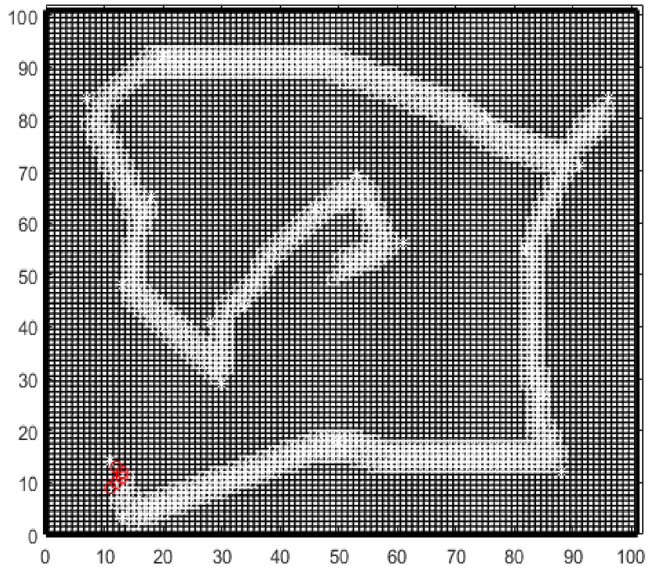

Fig. 7. Results of the cellular automaton operation on clusters with optimal parameters.
Source: developed by the authors using the developed model

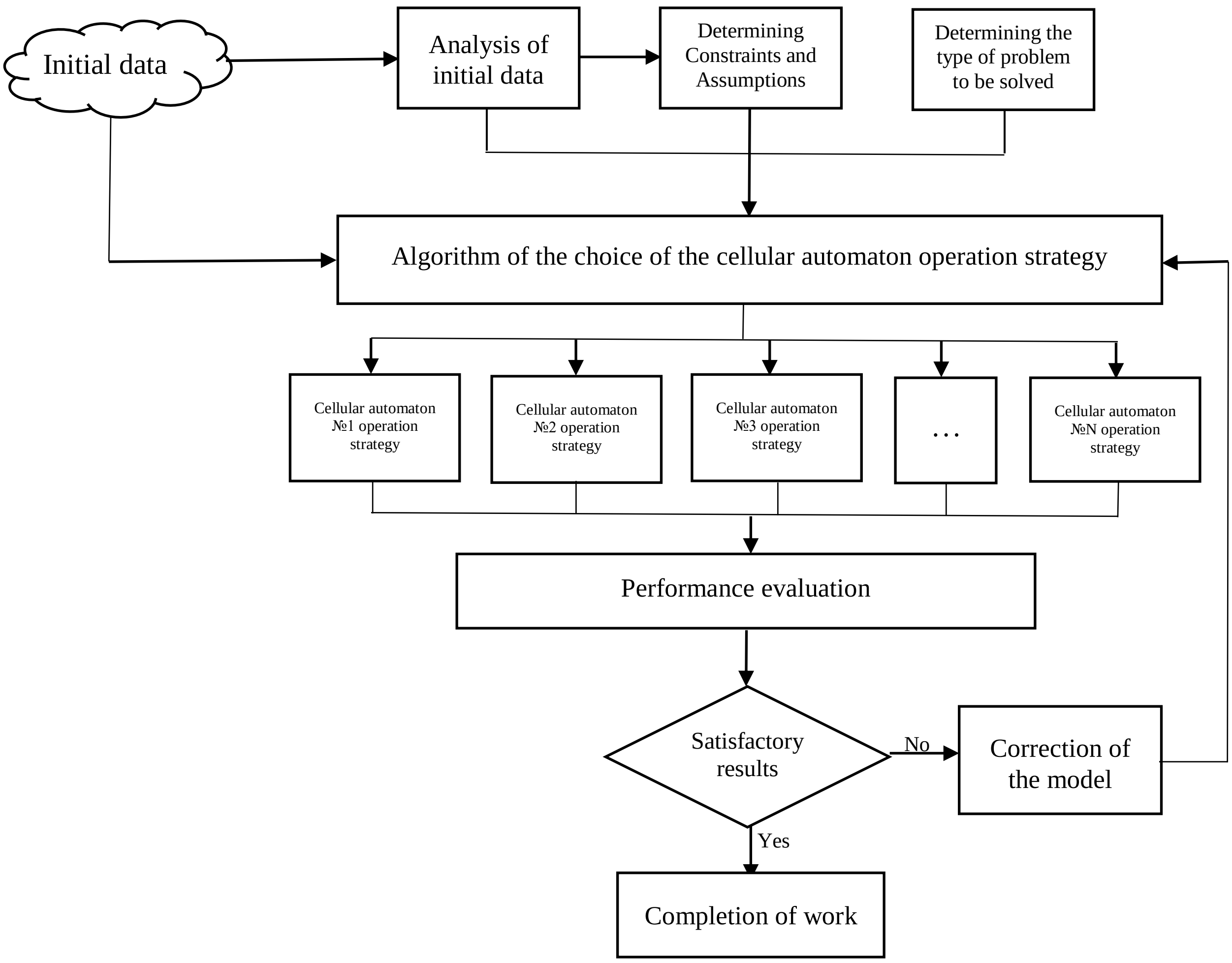

Fig. 8. The structure of the parameter selection method and the proceeding strategy of the cellular automaton when solving the problem of finding purpose by a group of moving objects

This approach will allow you to develop a decision support system for the management of a group of moving objects.

It is adaptable both to external conditions and to features of the solved tasks. It can also be used to obtain results and evaluate a wide range of possible alternatives.

Conclusions. Studies of the cellular automaton for finding targets by a group of moving objects suggest that this problem can be successfully solved. The use of a cellular automaton allows you to implement a wide range of search strategies.

Modeling of the machine showed that additional research is needed on the selection of operating parameters and rules for changing the state of objects. In the future it is necessary to simulate his work. Its purpose is to identify patterns of formation of the parameters of the machine and adjust the rules of its operation to increase the speed and accuracy of the task. Similarly, in the future it is necessary to take into account the resource of the search group to move and take into account the dynamic change in the characteristics of the goals.

The results of modeling the operation of the cellular automaton and evaluation of the dynamic characteristics of the work can be studied by following the link provided in the form of a QR-code.

REFERENCES

1. Pozhidaev, M.S. (2010), *Algorithms for solving the problem of transport routing* [Algoritmy resheniya zadachi transportnoy marshrutizatsii], dissertation, Tomsk: Tomsk State University, 2010, 136 p., available at : https://marigostra.ru/materials/thesis.pdf.
2. Slastnikov, S.A. (2014). "Application of metaheuristic algorithms for the transport routing problem [Primeneniye metaevristicheskikh algoritmov dlya zadachi transportnoy marshrutizatsii]", *Economics and Mathematical Methods*, Vol. 1, pp. 117–126.
3. Matsyuk, N.O. (2013), "Features of solving the problem of a salesman for wholesalers [Osoblyvosti rozv″yazannya zadachi komivoyazhera dlya pidpryyemstv hurtovoyi torhivli]", *Bulletin of the KhNU*, Vol. 5, pp. 95–100.
4. Bjarnadottir, A.S. (2004), *Solving the Vehicle Routing Problem with Genetic* / Aslaug Soley Bjarnadottir, Technical University of Denmark, 127 p.
5. Li, Yang, (2019), A review of cellular automata models for crowd evacuation. Physica A: *Statistical Mechanics and its Applications*, 526 p.
6. Aladiev, V.Z. (2009), *Classic homogeneous structures. Cellular automata [Klassicheskiye odnorodnyye struktury. Kletochnyye avtomaty]*, Publishing house Fultus Books, 535 p.
7. Bandman, O.L. (2005), "Cellular-automatic models of spatial dynamics [Kletochno-avtomatnyye modeli prostranstvennoy dinamiki]", *System informatics*, Vol. 10, pp. 57–113.
8. Toffoli, T. and Margolus, N. (1991), *Cellular automata machines*, 280 p..
9. Makarenko, O.S. (2010), „Modeling the movement of pedestrians on the basis of cellular automata [Modelyuvannya rukhu pishokhodiv na osnovi klitynnykh avtomativ]", *System research and information technologies*, Vol. 1, pp. 100–109.
10. Babaei, Abdorreza, Homayun, Motameni, and Rasul, Enayatifa (2020), "A new permutation-diffusion-based image encryption technique using cellular automata and DNA sequence", *Optik*, 203: 164000.
11. Pavlenko, M.A. (2014), "Method of solving the problem of laying routes when controlling the movement of an air object [Metod reshenyya zadachy prokladky marshrutov pry upravlenyy dvyzhenyem vozdushnoho ob″ekta]", *Information processing systems*, Vol. 5, pp. 87–90.
12. Matsyuk, N.O. (2016), "Solving the routing problem using a modified ant-cell-automatic algorithm [Rozv″yazannya zadachi marshrutyzatsiyi z vykorystannyam modyfikovanoho murashyno-klitynno-avtomatnoho alhorytmu]", *Visnyk ekonomichnoi nauki Ukrainy*, Vol. 1, pp. 49–54.
13. Zhykharevych, V.V. (2016), "Cellular-automatic approach to solving the problem of routing wholesale trade enterprises taking into account the transport infrastructure of the region [Klitynno-avtomatnyy pidkhid do rozv″yazannya zadachi marshrutyzatsiyi optovykh torhovelʹnykh pidpry-yemstv iz urakhuvannyam transportnoyi infrastruktury rehionu]", *Visnyk ekonomichnoi nauki Ukrainy*, Vol. 2, pp. 69–73.
14. Khmelevskiy, S., Pavlenko, and Petrov, O. (2020), "Information analysis method about current situations in ACS of special operations", Advanced Information Systems, Vol. 4, No. 1, pp. 103-106, DOI: https://doi.org/10.20998/2522-9052.2020.1.15
15. Burova, E.M. (2020), "Heuristic algorithm for finding shoals of fish [Evristicheskiy algoritm poiska kosyakov ryb]", *Electronic Scientific Journal*, Vol. 1, pp.18–21.
16. Pavlenko, M.A. (2021), "Method of studying the behavior of groups of mobile objects using cellular automatic machines [Metod vyvchennya povedinky hrup mobilʹnykh ob″yektiv za dopomohoyu klitynnykh avtomativ]", *Armament systems and military equipment*, Vol. 3, pp. 92-98.

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Метод выбора стратегии поведения клеточного автомата при решении задачи поиска группой подвижных объектов

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Аннотация. В настоящее время разработано большое количество различных математических моделей и методов направленных на решение задач многомерной оптимизации и моделирования сложных поведенческих систем. Одним из направлений поиска решений является поиск решений в условиях неполноты информации и необходимости учета изменяющихся внешних факторов. Зачастую такие задачи решаются методом полного перебора. В некоторых условиях метод полного перебора может быть существенно усовершенствован за счет реализации и использования поведенческих моделей природных образований. Примерами таких образований могут быть групповое поведение насекомых, птиц, рыб, различных стай и др. В работе использована идея копирования групповой деятельности косяка рыб при решении задач совместной деятельности по добыче пропитания. Положенные в основу рассуждений о имитации поведения такого природного объекта позволило обосновать выбор в качестве математической модели – клеточные автоматы. В работе исследованы ключевые особенности работы такой модели. Проведено моделирования его работы, разработаны стратегии поведения группы подвижных объектов при поиске целей, исследованы ключевые характеристики и разработан метод адаптивного выбора стратегии и изменения правил поведения с учетом особенностей решаемой задачи. В работе реализована стратегия поиска, которая учитывает необходимость решения оптимизационной задачи по двум параметрам. Полученные результаты свидетельствуют о высокой описательной возможности такого подхода, возможности нахождения оптимальной стратегии поведения клеточного автомата и формализации процесса подбора параметров его работы. Дальнейшим совершенствованием такого подхода может быть проведение имитационного моделирования для исследования свойств разработанной модели, формирования оптимального набора правил работы и параметров автомата для всего множества решаемых задач.

Ключевые слова: клеточный автомат; поиск пути; задания оптимизации; случайный поиск; модель.

Метод вибору стратегії поведінки клітинного автомата при рішенні завдання пошуку групою рухових об'єктів

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Анотація. На даний час розроблено велику кількість різних математичних моделей і методів спрямованих на вирішення завдань багатовимірної оптимізації та моделювання складних поведінкових систем. Одним з напрямків пошуку рішень є пошук рішень в умовах неповноти інформації і необхідності обліку змінних зовнішніх факторів. Найчастіше такі завдання вирішуються шляхом повного перебору. У деяких умовах метод повного перебору може бути істотно вдосконалений за рахунок реалізації та використання поведінкових моделей природних утворень. Прикладами таких утворень може бути групове поведінка комах, птахів, риб, різних зграй тощо. У роботі використана ідея копіювання групової діяльності косяка риб при вирішенні завдань спільної діяльності з пошуку харчування. Покладення за основу міркування про імітацію поведінки такого природного об'єкта дозволило обгрунтувати вибір в якості математичної моделі – клітинні автомати. У роботі досліджено ключові особливості роботи такої моделі. Проведено моделювання його роботи, розроблено стратегії поведінки групи рухомих об'єктів при пошуку цілей, досліджено ключові характеристики та розроблено метод адаптивного вибору стратегії та зміни правил поведінки з урахуванням особливостей розв'язуваного завдання. У роботі реалізовано стратегію пошуку, яка враховує необхідність вирішення оптимізаційної задачі за двома параметрами. Отримані результати свідчать про високу описову можливість такого підходу, можливість знаходження оптимальної стратегії поведінки клітинного автомата та формалізації процесу підбору параметрів його роботи. Подальшим удосконаленням такого підходу може бути проведення імітаційного моделювання для дослідження властивостей розробленої моделі, формування оптимального набору правил роботи і параметрів автомата для безлічі розв'язуваних завдань.

Ключові слова: клітинний автомат; пошук шляхів; завдання оптимізації; випадковий пошук; модель.