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# Aircraft flight route search method with the use of cellular automata

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## ABSTRACT

The task of aircraft flight route search in severe environment of flight is discussed in the article. This task is related to multi-criteria optimization tasks types and requires significant timing budget and computation resource to solve it. This task solution method with the use of cellular automaton on 3D lattice gas model was discovered in the work. The main difference of the discovered method consists in elaboration of lattice gas cellular automaton 3D model features, development of a new approach to the calculation of changing probability of cell position and determination of rules of adjacent elements identification and development of new rules of transfer into them. The developed method allows constructing the model with the different level of detail that allows regulating the decision search time and searching the decisions in separate environmental areas.

**Key words :** Cellular automaton, route, flight routes, optimization.

## 1. INTRODUCTION

At the moment, there is no any unmistakable approach to solve the task as to the aircraft flight route search. For this task solution the strict rules of its solution in fixed conditions of space division and given tasks are created in civil aviation [1]. However, the essential task for civil aviation is the transportation of the most number of cargo or passengers in a minimum of time at maximum safety level [2], [3]. The entirely different requirements are made as to the flight routing to aircraft of special purposes. A high degree of uncertainty in the condition of environment, unknown or high risk level of tasks solution, diversity of the solved tasks and other factors will be illustrative for such kind of routes.
The existing methods of such tasks solution can be nominally divided into two big groups. They are the automated solution methods and non-automated solution methods. Automated methods have limited capacity that allows just mapping the direct route excluding tasks solution peculiarities, state of environment where the flight object will operate as well as targets and tasks that will be placed in front of it.
Non-automated solution methods allows approaching this task solution more properly. However, the essential disadvantage of them is low operational efficiency of solution, relatively low accuracy and impossibility to realize several flight planning strategies with one single solution. In other words, in order to solve under different conditions all the calculations must be done all over again [4] –[8].
So, there is a necessity to develop new flight objects route search methods with account of peculiarities of air space condition and list of tasks under solution. Herewith, we will take into account the necessity to solve the task as to mapping the flight routes under severe navigating conditions and account of the necessity of flight in navigating zones with special flight conditions.
The purpose of the article consists in the development of flight objects route search methods in order to increase the operation efficiency and accuracy of its solution.

## 2. LITERATURE REVIEW

The existing tasks solutions of route search methods of movable objects are divided into tree types by the author of the article[9]: accurate, classical heuristic and meta-heuristic methods. Accurate methods are of interest while developing and testing the optimization algorithms, but in order to solve practical tasks they are not used because of the rapid growth of calculation complication at increase of dimension of the task. Heuristic methods lie in search in relatively limited space of decisions and provide finding solutions close to optimal ones at a reasonable period of time. Meta-heuristic methods are subclass of classical heuristics the peculiarity of which is thorough study of the most advanced parts of decisions space [10]. The quality of the received decisions is higher then in classical heuristics. However, they include a great amount of parameters that must be adjusted for every specific task [11]. So, meta-heuristic methods form the basis of modern research in the field of close solution methods [12]. Meta-heuristics, based on mechanisms met in wildlife, are often used for optimization tasks solution including route search tasks. Such meta-heuristic methods are named as bio-algorithms. Among them are also cellular automata that allow modeling the behavior of different systems, objects and phenomena of any origin due to natural parallelism, simplicity and flexibility. Cellular automata instrument operation is described in detail in articles [13], [14],[15]. And the examples of their use for solving optimization problems prove its own effectiveness. Particularly, in the article [16] on the base of cellular automata the crowd behavior with account of mental peculiarities of pedestrians was designed. In the article [17] cellular-automaton approach to modeling the transport and pedestrians behavior was described. Optimal routes search with the use of cellular automata instrument is also realized in the article [18], but as the movement of objects is described in two-dimensional space then the transfer of it into three-dimensional space requires rework of developed model and account of the limitations as to the formation of zones in the air space. Substantiation of the reasonability to use cellular-automaton approach to solve voyageur task are presented in the work [13]. In the work [19] the successful use of cellular automata for solution the task of route search of vehicles movement from wholesale depots toward sales points was described. However, such approach can be applied only if there is a road network and a formulated voyager task for current conditions that do not allow using this particular approach to the task solution of air objects flight route search. In the works [14],[20]the use of routing algorithms for search the optimal routes of striking aviation flights was proposed. However, such approach differs in high computational complexity and rough space division with different features. The analysis shows the successful use of cellular automation for such types of tasks solution that allows supposing their effectiveness for task solution search of optimal route of air objects flights while reworking the indicated disadvantages.

## 3. MAIN MATERIAL

In order to solve the route search task let us discuss cellular automation on the base of lattice gas model that is supplemented up to the tree-dimensional model and is characterized by the following features [18].

1. Let us discuss tree-dimensional case. The whole search space is divided into parallelepipeds of the same size. Every parallelepiped is a mesh inside of which the cell can transit. All the possible positions of the gas meshes are given in the form of the space area in which the search of the decision is realized (Figure 1).

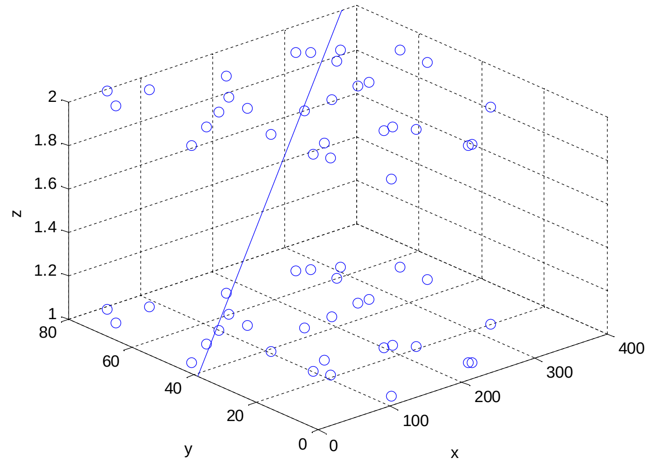


**Figure 1:** The space area for route search with zones prohibited for flight

2. The mesh can be in one of several conditions: "occupied" or "empty".
3. It is possible to determine the priority direction of the movement.
4. The immovable objects, other air objects as well as the fields (zones) of different nature can be the obstacles.

Every time step of the automation consists of two stages:
analysis of the situation in every cell;
transitof the cell according to the automation rules.
If there are no other movable objects it is possible to analyze just in context of the discussed object. It decreases considerably the amount of calculations on every step of the work of the automation.
In general case the transition is possible in 26 directions (adjacent meshes of space).
The analysis of the situation is made by means of calculation of choice probabilities of one of possible movement directions (Figure 2).

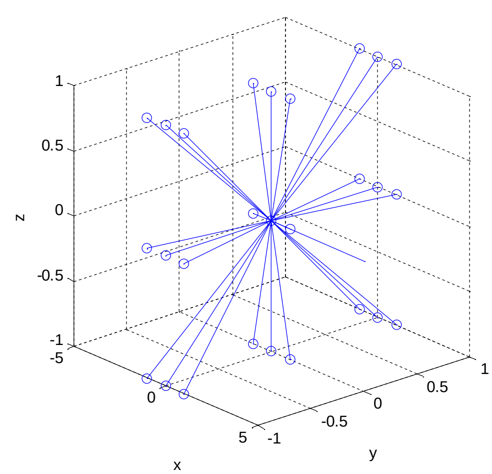


**Figure 2:** Graphical display of the term "possible movement directions"

If to approach formally, then the choice of movement direction at a moment of time $t_1$ does not depend on the direction of movement at a moment of time $t_0$. The cell movement is unexpected and is given by the following rules of probability calculation.
The movement of the cell in one of 26 probable directions:

$$P_i(x,y,z) = 1 - \frac{1}{N}\sum_{k=1}^{N} D(x,y,z+k),\ i = \overline{1..26}; \quad (1)$$

where $x, y, z$ are the current coordinates of the cell (object);
$N$ -the depth of the analysis of the cell surroundings;
$D(x,y,z)$-cell condition:

$$D(x,y,z) = \begin{cases} 1, \text{cell is occupied;} \\ 0, \text{cell is free.} \end{cases}$$

Let us realize the mechanism that regulates the direction of the cell movement from the current position in the given direction.
To provide for the latter, let us use the statements of the vector theory.
At first, let us find the vector from the current cell position to the target object $\overrightarrow{AB}$ (Figure 3).

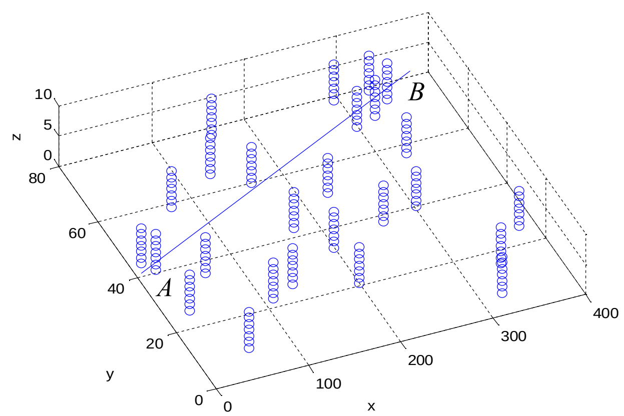


**Figure 3:** Vector from the current object to the target position

Then, let us find the vectors from the current mesh to all of 26 meshes possible for transit.
Foe corresponding directions they will have the following values (Figure 4) (relatively to the current position of the cell):

$$\vec{f}_j(x,y,z),\ x \in \{-1,0,1\},\ y \in \{-1,0,1\},\ z \in \{-1,0,1\}, \quad j = \overline{1..26}. \quad (2)$$

Then let us find the probabilities of cell movements in everyone from the possible directions with the use of expression (1).

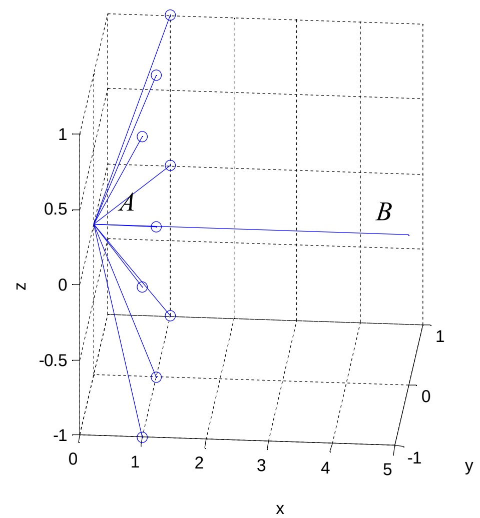


**Figure 4:** Graphic presentation of the vector $\overrightarrow{AB}$ and unitary vectors.

After that let us find the angles between the vector $\overrightarrow{AB}$ and all the unitary vectors (2) using the expression:

$$\alpha_j = \arccos\left(\frac{\overrightarrow{AB}\cdot\vec{f}_j}{\left|\overrightarrow{AB}\right|\cdot\left|\vec{f}_j\right|}\right). \quad (3)$$

After that we solve the optimization task:

$$D_j(x,y,z) = D_0(x,y,z) + \vec{f}_j, \quad (4)$$

under the conditions:

$$\max(P_i), \quad (5)$$
$$\min(\alpha_j). \quad (6)$$

If some of the values $P$ or $\alpha$ are equal, then the choice is realized in an unpredictable manner.
However, as it was shown above, the similar model has its own disadvantages. The disadvantages are the low sensibility to the probability of direction choice, hanging of the automation in one place, significant deviations from the basic movement direction and others.
In order to overcome these disadvantages it was proposed to use the following expression for probability calculation:

$$P_i = e^{-\frac{\sum_{k=1}^{N} D(x+k,y,z)}{\delta}}, \quad (7)$$

where $\delta$ is the coefficient that allows regulating the sensibility of the probability;

$\sum_{k=1}^{N} D(x+k,y,z)$ is calculated according to the expression (1) for every direction.

## 4. RESULTS AND DISCUSSIONS

Such approach to the probability calculation allows formalizing properly the procedure of movement direction choice. In addition, such kind of approach is suitable for search of track in the space areas with different features. "Flyover zone" can be the example of such area. This region is characterized by certain measures, the entrance to which is possible but not advisable. So, the expression (1) does not allow distinguishing the flight in this zone and outside of it, and the use of the expression (7) does.

Let us discuss the air object flight in air space with 3 zones with the different features. The first zone is available for free flight but there are zones that are prohibited for flight. The second zone is available for flight but is not recommended to be used. The third zone is located inside the second one and is prohibited for flight but herewith the flight inside of it is permissible.

While running of experiment as to the investigation of the features of the developed cellular automation, the cell is primarily located in the first zone, and the purpose of the flight is located in the second zone.

The results of automation operation are presented in the following Figures 5 – 8.

The example of flight routing if there are no zones with special conditions of flight is presented in Figure 5.

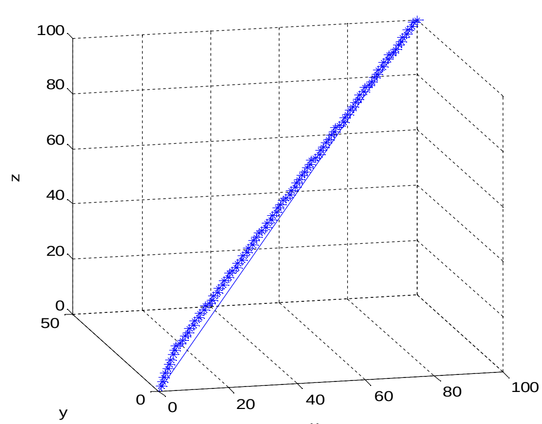


**Figure 5:** Flight routing if there are no zones with special conditions of flight

In general, if there are different zones the found route will take the form (Figure 8).

So, the routes search method of air objects flight with the use of cellular automation can be developed (Figure 9).

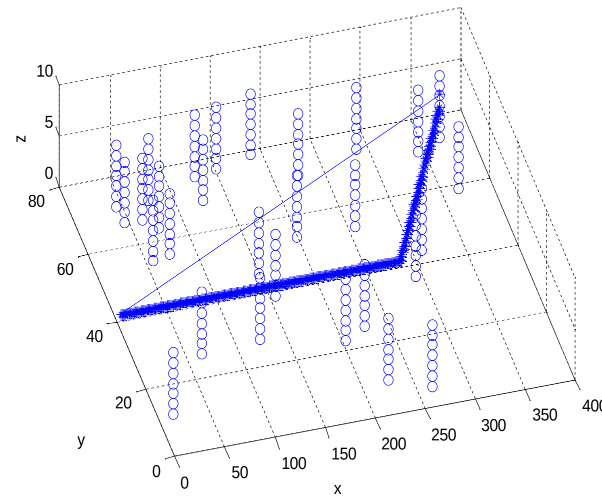


**Figure 6:** The results of cellular automation operation if there are 30 zones prohibited for flight

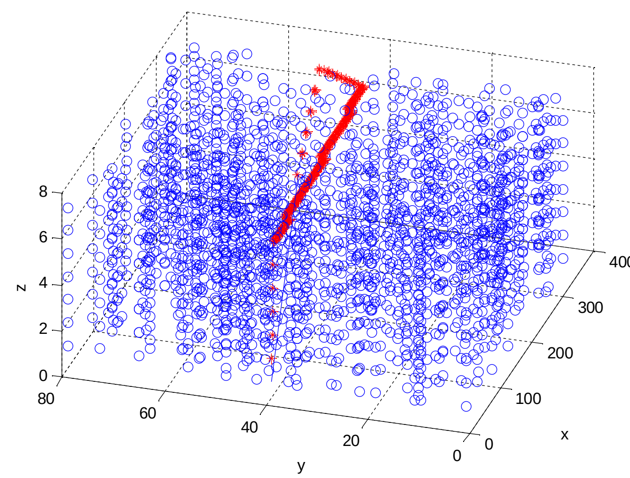


**Figure 7:**The results of cellular automation operation if there are 200 zones prohibited for flight

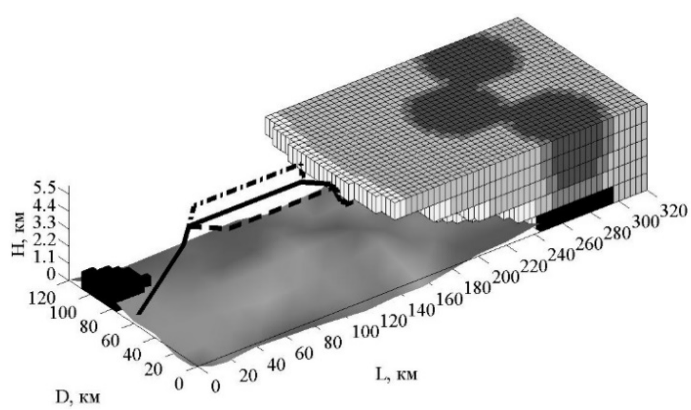


**Figure 8:** The results of cellular automation operation while flying over the areas with different features

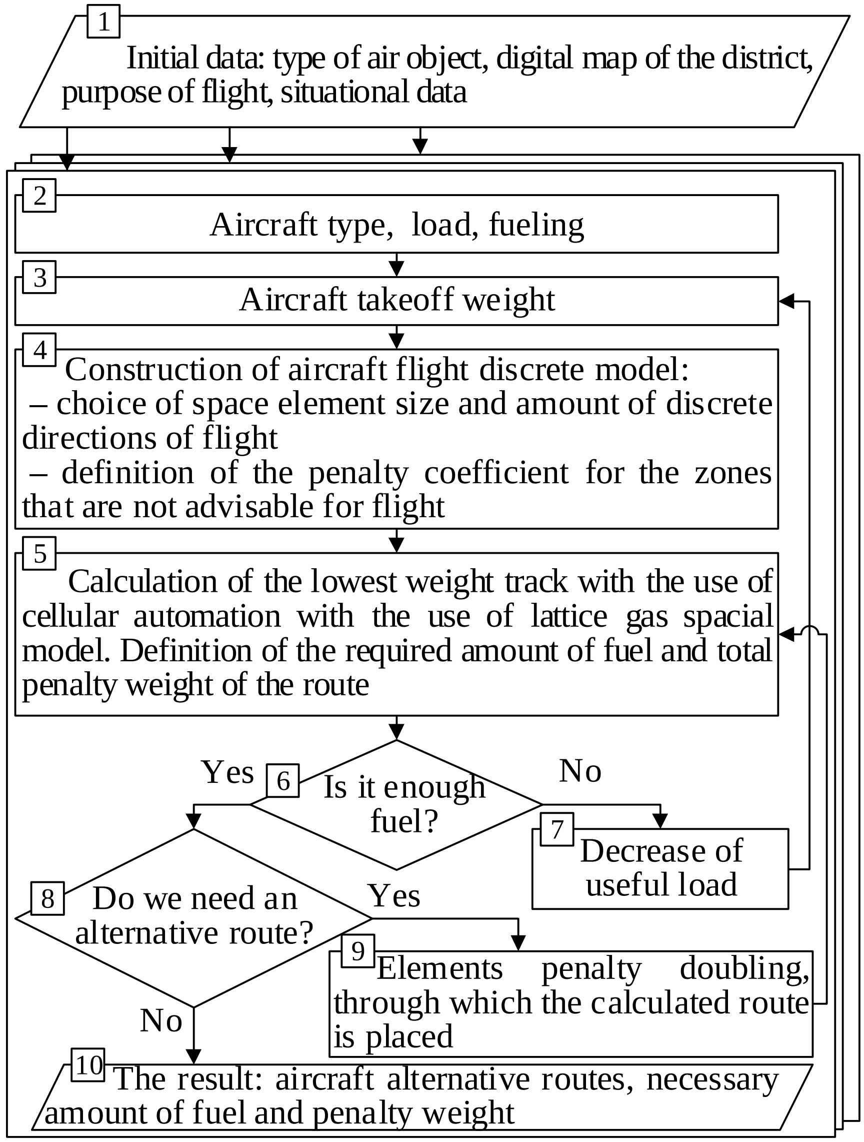


**Figure 9:** Route search method of aircraft flight with the use of special model of lattice gas

## 5. CONCLUSION

The presented results as to the development of the cellular automation for solution of the task as to the air object movement routing in different air space zones showed the necessity to develop new approaches to the formalization of the behavior rules of these instruments. Primarily, it was necessary to develop new approaches to calculate the probability of movement in different zones, as well as the development of the compensatory strategy of cellular automation "hanging" in stable and alternative conditions. The obtained results allow transferring to the task solution for changeable conditions of route search, accounting of the aircraft features and increasing the flight routing accuracy.

## 6. ACKNOWLEDGEMENT

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