MODIFIED METHOD OF A PATH PLANNING ON A LOCAL MAPS FOR TRANSPORT AND AEROSPACE ROBOTS

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In this paper we consider the modification of the method of planning the A-star path for transport and aerospace robots. It is necessary to take into account obstacles in the local neighborhood of aerospace robot, but not sufficient for the rational path planning. The essence of the modification is to use additional information about the features of original cell array. This additional information is represented by binary flags. They represent obstacle-free rows and matrix columns. The modification allows you to build paths that include straight sections of free cells. The main feature of this method is the use of bitwise logical operations on cell values.

Key words: robotics, planning, Path, modification, maps, Aerospace, additives

INTRODUCTION

The development of control systems for transport and aerospace robots is one of the critical directions for creating advanced robotic systems with artificial intelligence elements on board the machine [1,2]. This direction is determined by modern achievements of theoretical computer science, computer technology, theory of automatic control with using maps of the area (sea surface) and different high-tech production [3,4].

The tasks of constructing a digital terrain matrix, build of a vector maps, recognizing geometric objects (images of the sea surface, objects of near coastal infrastructure) are effectively solved on the basis of artificial intelligence technologies. Artificial intelligence technologies allow you to get and use additional information about the terrain matrix [5].

The vector data models are constructed on vectors that occupy part of the space in contrast to the raster models that occupy the entire space. In this case objects are created by connecting points with straight lines, arcs of circles, polylines [5,6]. Transport and aerospace robots that decrypt images of the sea surface and near coastal infrastructure objects can plan their route based on hardware logic operations with map cell coordinates.

From the computational point of view, the robot is a multifunctional executor with executive bodies, an action program and carrying out targeted movements in the external environment. Planning and robot movement along the path is a multi-criteria optimization-calculation task. In this task, various means of visual facilities are used to collect information about the external environment and to provide a decision on the preparation or correction of the path, including on board the robot [7]. To implement the functions of automatic planning and motion control of the control system, data from the following standard input devices can be used as part of visual facility system [8,9]:

- lidar (laser scanner);
- radar;
- camera-recorder;
- position evaluation aero- and space- sensor;
- inertial motion sensor;
- GPS receiver, etc.

Data from these input devices are transferred to the robot control system, where they are processed and integrated. Thus, there are objective prerequisites for creating methods and algorithms for planning or correcting the path, which are based on the use of the created model of the external environment. Noted methods and algorithms use information only about the local neighborhood around the aerospace robot. This restriction does not allow planning the path taking into account the perspective and global properties of the external environment.

Research objective

Planning the motion path of robot R is the process of finding a conflict-free path for moving a robot in an external environment (its model). According to [10], the external environment is given as a non-empty set of obstacles $O \subset W$ in the domain of the Euclidean space $W \subset E^N$, $N \in \{2,3,4\}$.

Suppose it is given a surface mobile robot R capable of moving in two-dimensional Euclidean space ($R \subset W$). The acceptable state $C \in CA$ is understood as a set of parameters of the robot R, including its coordinates (x,y). These parameters determine the position of the robot R of the object on the plane and describe its functional state.

The sequence of acceptable robot states (C_{tree}) is a set of states $c' \subset C$ ($C \in CA$), which does not allow collisions with obstacle objects O in W and satisfies the condition of contiguity of neighboring states with respect to coordinates [10], i.e.

$$C_{free} = \{c' \in C_A | R(c') = \emptyset\} \qquad (1)$$

$$C_{free} = \{(... c'_i, c'_j ...) | (x_j = x_i \pm \Delta_x),$$

$$(y_j = y_i \pm \Delta_y\} \qquad (2)$$

Δ_x, Δ_y – coordinate increment of adjacent cells.

The goal of path planning is understood as the task of finding a conflict-free path from free states of the external environment. To organize the search, you specify a pair of edge states on the C_{start}, C_{goal} scene. It is necessary to form a continuous path $\pi(t):[0,1] \rightarrow C_{free}$, where $\pi(0)=C_{start}$ and $\pi(1)=C_{goal}$.

The goal of path planning is treated as a task of checking the existence of a path that satisfies the requirements (1), (2) and some target criterion $\Im$. The criterion for maximizing the average speed of the robot along the path is chosen as the target criterion

$$\Im((V_{cp}\pi(t)) \rightarrow max \qquad (3)$$

V_{cp} is the average speed of the robot along the path, $\pi(t)$ is the sequence of the selected allowed states (route).

THEORY METHOD

To plan a path, grid approach is used to represent the external environment. The external environment is divided by a grid with step Δ_x, Δ_y into cells. Provided $\Delta_x=\Delta_y$, a two-dimensional cell array $M=\{m_{ij}\}$, $(i=1–n, j=1–n)$ is formed. In the future, path planning is the determination of the coordinates of the cell centers through which the path passes.

Typical initial situation for the organization of path search is shown in Fig1. In the initial situation, the coordinates of the robot R (x_R,y_R), goals Goal (x_{GOAL},y_{GOAL}), and the coordinates of obstacles O having arbitrary geometry (gray cells) are given. It is assumed that the obstacles are fixed objects.

In this paper, the well-known heuristic method A* - (A-star) is chosen as the basic method of path planning (searching) [8,9]. For this method, the direction of robot movement between cells is evaluated at each step as minimization of the target distance function *Limit*

$$Limit = G + H \rightarrow min \qquad (4)$$

G is the total length of the traversed path, calculated as $G_{k+1} = G_k + L_{ij}$; G_k is the length of the previously traversed section; L_{ij} - the current length; H is the heuristic estimate of the length of the site remaining to target H.

The path planning is associated with the analysis of the local neighborhood around the current location of the robot R. Each cell of the matrix M has quantitative estimates of the distance to the target cell Goal. The path is formed taking into account the distance traveled and the current length that the robot R takes.

The main drawback of the A-star method is that it does not exclude the uncertainty of choosing a new cell by comparing a limited number of cells closest to the robot [11].
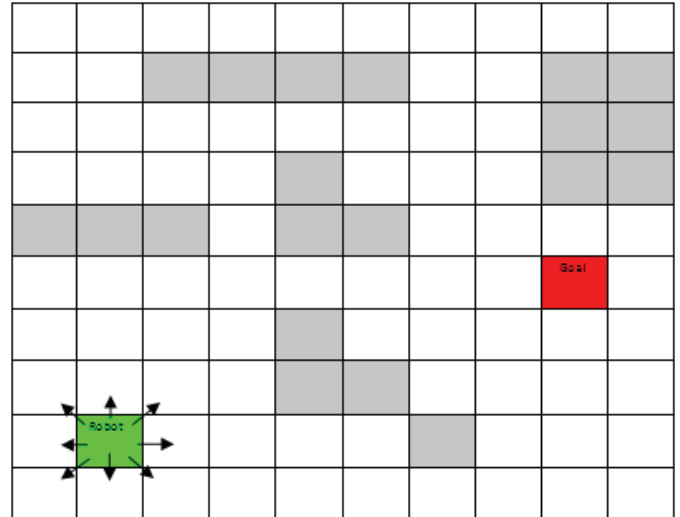

Figure 1: Typical initial situation for path planning

This feature leads to unproductive time consumption, stopping the robot and implementation of return movements along the path. As a result, the length of the path increases, and the average speed of the path significantly decreases.

To mainstream the decisions taken, additional information on the state of groups of cells within the rows and columns of the matrix M is given in the classical method of searching for A *. This information is represented by binary flags denoting free from obstacles rows and columns of the matrix *fl_x1 –fl_xn* и *fl_1x – fl_nx*, respectively (Fig. 2).

For the square matrix n*x*n cells, the flag row and the flags column *fl_x1 –fl_xn* and *fl_1x – fl_nx* are additionally introduced, respectively. Each bit of the status flag informs the robot that the corresponding column / row is free or busy:

$$\forall k | fl\_xk = \begin{cases} 1, if \ \&_{j=1}^{n} (status(m_{xj}) = free) \\ 0, otherwise \end{cases} \qquad (5)$$

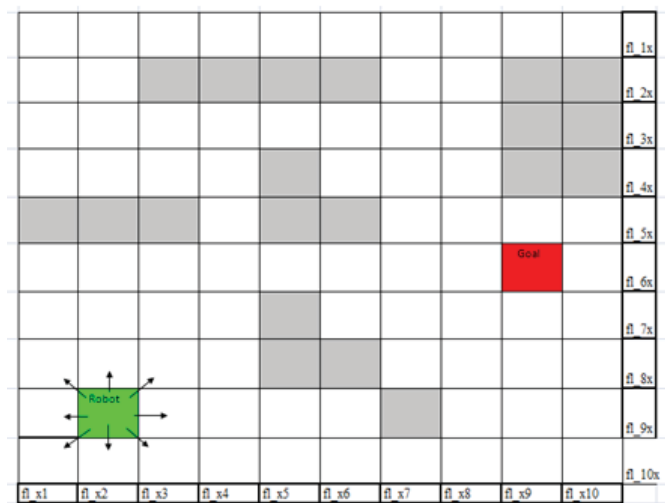*Figure 2: The initial situation for path building, extended with binary flags*

$$\forall k \mid fl\_kx = \begin{cases} 1, if\ \&_{j=1}^{n}\ (status\ (m_{jx}) = free) \\ 0, otherwise \end{cases} \quad (6)$$

k is the cell index in a row or column *(k = 1 - n)*.

The global nature of processing of groups of column cells and rows is the bit-by-bit implementation of the conjunction or disjunction operation over bits denoting the status of cells. For fixed objects, this information is updated for the time of path planning. It allows you to build a path from extended rectilinear sections in the cell array. As a result, when performing checks on the selection of the next cell, an additional priority step is entered according to (4) and (5) of the next cell that enters the free row or column. Motion along a section of a free row or column of the matrix is carried out taking into account the control of the coordinates of the target cell Goal. In such areas, the robot R moves for a long distance (a section of the path) with the maximum speed of the robot.

Thus, we have developed a modified method for planning a path, which includes additional steps to the A-star method, namely:

a) preparation of an extended cell array containing not only information about obstacles in the terrain, but also an additional row and the flags column fl_x1 - fl_xn and fl_1x - fl_nx, each bit of which contains information on the presence of a free column or a row in the original matrix;

b) additional check of a subset of free cells by flag-row and flag-column and selecting the nearest next cell that has the minimum distance to a free row or column in the cell array;

c) checking the coordinates of the current cells of the robot R and the target cell Goal, i.e. test Boolean conditions ((xR=xGOAL) *V* (yR=yGOAL))=TRUE.

EXPERIMENTAL SECTION OF MODIFIED METHOD

Arrays with geometrical arrangement of impassable cells are standard test examples. Such arrays are chosen so that modified and classical route planning methods have disadvantages. Heuristic routing or directed search of alternatives is implemented by both methods.

Distance ratio of routes by both methods is the first route assessment indicator. K assessment of a route is

$$K = \frac{F_{MODIFY}}{F_{BASE}} \quad (7)$$

where F_{BASE} is route length according to classical method, F_{MODIFY} is route length according to modified method.

Time ratio of route passing according to classical and modified methods is the second indicator of route assessment. Robot R moves with minimum speed according to classical method. The speed is minimum. Check of function distance (Limit) criterion in each cell is carried out (3). Robot R moves in final range of allowed speeds using modified method. Cell passing time coefficient tCELL={1; 0,5; 0,25} is used for dynamics formaliza-

tion of robot R movement. This is according to classical method

$$\forall x_i, y_j \mid t_{CELL}(x_i y_j) = 1, i = 1 - n, j = 1 - n$$

There are three types of movement according to modified method DRIVE$_1$, DRIVE$_2$, DRIVE$_3$:

- movement on 1 cell or turn on 90° t_{CELL}=1 (DRIVE$_1$);
- movement with acceleration or braking on 1 cell t_{CELL}=0,5 (DRIVE$_2$);
- movement with maximum speed on1 cell t_{CELL}=0,25 (DRIVE$_3$).

Time assessment indicator T is

$$T = \frac{n_1 \cdot 1 + n_2 \cdot 0,5 + n_3 \cdot 0,25}{N} \quad (8)$$

where n_1, n_2, n_3 are cells according to movement types DRIVE$_1$, DRIVE$_2$, DRIVE$_3$ respectively, N –cells according to classical method.

Figs. 4-6 show test situations (Test1, Test2, Test3) with robot (R) placement, goals (Goal) and obstacle cells.

Fig. 4 shows various search results by two methods with such distribution of obstacles that there is an uncertainty of route choice for both methods. Route is shown by thin lines according to classical method. According to modified method route is shown by blocked arrows. This route consists of straight orthogonal sections including sequence of free cells. Starting heuristics for A-star leads to bypass of cells with obstacles on smaller distance than heuristics for modified method.

Lengths of routes are 8 cells and 12 cells for classical and modified methods respectively at Manhattan distance of 7 cells. Manhattan distance is the shortest way between starting and target cells arrays, including impassable cells.

Fig. 4 shows various search results by two methods for an obstacle - "bucket". This is the most difficult shape which has local and global deadlock points. These points are out of robot technical range and current situation analysis of a robot. In conditions of uncertainty classical
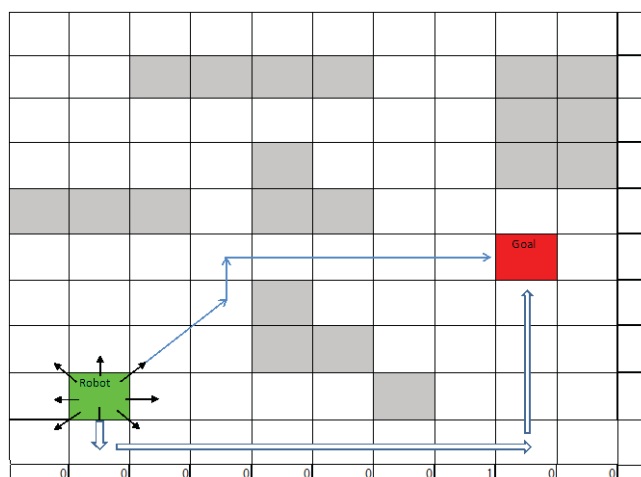

Figure 3: Routes according to classical and modified methods for casual distribution of obstacles

A-star method moves to the right and at deadlock moves up. Starting heuristics for A-star leads to obstacle cells bypass inside "bucket".

Lengths of routes are 19 cells and 14 cells for classical and modified methods respectively at 8 cells of Manhattan distance.

Fig. 5 describes various search results by two methods for an obstacle – "bucket with handle". It also has local

Figure 4: Routes by classical and modified methods for "bucket"

Figure 5: Routes by classical and modified methods for "bucket with handle"

and global deadlock points out of robot technical range and current situation analysis of a robot. Lengths of routes are 19 cells and 14 cells for classical and modified methods respectively at 8 cells of Manhattan distance.

Table with results shows quantitative assessment of planned routes according to test examples.

DISCUSSION

Comparison of route planning methods showed that the modified method has an advantage for the options for the location of obstacles on the matrix in the form of concave geometric shapes. Such figures (type - moon, bucket, trough, etc.) are preferably circumvented along their border. The classical method is based on the analysis of a local neighborhood of cells. This does not allow him to detect dead ends and does not allow to avoid return movements along the matrix cells. The modified method, through the use of additional information, detects dead ends. This allows him to avoid unproductive time spent on return movements in the matrix cells. Nevertheless, the modified method may not give advantages in the length and time of the route for obstacles in the form of simple geometric shapes.

CONCLUSION

Modified method of route planning using additional information on cell array is developed. This information is global. It is applicable irrespectively of a aero robot initial position, target position and percent of impassable cells in arrays. The entity of modification is to prepare augmented cell arrays and execute additional step of a priority choice of the following cell. This cell is in free line or a column that allows robot to move at long distance without obstacles with maximum speed. From the computing point of view modified method uses logical actions (conjunction and disjunction) and also search next figure.

Model inspection on test examples of obstacles in cells' array was carried out. It was carried out using relative indicator of route length and speed assessment movement. It is shown that in the worst situation modified method of route time movement equals to classical method. But in problem situations for classical method modi-
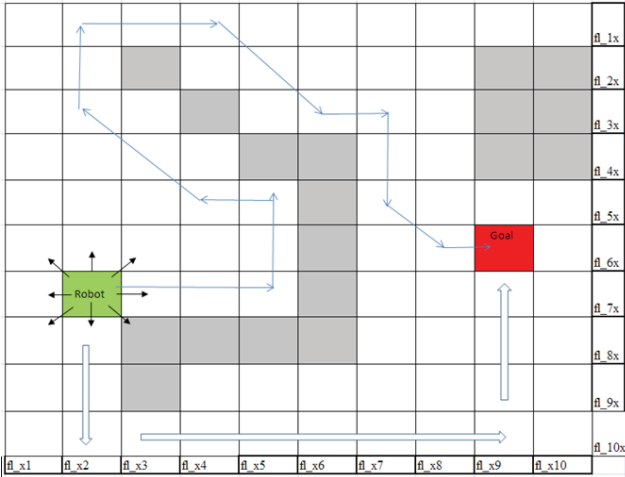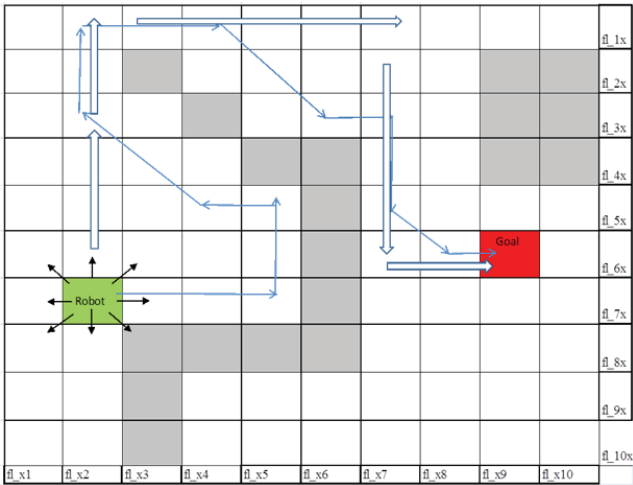
Table 1: Comparison of planned routes

Test name	A-star method, route		Modified A-star method, route		Route assessment	
	length	time	length	time	K	T
Test 1	8	N=8	12	n_1=6, n_2=3, n_3=3	$K = \dfrac{12}{8} = 1,5$	$T = \dfrac{8,25}{8} = 1,03$
Test 2	19	N=19	14	n_1=7, n_2=4, n_3=3	$K = \dfrac{14}{19} = 0,74$	$T = \dfrac{9,25}{19} = 0,51$
Test 3	19	N=19	18	n_1=8, n_2=6, n_3=4	$K = \dfrac{18}{19} = 0,95$	$T = \dfrac{12}{19} = 0,63$

fied method shows essential reduction of route passing time (to 2 times) and reduction of its length. On average, modified method provides passing time reduction on a route for 8-14%. At the same time route consists of orthogonal sites on which aerospace robot shows the best high-speed characteristics.

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REFERENCES

1. Germanovitch, V. A., & Gennadievitch, S. E. [2018]. Autonomous navigation and attitude control of spacecraft's on near-earth circular orbits. *Journal of Applied Engineering Science*, 16(1), 107-110.

2. Psychopop V. H. (2009). Position-trajectory control of mobile objects. Publishing house TRTU, Taganrog.

3. Kolmykova T.S., Merzlyakova E.A., Bredikhin V.V., Tolstykh T.O., Ovchinnikova O.P (2018). Problems of formation of perspective growth points of high-tech productions. Advances in Intelligent Systems and Computing, vol. 622, 469-475, DOI: 10.1007/978-3-319-75383-6_60.

4. Vladimirovna-Bredikhina, N. [2017]. Basic principles of production-and-technical potential capacity formation in the construction industry of a region. *Journal of Applied Engineering Science*, 15(4), 495-497.

5. Titenko E.A., Katykhin A.I., Kurochkin A.G., Lotorev P.V., Skopin D.E., Pykhtin A.I. (2019). Multilayer geoinformation data access and representation model. Journal of Engineering and Applied Sciences. vol. 14, no. 18, 6753-6757, DOI: 10.3923/ jeasci 2019.6753.6757.

6. Titenko E.A., Katykhin A.I., Kurochkin A.G., Lotorev P.V., Skopin D.E., Pykhtin A.I. (2019). Multilayer geoinformation data access and representation model. Journal of Engineering and Applied Sciences. vol. 14, no. 18, 6753-6757, DOI: 10.3923/ jeasci 2019.6753.6757.

7. Shaozhong Shi, Nigel Walford (2012). Automated Geoprocessing Mechanism, Processes and Workflow for Seamless Online Integration of Geodata Services and Creating Geoprocessing Services. Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 5. no. 6, 1659 – 1664.

8. Huey-Ru Wu ; Mi-Yen Yeh ; Ming-Syan Chen (2013). Profiling Moving Objects by Dividing and Clustering Trajectories Spatiotemporally. Transactions on Knowledge and Data Engineering, vol. 25, no. 11, 2615 – 2628.

9. Delling D., Sanders P., Schultes D., Wagner D. (2009). Engineering route planning algorithms.Algorithmic of large and complex networks, Springer.

10. Kazakov K. A., Semenov V. A. (2016). Review of modern methods of traffic planning. Papers of the Institute of system programming RAS, vol. 28, no. 4, 241-296.

11. Avdeev V. O., Kurochkin A. G., Lotorev P. V., Titenko E. A. (2016). Modified method and algorithm with iterative deepening for work a route through of the cells matrix. Information-measuring and control systems, vol. 14, no. 10, 46-50.