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FIELD BUG ALGORITHM IN THE PROBLEM OF LOCAL MOTION PLANNING FOR MOBILE ROBOTS

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Keywords: mobile robots, local navigation, motion planning, bug algorithm, artificial potential fields, obstacle avoidance problem, unknown environment.

Abstract. The problem of local motion planning for mobile robots in an unknown environment is considered. The new algorithm of a field bug is suggested. The main feature of the algorithm is a combination of Bug algorithms and potential fields' methodology.

АЛГОРИТМ ПОЛЕВОГО ЖУКА В ЗАДАЧЕ ЛОКАЛЬНОГО ПЛАНИРОВАНИЯ ДВИЖЕНИЯ МОБИЛЬНЫХ РОБОТОВ

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Ключевые слова: мобильные роботы, локальная навигация, планирование движения, алгоритм жука, искусственные потенциальные поля, задача обхода препятствий, неизвестная среда.

Аннотация. Рассматривается задача локального планирования движения мобильных роботов в неизвестной среде. Предлагается новый алгоритм полевого жука. Основной особенностью предлагаемого алгоритма является совмещение алгоритмов группы Bug и методологии потенциальных полей.

Task of the Local Planning

One of the relevant issues in modern robotics is the problem of *motion planning* of a mobile robot (MR) when performing various tasks. Methods for solving this problem can be divided into global planning methods and local planning methods.

Global planning allows MR to construct the optimal route along which it should move from the initial position to the goal. Global planning algorithms require complete information about the shape and location of obstacles. In this case, this problem can be successfully solved using algorithms on graphs.

To implement the movement of MR along the constructed route, which is obtained by global planning methods, it is necessary to solve the problem of *local planning*. The need to solve this problem may be due to the insufficient amount of a priori information, as well as the non-stationary nature of the environment. For local planning, the robot needs to have only information about its position, the position of the goal and the position of the nearest obstacles.

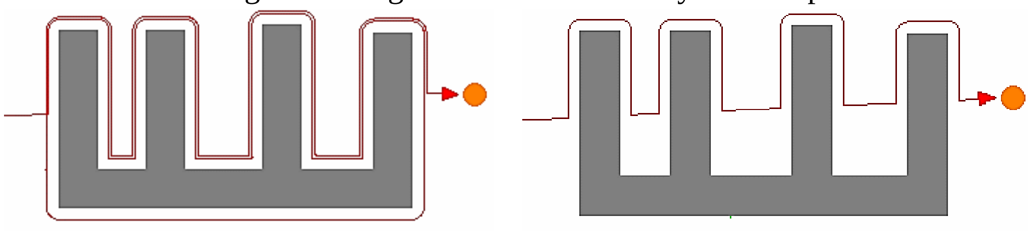
Algorithms of Bug Group

The most popular methods of local planning in an unknown environment are algorithms of the Bug group [1]. They are based on observing the behaviour of a bug: having encountered an obstacle, it bypasses it and continues to move in the same direction.

The first representative of this group is the *Bug1* algorithm. This algorithm assumes that the MR follows the contour of the obstacle and continuously measures the distance from its current position to the goal point. After the robot makes a complete turnover around the obstacle, it returns to the point at which the distance to the goal is minimal. The main drawback of the Bug1 algorithm is the necessity to move through all the points around the obstacle, so the robot needs to cover a distance exceeding the perimeter of the obstacle to bypass it.

The evolution of algorithms of this group is the *Bug2* algorithm. Its fundamental difference is that when an obstacle is detected, the robot remembers the vector directed to the goal point. The robot moves along the boundary of the obstacle and, when crossing the remembered vector, changes its trajectory, following directly to the goal. Bug2, as well as Bug1, requires the robot to perform unnecessary movements, but in less quantity. Figure 1 shows a comparison of the trajectories obtained during movement of MR using the Bug1 and Bug2 algorithms.

Also, algorithms of this group include *Tangent Bug* [2], which is based on the search for an optimal route along the graph of tangents to the edges of obstacles. The advantage of this method is the ability to find routes which are close to optimal. The main disadvantage of the algorithm is the difficulty of its implementation.



a) *b*)

Fig. 1. Obstacle bypass trajectories with Bug1 (*a*), and Bug2 (*b*) algorithms

All algorithms of the Bug group consider the robot as a material point, and therefore do not take into account the width of the passage between obstacles.

Methodology of Potential Fields

Another popular method of motion planning for mobile robots is the method of *potential fields* (PF), proposed by A.K. Platonov in 1970 [3]. The current state of the method and features of its application in robotics is discussed in [3–9]. The PF method can be used both in global planning, when a map of the area is known, and in local planning, in conditions of incomplete information.

The PF method is as follows: it is assumed that the goal has some positive charge, and the obstacles are negatively charged. The robot appears to be a negatively charged point, which is capable of moving. Under the influence of potential forces, the robot will be “attracted” to the goal and “repelled” from obstacles.

The main advantage of the PF method is the simplicity of calculating the potential forces that specify the direction of motion of the MR.

The main disadvantage of the PF method is the problem of so-called "*local minima*" – existence of regions where the gradient of the potential field equals to zero. When the robot gets there, it gets stuck. To ensure the way out of such regions, the use of additional heuristic rules is required [5].

An Idea of Field Bug Algorithm

This article proposes a new algorithm for local planning in non-deterministic environments, which combines methods borrowed from the bug algorithms, as well as from the method of potential fields.

The motion of a ground MR is observed in a fixed base reference system (BRS) of two-dimensional physical space (Fig. 2). The position of MR is given by the vector $\mathbf{r} = (x,\ y)$. The goal of the MR's movement is set in the BRS by a radius vector $\mathbf{r}_g$. The robot and the goal are connected by vector $\mathbf{d}_g(\mathbf{r})$:

$$\mathbf{d}_g(\mathbf{r}) = \mathbf{r}_g - \mathbf{r}.$$

The environment contains impassable points (obstacles). For each position $\mathbf{r}$ of MR is given a vector $\mathbf{d}_o(\mathbf{r})$, connecting the robot and the nearest impassable point.

The point of the trajectory at which the MR changes the direction of motion is called *the turning point*.

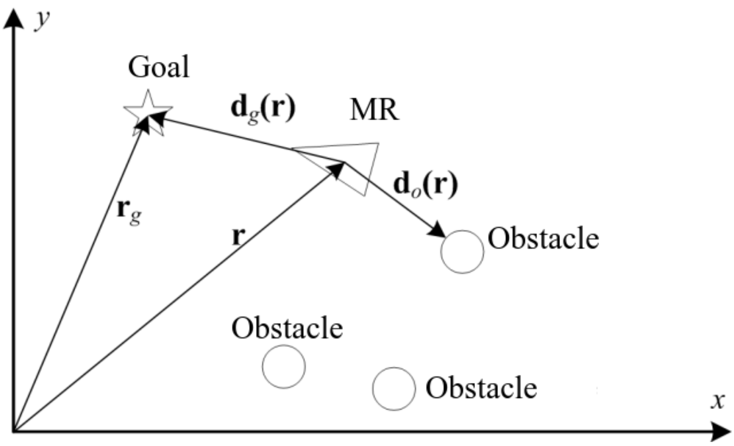


Fig. 2. An environment where the robot operates

The algorithm is based on the following rules.

1. The movement of MR in free space is carried out in a straight line towards the goal.

2. If the MR approaches the obstacle at some point $\mathbf{r}^+$, then it changes direction and begins to move along the border of the obstacle. In addition, he remembers the coordinates of the turning point $\mathbf{r}^+$.

3. Movement along the border continues until the point of departure from the obstacle is reached $\mathbf{r}^-$, which is determined by two conditions:

1) $\mathbf{r}^-$ is closer to the goal compared to the turning point $\mathbf{r}^+$, i.e. $\|\mathbf{d}_g(\mathbf{r}^-)\| < \|\mathbf{d}_g(\mathbf{r}^+)\|$;

2) the direction of movement to the goal is free.

4. Then the MR performs a straightforward movement towards the goal.

Application of Potential Fields

To determine the vector of the control action $\mathbf{u}$ to the actuators of the robot at each discrete time instant τ, it is proposed to apply the method of potential fields.

The goal of the movement forms an attractive field $U_{att}(\mathbf{r})$, and the obstacles – repellent $U_{rep}(\mathbf{r})$. The antigradients of these fields are potential forces $\mathbf{F_{att}}(\mathbf{r}) = -\nabla U_{att}(\mathbf{r})$ and $\mathbf{F_{rep}}(\mathbf{r}) = -\nabla U_{rep}(\mathbf{r})$.

These forces are used to form the vector of the control action $\mathbf{u}$, which determines speed and direction of movement of the MR. The vector $\mathbf{u}$ is calculated according the rules on which the field bug algorithm is based.

It is decided to take a parabolic function near the target and a linear far from it as an attractive potential [6]. Such a potential function generates to the following potential force:

$$\mathbf{F_{att}}(\mathbf{r}) = \begin{cases} \dfrac{k_a}{\rho_g}\mathbf{d}_g(\mathbf{r}), & \|\mathbf{d}_g(\mathbf{r})\| \le \rho_g, \\ k_a \dfrac{\mathbf{d}_g(\mathbf{r})}{\|\mathbf{d}_g(\mathbf{r})\|}, & \|\mathbf{d}_g(\mathbf{r})\| > \rho_g, \end{cases} \quad (1)$$

where $\rho_g > 0$ – radius of the area around the goal, within which a parabolic potential function is used; $k_a > 0$ – a constant; and $\| \bullet \|$ - Euclidean norm of a vector.

The repulsive field creates a “potential barrier” of width ρ_r around the obstacle, in which the potential increases sharply when approaching the obstacle [6]. Potential force created by this field:

$$\mathbf{F_{rep}}(\mathbf{r}) = \begin{cases} -k_r\left(\dfrac{1}{\|\mathbf{d}_o(\mathbf{r})\|} - \dfrac{1}{\rho_r}\right)\dfrac{\mathbf{d}_o(\mathbf{r})}{\|\mathbf{d}_o(\mathbf{r})\|^3}, & \|\mathbf{d}_o(\mathbf{r})\| \le \rho_r, \\ 0, & \|\mathbf{d}_o(\mathbf{r})\| > \rho_r, \end{cases} \quad (2)$$

where $k_r > 0$ is a constant.

A Field Bug Algorithm

The robot, controlled by the field bug algorithm, has two modes of movement: *free movement* and *obstacle bypass.*

In the absence of obstacles located near the robot in a radius of ρ_o^+, the robot performs free movement. The value of $\rho_o^+ > \rho_r$ is a constant that sets the width of the zone of influence of obstacles in free movement mode. The control action is determined by the attractive potential force (1):

$$\mathbf{u} = \mathbf{F_{att}}(\mathbf{r}) .$$

In the case when the distance from the MR to the nearest point of the obstacle becomes smaller than the value of ρ_o^+, and this point is on the route of the robot, the robot begins to bypass the obstacle. It is considered that the point lays on the

MR's way if the scalar product of vectors $\mathbf{d}_g(\mathbf{r})$ and $\mathbf{d}_o(\mathbf{r})$ is greater than zero. At the beginning of the obstacle bypass, the robot remembers the turning point $\mathbf{r}^+$.

The obstacle bypass mode is based on the idea from [6, 6], where it is proposed for the robot to go around the obstacles along the equipotential lines (isolines) of the repulsive potential field.

In the obstacle bypass mode, the width of the obstacle influence zone is set by the constant $\rho_o^- > \rho_o^+$. The control action vector is primarily formed by the *tangential force* $\mathbf{F_{tan}}(\mathbf{r})$, which is directed along the tangent to the isoline of the repulsive potential field of the obstacle and, therefore, perpendicular to the vector $\mathbf{d}_o(\mathbf{r})$. The absolute value of the force $\mathbf{F_{tan}}(\mathbf{r})$ is set equal to the magnitude of $\mathbf{F_{att}}(\mathbf{r})$. Thus, the tangential force vector is found from the solution of the following system of equations:

$$\begin{cases} \langle \mathbf{F_{tan}}(\mathbf{r}),\ \mathbf{d}_o(\mathbf{r}) \rangle = 0, \\ \|\mathbf{F_{tan}}(\mathbf{r})\| = \|\mathbf{F_{att}}(\mathbf{r})\|, \end{cases} \tag{3}$$

where the angle brackets $\langle\ ,\ \rangle$ denote the scalar product of vectors.

System (3) has two solutions corresponding to the directions of bypassing the obstacle on the left and right sides. In this paper, it is proposed to bypass by the left side. Thus, the tangential force is determined by the following expression:

$$\mathbf{F_{tan}}(\mathbf{r}) = \left(-d_{o2} \frac{\|\mathbf{F_{att}}(\mathbf{r})\|}{\|\mathbf{d}_o(\mathbf{r})\|},\ d_{o1} \frac{\|\mathbf{F_{att}}(\mathbf{r})\|}{\|\mathbf{d}_o(\mathbf{r})\|} \right), \tag{4}$$

where d_{o1}, d_{o2} – coordinates of vector $\mathbf{d}_o(\mathbf{r}) = (d_{o1},\ d_{o2})$.

To avoid the collision of the robot with obstacles, the repulsive force (2) is added to the tangential force (4):

$$\mathbf{u} = \mathbf{F_{tan}}(\mathbf{r}) + \mathbf{F_{rep}}(\mathbf{r})\ .$$

Obstacle bypass must be completed when the following three conditions are met.

1. The vector directed to the goal and the vector directed to the nearest obstacle point form an obtuse angle: $\langle \mathbf{d}_g(\mathbf{r}),\ \mathbf{d}_o(\mathbf{r}) \rangle < 0$.

2. The distance from the current position to the goal is less than from the remembered turning point $\mathbf{r}^+$:

$$\|\mathbf{d}_g(\mathbf{r})\| < \|\mathbf{d}_g(\mathbf{r}^+)\|.$$

3. There are no obstacles at a distance from the robot, not exceeding ρ_o^-, in the direction of the vector $\mathbf{d}_g(\mathbf{r})$.

If the first two conditions are met, but the third is not satisfied, the new position of the turning point should be remembered: $\mathbf{r}^+ = \mathbf{r}$.

Also, the bypass should be completed if no obstacles are found in radius ρ_o^- from the robot.

Computer Simulation Results

To study the developed method, a robot motion simulation environment was created using Python 3 programming language.

Robots were modelled by material points that are not sized and are able to move in any direction. The motion of the robot is described by the following equation:

$$T\ddot{\mathbf{r}} + \dot{\mathbf{r}} = k\mathbf{u},$$

where T, k – constants and $T = 0.20$; $k = 1.00$.

The radiuses of the zones were taken as follows:

$$\rho_g = 0.27 \text{ м}, \ \rho_r = 0.18 \text{ м}, \ \rho_o^+ = 0.50 \text{ м}, \ \rho_o^- = 2.00 \text{ м}.$$

When calculating the potential forces (1), (2), the following coefficient values were used: $k_a = 0.60$; $k_r = 0.12$. The simulation results of bypass of obstacles of various types are presented in Fig. 3.

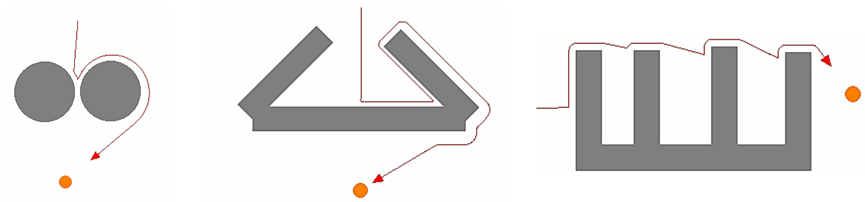


Fig. 3. Trajectories of bypassing simple obstacles of various kinds by MR

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