Research on obstacle avoidance path planning of electrical control robot in unknown environment

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Abstract. Aiming at the problems of robot path planning with artificial potential field method, such as target unreachable and local minimum points, an improved artificial potential field method model is proposed. The obstacles in unknown environment are designed in the form of grid map, so that the robot can avoid obstacles and move towards the target through perception. Matlab GUI is used to set up a two-dimensional coordinate system environment including obstacles and target points, and the optimal trajectory movement simulation experiment is carried out from the initial position to the desired position in the plane map. Experiments show that the improved artificial potential field method can make the mobile robot navigate in unknown environment, avoid obstacles and find the appropriate path, so as to achieve the requirement of collision free. The simulation results are close to the expected results, which shows that this method can effectively improve the feasibility of path planning and the effectiveness of obstacle avoidance of mobile robot in unknown environment.

Keywords: Robot, Path planning, Artificial potential field, Obstacle avoidance, MATLAB.

1. Introduction
In mobile robot navigation, path planning aims to get an optimal collision free path between the starting point and the target position. In the navigation phase, the robot follows the line toward the target and determines the optimal path according to the surrounding environment [1].

The artificial potential field method [2] can obtain a smooth path in path planning, but it is easy to generate unreachable target and local minimum points. In the improved artificial potential field method, the proposed path finding strategy is to design the static unknown obstacles in the unknown environment in the form of grid map, and the robot moves to the target by perceiving and avoiding obstacles in the unknown environment. In the improved artificial potential field model, each obstacle is regarded as a charge with repulsive potential, and the target point is regarded as a charge with potential attraction. By combining these potentials, a new map and optimal path will be generated in the potential field.

2. Principle of artificial potential field method
The artificial potential field method is a method of constructing virtual potential function first proposed by Khatib. Its basic idea is that in the artificial potential field, the robot is attracted by the attraction from the target point, the potential field attracts it to move towards the target point, and the repulsive force...
from the obstacle prevents it from moving towards the obstacle. The two works together to make the robot finally reach the target point.

The vector of the robot in two-dimensional environment is \( X = (x, y) \), the coordinate vector of the target point is \( X_g = (x_g, y_g) \), and the combined potential field \([3-7]\) composed of attractive potential field \( U_a \) and repulsive potential field \( U_r \) is \( U \). The combined force field at \( x \) is:

\[
U(X) = U_a(X) + U_r(X)
\]  

(1)

In the force field, the gravitational force \( F_a = -\text{grad}[U_a(X)] \) and the repulsive force \( F_r = -\text{grad}[U_r(X)] \), so the resultant force \( F_t \) of the robot is:

\[
F_t = F_a + F_r
\]  

(2)

The resultant force of the robot in two-dimensional space is as follows:

\[
\nabla U(X) = \begin{bmatrix}
\frac{\partial U}{\partial x} \\
\frac{\partial U}{\partial y}
\end{bmatrix}
\]  

(3)

2.1. Gravitational field of target point

Since the gravitational field is related to the position of the target, the gravitational field of the target point is defined as:

\[
U_a(X) = \frac{1}{2} k (X - X_g)^2
\]  

(4)

If the negative gradient of the target potential field is its gravity \( F_a(X) \), then:

\[
F_a = -\text{grad} [U_a(X)] = - k (X - X_g) = kp_a
\]  

(5)

Where \( k \) is the gravitational gain coefficient and is positive; \( X \) is the coordinate of the current robot in two-dimensional space; \( X_a \) = the position of the target point; \( p_a = \| X - X_g \| \) is the relative distance between the robot and the target point \( g \), the robot can converge to the target point linearly under the action of gravity.

2.2. Repulsive force field of obstacles

The repulsive force field near an obstacle is generally expressed by the FIRAS function proposed by Khatib:

\[
U_r(X) = \begin{cases}
\frac{1}{2} m \left( \frac{1}{p} - \frac{1}{p_0} \right)^2, & p \leq p_0 \\
0, & p > p_0
\end{cases}
\]  

(6)

In equation (6), \( m \) is the repulsion gain coefficient and is positive; \( p \) is the shortest distance between robot and obstacle; \( p_0 \) is a positive constant, which indicates the influence distance of the obstacle. The robot is not affected by the obstacle outside \( p_0 \).
The corresponding gravity is the negative gradient of the target potential field:

$$F_r = -\text{grad} \left[ U_r(X) \right] = \begin{cases} m \left( \frac{1}{p} - \frac{1}{p_0} \right) \frac{1}{p^2} \frac{\partial p}{\partial x} \quad p \leq p_0 \\ 0, \quad p > p_0 \end{cases} \tag{7}$$

In equation (7), $\frac{\partial p}{\partial x} = \left[ \frac{\partial p}{\partial x} \quad \frac{\partial p}{\partial y} \right]^T$.

3. Improved artificial potential field method

3.1. Brief introduction of algorithm principle

In this algorithm, every obstacle in the artificial potential field is treated as a point source with repulsive effect, and its repulsive force $F_r'$ is:

$$F_r' = \frac{W}{(I_r - B_x)^2 + (I_r - B_y)^2} \tag{8}$$

In Equation (8), $W$ represents the energy of the charge, $I_x$ and $I_y$ represent all points distributed on the map, and $B_x$ and $B_y$ represent the center of the obstacle.

In this way, a matrix graph is generated in the artificial potential field. In the matrix graph, every element has potential energy on the coordinate $(I_r, I_y)$, and the center and boundary of the obstacle in the map will generate large potential energy values [8 - 10].

Other forces are generated by attractive targets and are proportional to the distance of the robot. The attraction $F_a'$ is:

$$F_a' = W \cdot \sqrt{(I_y - y_e)^2 + (I_x - x_e)^2} \tag{9}$$

A $100 \times 100$ matrix graph is generated in the artificial potential field, with a minimum potential energy value at the target and a maximum potential energy value at the robot position. By combining the two forces, a repulsive and attractive potential energy map can be obtained, as shown in Fig. 1. These two forces are shown in the figure, making the repulsive field like a wall and the gravitational field like a valley. Through the interaction of the potential field, the feasible path of the robot can be plotted.

Figure 1. Artificial potential field simulation diagram
A numerical example of the artificial potential field simulation diagram is shown in Table 1. Each value of 300 shown in the table represents an obstacle.

| Table 1. Numerical examples of artificial potential field simulation |
|---------------------------------------------------------------|
| 131.1 141.9 155.7 174.2 199.8 237.7 297.8 300 300 300 |
| 130.9 141.8 155.8 174.5 200.4 238.6 299.6 300 300 300 |
| 130.6 141.7 155.9 174.7 201.0 240.5 300 300 300 300 |
| 130.2 141.4 155.8 174.9 201.4 241.1 300 300 300 300 |
| 129.7 141.1 155.7 175.0 201.6 240.6 300 300 300 300 |
| 129.1 140.8 155.6 175.2 202.1 241.4 300 300 300 300 |
| 128.5 140.3 155.5 175.4 202.9 243.7 300 300 300 300 |
| 127.8 139.8 155.3 175.6 203.7 245.4 300 300 300 300 |
| 126.9 139.2 155.0 175.9 204.5 246.0 300 300 300 300 |
| 125.9 138.5 154.7 176.2 205.6 248.0 300 300 300 300 |

3.2. Steps to find a path
In the entire artificial potential field, obstacles and target points are endowed with certain potential energy values as elements of the potential field map. The following steps are taken to obtain a reliable path:

Step 1: Set the size of the potential field map as 100 × 100. The first Step of the algorithm starts from the first element (1,1) or the origin to form a 3 × 3 submap containing 9 elements.

Step 2: After a 3 × 3 map is formed from the corner of the largest map, the 9 elements are compared with each other, and the smallest element found represents the smallest potential energy.

Step 3: By transforming the submap, the smallest element found in Step 2 will serve as the center of the new map.

Step 4: Compare the minimum element coordinates with the target coordinates. If they are equal, stop looking.

Step 5: Repeat Step 2, 3, and 4 until the 100 × 100 potential field map is completed.

3.3. The solution of local minimum problem
If the robot is in a certain region from the 3 × 3 subgraph formed by Step 2, if the new target potential energy is found to be equal to the previous target potential energy but not equal to the final coordinate potential energy, then this region is called the local minimum region.

The solution to the local minimum problem is to replace the existing local minimum point with an obstacle with high potential, and repeat the operation of Step 2. After several iterations, the robot can be excluded from the local minimum area. Specific solutions are as follows:

In the first table, where the first element is the local minimum, replace it with a value of 300, as shown in Table 2.

After this step, if you find that its next value is still a local minimum, as shown in Table 3, repeat the procedure and replace it with a value of 300.
### Table 2. The first time search

|    | 96.9 | 96.91 | 97.1 | 97.5 | 98.2 | 99.2 | 100.6 | 102. | 105.1 | 108.6 |
|----|------|-------|------|------|------|------|-------|------|-------|-------|
|    | 97.3 | 97.4  | 97.7 | 98.2 | 99.0 | 100.2 | 101.7 | 103.9 | 106.7 | 110.6 |
|    | 97.7 | 97.9  | 98.2 | 98.9 | 99.8 | 101.1 | 102.8 | 105.2 | 108.3 | 112.4 |
|    | 98.1 | 98.4  | 98.8 | 99.57| 100.6| 102.0 | 105.9 | 108.4 | 109.8 | 114.2 |
|    | 98.5 | 98.8  | 99.4 | 100.2| 101.3 | 102.9 | 104.9 | 107.6 | 111.2 | 115.8 |
|    | 99.0 | 99.3  | 99.9 | 100.8| 102.1 | 103.7 | 105.9 | 108.8 | 112.5 | 117.3 |
|    | 99.4 | 99.8  | 100.5| 101.5 | 102.8 | 104.6 | 106.9 | 109.3 | 113.7 | 118.8 |
|    | 99.85| 100.3 | 101.0| 102.1 | 103.5 | 105.4 | 107.8 | 110.9 | 114.9 | 120.1 |
|    | 100.2| 100.8 | 101.6| 102.7 | 104.2 | 106.1 | 108.7 | 111.9 | 116.0 | 121.4 |
|    | 100.6| 101.2 | 102.1 | 103.3 | 104.8 | 106.9 | 109.5 | 112.8 | 117.1 | 122.6 |

### Table 3. The second time search

|    | 300  | 96.91 | 97.1 | 97.5 | 98.2 | 99.2 | 100.6 | 102. | 105.1 | 108.6 |
|----|------|-------|------|------|------|------|-------|------|-------|-------|
|    | 97.3 | 97.4  | 97.7 | 98.2 | 99.0 | 100.2 | 101.7 | 103.9 | 106.7 | 110.6 |
|    | 97.7 | 97.9  | 98.2 | 98.9 | 99.8 | 101.1 | 102.8 | 105.2 | 108.3 | 112.4 |
|    | 98.1 | 98.4  | 98.8 | 99.57| 100.6| 102.0 | 105.9 | 108.4 | 109.8 | 114.2 |
|    | 98.5 | 98.8  | 99.4 | 100.2| 101.3 | 102.9 | 104.9 | 107.6 | 111.2 | 115.8 |
|    | 99.0 | 99.3  | 99.9 | 100.8| 102.1 | 103.7 | 105.9 | 108.8 | 112.5 | 117.3 |
|    | 99.4 | 99.8  | 100.5| 101.5 | 102.8 | 104.6 | 106.9 | 109.9 | 113.7 | 118.8 |
|    | 99.85| 100.3 | 101.0 | 102.1 | 103.5 | 105.4 | 107.8 | 110.9 | 114.9 | 120.1 |
|    | 100.2| 100.8 | 101.6 | 102.7 | 104.2 | 106.1 | 108.7 | 111.9 | 116.0 | 121.4 |
|    | 100.6| 101.2 | 102.1 | 103.3 | 104.8 | 106.9 | 109.5 | 112.8 | 117.1 | 122.6 |

### Table 4. The fourth time search

|    | 300  | 300   | 97.1 | 97.5 | 98.2 | 99.2 | 100.6 | 102. | 105.1 | 108.6 |
|----|------|-------|------|------|------|------|-------|------|-------|-------|
|    | 97.3 | 97.4  | 97.7 | 98.2 | 99.0 | 100.2 | 101.7 | 103.9 | 106.7 | 110.6 |
|    | 97.7 | 97.9  | 98.2 | 98.9 | 99.8 | 101.1 | 102.8 | 105.2 | 108.3 | 112.4 |
|    | 98.1 | 98.4  | 98.8 | 99.57| 100.6| 102.0 | 103.9 | 106.4 | 109.8 | 114.2 |
|    | 98.5 | 98.8  | 99.4 | 100.2| 101.3 | 102.9 | 104.9 | 107.6 | 111.2 | 115.8 |
|    | 99.0 | 99.3  | 99.9 | 100.8| 102.1 | 103.7 | 105.9 | 108.8 | 112.5 | 117.3 |
|    | 99.4 | 99.8  | 100.5| 101.5 | 102.8 | 104.6 | 106.9 | 109.9 | 113.7 | 118.8 |
|    | 99.85| 100.3 | 101.0 | 102.1 | 103.5 | 105.4 | 107.8 | 110.9 | 114.9 | 120.1 |
|    | 100.2| 100.8 | 101.6 | 102.7 | 104.2 | 106.1 | 108.7 | 111.9 | 116.0 | 121.4 |
|    | 100.6| 101.2 | 102.1 | 103.3 | 104.8 | 106.9 | 109.5 | 112.8 | 117.1 | 122.6 |
Table 5. The fifth time search

| 300 | 300 | 300 | 97.5 | 98.2 | 99.2 | 100.6 | 102.105.1108.6 |
| 97.3 | 97.4 | 97.7 | 98.2 | 99.0 | 100.2 | 101.7 | 103.9106.7110.6 |
| 97.7 | 97.9 | 98.2 | 98.9 | 99.8 | 101.1 | 102.8 | 105.2108.3112.4 |
| 98.1 | 98.4 | 98.8 | 99.57 | 100.6 | 102.0 | 103.9 | 106.4109.8114.2 |
| 98.5 | 98.8 | 99.4 | 100.2 | 101.3 | 102.9 | 104.9 | 107.6111.2115.8 |
| 99.0 | 99.3 | 99.9 | 100.8 | 102.1 | 103.7 | 105.9 | 108.8112.5117.3 |
| 99.4 | 99.8 | 100.5 | 101.5 | 102.8 | 104.6 | 106.9 | 109.9113.7118.8 |
| 99.85 | 100.3 | 101.0 | 102.1 | 103.5 | 105.4 | 107.8 | 110.9114.9120.1 |
| 100.2 | 100.8 | 101.6 | 102.7 | 104.2 | 106.1 | 108.7 | 111.9116.0121.4 |
| 100.6 | 101.2 | 102.1 | 103.3 | 104.8 | 106.9 | 109.5 | 112.8117.1122.6 |

In Table 4 and table 5, continue the above replacement operation until the robot leaves the local minimum area.

4. Simulation experiment

The GUI program of MATLAB is used to implement this algorithm, which can randomly set obstacles and target points, and realize and verify the reasonable planning of robot obstacle avoidance path. Fig. 2 shows the designed GUI simulation interface, which is composed of three-dimensional simulation diagram of artificial potential field, two-dimensional plane simulation diagram, control command button, result display and other functions.

The operation of GUI simulation interface is as follows: after clicking the "insert obstacle" button, any obstacle can be set in the simulated artificial potential field and displayed in the simulation interface; Click the "insert target" button to locate the target at will; Finally, the path planning of mobile robot can be generated and displayed through the button "get result".

The simulation experiment uses three predefined map maps and a randomly defined map to test. According to the selected target point and the set obstacle, the robot starts from the center of the origin (1,1) to find the appropriate path to avoid the obstacle and reach the target point.

Figure 2. GUI simulation interface
Figure 3. Test in MAP1

Figure 4. Test in MAP2
Select and generate MAP1 in the GUI simulation window, as shown in Fig. 3, and mark the target at about (9.4, 8.8). The right figure in Fig. 3 shows the set obstacle, the defined target and the path created by the algorithm; The middle left figure of Figure 3 shows the found path in another way. There is an extra high potential in the map, which shows that there is a local minimum problem and it has been solved.

The generated MAP2 is shown in Fig. 4. When obstacles are set and target points are set in MAP2, the problem of local minimum is solved, and the path is smooth.

The generated map3 is shown in Fig. 5. The above situation also appears and is solved when the path of map3 is solved.

The user-defined map is generated randomly, as shown in Fig. 6. The target is marked in the map, and the path that can accurately avoid obstacles and reach the target point is obtained after solving.
5. Conclusion
In this paper, the obstacle in the artificial potential field is treated as the electric potential with repulsive effect, and the artificial potential field model is improved, so that the robot can avoid the existing obstacles when searching the path. For the local minimum problem that may be faced, the local minimum point is replaced by the obstacle with high electric potential, and the local minimum problem can be solved after several iterations. The simulation results show that the improved artificial potential field method is simple and effective, the path is smooth, the method has real-time and flexibility, can adapt to unknown environment, and the planning result is better than the traditional artificial potential field method.

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