Research of Robot Path Planning Based on Improved Artificial Potential Field

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Keywords: Mobile robot; Path planning; Artificial potential field; Local minimum

Abstract. Though the artificial potential field applying to the path planning of mobile robot has the advantages of rapid respondent speed, small computation and real-time property, there are still problems such as the goal unreachable and existence of a local minimum point value, thus the improved artificial potential field is proposed in this paper. Considering the relative distance between the robot and the goal the improved algorithm adopts the improved potential function to make sure that the goal is the global minimum of the whole potential field. The repulsion direction is modified to avoid the robot suffers into local minimum, so the robot can reach the goal freely. The simulation results show that the robot can get a smooth and no touching optimal path in the environment of many obstacles. The effectiveness of the improved algorithm is verified.

Introduction

The artificial potential field method was proposed by Khatib[1] in 1986. It was designed just to solve problem that when mechanical arm grab mobile objects ,can not meet the work table. It was later found that this method has a good effect on the mobile robot, which can produce a very smooth running track. The basic idea is to introduce a numerical function which called artificial potential field to describe the spatial structure. In which the obstacle generates repulsive force, the target point generates attractive force, the forces in the potential field guide robot around the obstacle to reach the target point smoothly. In artificial potential field method, the robot's motion is determined by the potential field and its gradient direction. Therefore, it has the advantages of small computation and good real-time performance comparing other path planning methods. However , the traditional artificial potential field method has the limitations of local minimum and the target can not be reached. At present, there are many methods to jump out of the local minimum , such as increased guidance, introduced the escape force, geometric information method, simulated annealing algorithm, dynamic step length binary method, walking along the wall method and so on[2-7]. In this paper, the problem of local minimum is solved by changing the direction of repulsion force and the robot moves toward the target point.

The basic principles of artificial potential field

Assuming that the robot is a particle, the position of the robot is $X=[x,y]^T$, the target position is $X_g=[x_g,y_g]^T$ in the working space, the artificial potential field function can be described as:

$$U(X)=U_{att}(X)+U_{rep}(X) \tag{1}$$

In which: $U(X)$ is the potential energy function of the particle, $U_{att}(X)$ is the gravitational potential field generated by the target point, and $U_{rep}(X)$ is the repulsive force field caused by the obstacle. Therefore, the resultant force of the robot is:

$$\overrightarrow{F}=\overrightarrow{F_{att}}+\overrightarrow{F_{rep}} \tag{2}$$

Where $\overrightarrow{F_{att}}=-grad[U_{att}(X)],\overrightarrow{F_{rep}}=-grad[U_{rep}(X)]$ .The resultant force of the robot in the two

dimensional space is:

$$\nabla U = \begin{bmatrix} \frac{\partial U}{\partial x} \\ \frac{\partial U}{\partial x} \end{bmatrix} \tag{3}$$

The gravitational field function of the robot is:

$$U_{att}(X) = \frac{1}{2} k \rho^2 (X, X_g) \tag{4}$$

Where: k is the direct proportion position gain coefficient, X, X_g represent the space position of the mobile robot and the target point respectively. $\rho(X, X_g) = \|X_g - X\|$ represents the distance between the mobile robot and the target point.

The gravitational pull of gravitational field:

$$F_{att}(X) = k(X_g - X) \tag{5}$$

The direction of gravity is in the connection between the mobile robot and the target point,and point to the target.

Repulsive force field function of robot for obstacles:

$$U_{rep}(X) = \begin{cases} \frac{1}{2}\eta \left[\frac{1}{\rho(X, X_o)} - \frac{1}{\rho_o} \right]^2 & \rho(X, X_o) \le \rho_o \\ 0 & \rho(X, X_o) > \rho_o \end{cases} \tag{6}$$

In which: η is a constant of repulsive force; X is the robot's current position; X_o indicates the location of the obstacle; $\rho(X, X_o)$ is a vector of Euclidean distance $\|X - X_O\|$ between the robot and the obstacle, vector direction is on the line which the robot point to the obstacle , ρ_o is defined as the maximum distance which the robot is affected by obstacles. When the distance between the robot and the obstacle is greater than the affected distance, obstacles do not produce a repulsive force. When the distance is less than the affected distance, the repulsion force will be considered. Then the corresponding repulsion is:

$$\overrightarrow{F_{rep}} = \begin{cases} \eta \left[\frac{1}{\rho(X, X_o)} - \frac{1}{\rho_o} \right] \frac{1}{[\rho(X, X_o)]^2} \frac{\partial \rho(X, X_o)}{\partial X} & \rho(X, X_o) \le \rho_o \\ 0 & \rho(X, X_o) > \rho_o \end{cases} \tag{7}$$

Although the potential field method is simple mathematically, it is widely used in robot path planning. However, because the distance definition from robot to obstacle and target point abandoned the other valuable information of local obstacles, the artificial potential field function is lack of coordination and integration of local environmental and global information. So the two main limitations of artificial potential field are the Destination Unreachable and the local minimum problem[6-8].

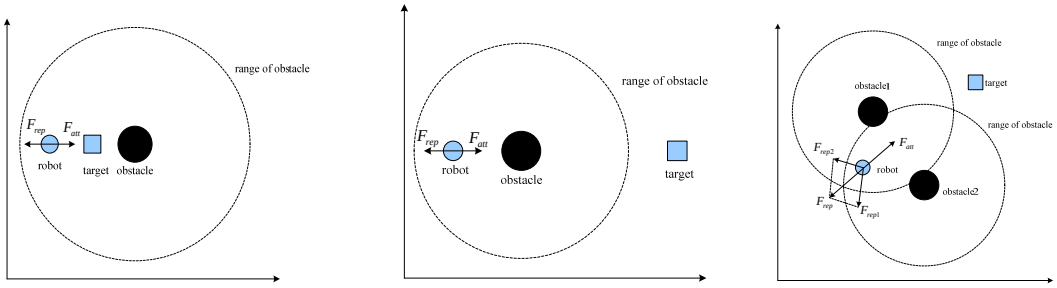
Improved artificial potential field algorithm and realization

There are three cases for the limitation of the traditional artificial potential field method applied to the path planning of mobile robot[9-10]:

1) When the obstacle is close to the target, the robot, obstacle and target point are in the same line, and the target points are in the robot's influence range, the attractive force and repulsive force are equal, which is shown in Figure 1 (a):

2) When the obstacle distance is far from the target point, the robot, obstacle and target point are in the same line, and the attractive force target to robot equals repulsive force obstacle to robot, the robot will be into local minimum, which is shown in Figure 1 (b):

3) When there are many obstacles and the target point is in the obstacles range, the resultant force of all the repulsive force is equal to the attractive force target to the robot , the local minimum value will be formed which is shown in Figure 1 (c):



(a) (b) (c)

Fig.1. Local minimum problem

As the distance between target and obstacle is far and the robot is approaching the target, the repulsive force of the obstacle becomes small, even can be ignored. The robot can reach the target point under the gravitation. In the case that there are obstacles near the target points, when the robot is closing to the target, and it is also closing to the obstacle at the same time, then the robot will stop in front of the obstacle and can not reach the target point, which is shown in Figure 2.So,in order to ensure that the target point is the global minimum in the potential field, a new repulsion function is introduced to make the repulsion tend to zero when the robot is closing to the target by considering the relative distance between the robot and the target point. The new repulsive field function is:

$$U_{rep}(X)=\begin{cases}\frac{1}{2}\left[\frac{1}{\rho(X,X_o)}-\frac{1}{\rho_o}\right]^2(X-X_g)^n & \rho(X,X_o)\le\rho_o\\ 0 & \rho(X,X_o)>\rho_o\end{cases} \tag{8}$$

In which, n is an arbitrary real number greater than zero. The negative gradient of the repulsion function is the repulsion force after correcting the repulsion field:

$$F_{rep}(X)=-\nabla U_{rep}(X)=\begin{cases}F_{rep1}(X)+F_{rep2}(X) & \rho(X,X_o)\le\rho_o\\ 0 & \rho(X,X_o)>\rho_o\end{cases} \tag{9}$$

$$F_{rep1}=\eta\left[\frac{1}{\rho(X,X_o)}-\frac{1}{\rho_0}\right]^2\frac{1}{\rho(X,X_o)^2}\frac{\partial\rho(X,X_o)}{\partial X}(X-X_g)^n \tag{10}$$

$$F_{rep2}=-\frac{n}{2}\eta\left[\frac{1}{\rho(X,X_o)}-\frac{1}{\rho_0}\right]^2\frac{\partial(X-X_g)^n}{\partial X}(X-X_g)^{n-1} \tag{11}$$

In which, F_{rep1} is the first component of the repulsive force, which can be calculated by the formula, its direction from the obstacle to the robot. F_{rep2} is the second component of the repulsive force, which can also be obtained by the formula , and the direction is from the robot to the target. After improving the repulsion function, in order to clearly express the change of the robot's force, the force analysis of robot is made in the case there is only one obstacle in the environment. The robot force situation is shown in Figure 3:

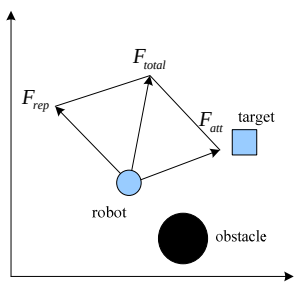


Fig.2. The target is not reachable

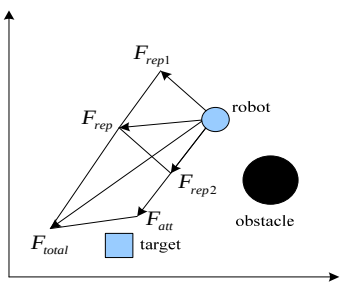


Fig.3. The improved potential field

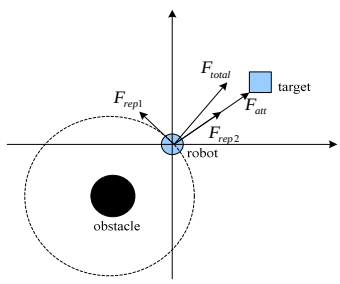


Fig.4. Repulsion force of the new definition.

The new parameter n is introduced by the improved repulsion function. It can be seen that the improved repulsive force field function is the same as that of the non improved potential field, when n equals zero. When n takes different values, the characteristics of potential field force function are

discussed, as followed:

1) When $0 < n < 1$, the improved repulsive force function is not differential at $X = X_g$. When $X - X_o \le \rho_0, X - X_o \ne 0$,

$$F_{rep1} = \eta\left[\frac{1}{\rho(X, X_o)} - \frac{1}{\rho_0}\right]\frac{1}{\rho(X, X_o)^2}(X - X_g)^n \tag{12}$$

$$F_{rep2} = \frac{n}{2}\eta\left[\frac{1}{\rho(X, X_o)} - \frac{1}{\rho_0}\right]^2\frac{1}{(X - X_g)^{1-n}} \tag{13}$$

While the mobile robot approaches the target, $(X - X_g)$ tends to zero, and the first component F_{rep1} also tends to zero, but the second component F_{rep2} tends to infinity because it is opposite to F_{rep1}.The robot can realize the path planning.

When $n = 1$, $X - X_o \le \rho_0, X - X_o \ne 0$,

$$F_{rep1} = \eta\left[\frac{1}{\rho(X, X_o)} - \frac{1}{\rho_0}\right]\frac{1}{\rho(X, X_o)}(X - X_g) \tag{14}$$

$$F_{rep2} = \frac{1}{2}\eta\left[\frac{1}{\rho(X, X_o)} - \frac{1}{\rho_0}\right]^2 \tag{15}$$

While the robot approaches the target position, $(X - X_g)$ tends to zero, the F_{rep1} is more close to zero, and the F_{rep2} becomes a constant, the robot can move towards the target point.

When n>1, the repulsive force field function of obstacle is differential at the target point. When the mobile robot moves toward the target, the total repulsive force tends to zero.

The improved artificial potential field method can solve local minimum problem1 when the robot is close to the target point and the target point is in the range of obstacles. The repulsive force field increases rapidly, and gravitational field of the target point rapidly attenuates. But this method has no effect on solving the local minimum problem b and problem c.

In order to solve the problem b,c of local minimum, the method by changing the direction of repulsion force is proposed in this paper. Mobile robot model is regarded as a particle, and the obstacles are expand to the round surface, considering the actual size of the robot at the same time. In reality, in order to avoid the collision of robot in the bypass obstacles, the size of the robot is converted into the round surface of the obstacles. The repulsion F_{rep} is still decomposed into F_{rep1} and F_{rep2} ,the F_{rep1} direction is from obstacle which is the nearest from robot point to the robot ,the direction of F_{rep2} is from the robot to the target. If the angle between the F_{rep1} and the gravitation is greater than 90° in some cases, there will be a local minimum point. In this paper, the direction of F_{rep2} is defined from the robot to the target, while is the same as the improved artificial potential field method, but direction of F_{rep1} is tangent to the sphere of influence of obstacles, and the angle between F_{rep1} and the gravitation is not greater than 90.The plane right angle coordinate system is set up, and the robot is the origin of the coordinate system. The connection of the robot and the target point with the X axis is 45° and points to the target point. The repulsion direction of new definition is shown in Figure 4:

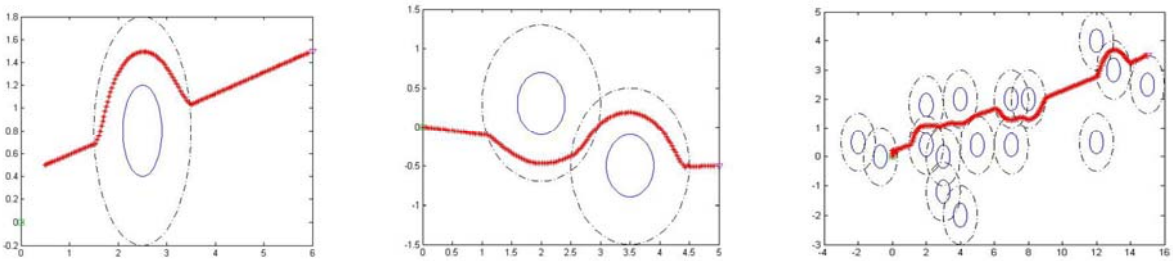
Simulation experiment

Simulation experiments are carried out for the local minimum in the path planning problem. If the robot is moving at a constant rate, the resultant force only determines by the robot's movement direction. The circular obstacles are distributed in the region, the starting point of the simulation is the origin of the coordinates.

1) The obstacle is between the robot and the target point,which is shown in Figure 5(a):

2) The robot crosses through the narrow passage of obstacles,which is shown in Figure 5(b):

3) There are multiple obstacles in the complex environment,which is shown in Figure 5(c):



(a) (b) (c)

Fig.5. Path planning for escaping local minimum

From the simulation results, the robot can effectively escape from local minimum point and plan the optimal path to the target point by in the environment of the known obstacles. The method of modifying the direction of repulsion force based on the improved potential field function is effective.

Aiming at the existing problem of robot path planning, comparative experiments are carried out. Assuming that the initial position of the robot is[0 0], the target point is [13.5 12] ,the number of obstacles is 10, the gravitation gain coefficient k is100, the repulsion gain coefficient is 5, the step size l=0.2, the iteration number is 200. The path planning with non improved method is shown in Figure 6, and the path planning with the improved method is shown in Figure 7.

From simulation results, we can see that the robot planning path is shorter and more smooth, and robot reach the target point finally by using the improved method.

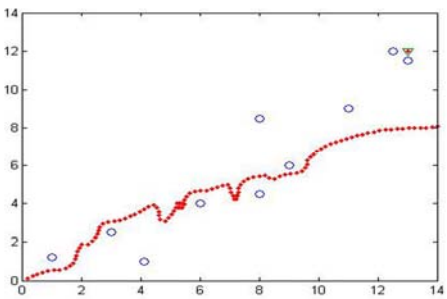


Fig.6. Path planning with non improved method.

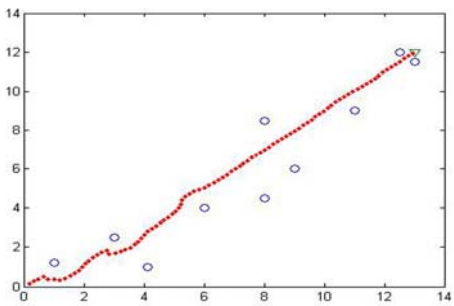


Fig.7 The path planning with the improved method.

Conclusion

Artificial potential field method is simple and real time is very good, but, it is easy to fall into local minimum because of the limited amount of environmental information.In this paper, detailed analysis is made on the local minimum point problem of the traditional artificial potential field method. Because the target point is too close to the obstacle, the repulsion force field increases and the gravitational potential field decreases, the robot can not reach the target. By introducing the distance between the robot and the target, the robot can find the target accurately. Aiming at the problem that the robot can easily fall into local minimum, by modifying the repulsion direction on the basis of the modified potential field function, a smooth planning path can be obtained in the environment of many obstacles. Finally, the effectiveness of the improved algorithm is proved by simulation results.

Acknowledgement

This study was made possible through a project grant (C201400114), the Technology Foundation for Selected Overseas Chinese Scholar which is supported by Hebei Provincial Department of Human Resources and Social Security.

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