Adaptive artificial potential field approach for obstacle avoidance path planning

Li Zhou[1], Wei Li[1]
Research Institute of Electronic Science and Technology of UESTC
Chengdu 611731, China
zhouli11.1@163.com

Abstract—**This paper presents an adaptive artificial potential field method for robot's obstacle avoidance path planning. Despite the obstacle avoidance path planning based on the artificial potential field method is very popular, but there is local minima problem with this approach. As a result, this paper proposes an improved obstacle potential field function model considering for the size of the robot and the obstacles and changes the weight of the obstacle potential field function adaptively to make the robot escape from the local minima. Three simulations have been done and the simulation results show: the improved algorithm can make the robot escape from the local minima and accomplish the robot collision avoidance path planning well.**

Key words: robots, obstacle avoidance, path planning, potential field.

I. INTRODUCTION

Path planning is one of the important research areas of mobile robot, which means to find a safe, collision-free path from the start to the goal according to some method when there are obstacles in the environment[1]. Typical path planning methods are artificial potential field method, grid method, template matching method and genetic algorithm, etc. Grid method has poor accuracy and poor real-time performance. Because the sensor information resource of the robot is limited, so the obstacle information with the grid map is difficult to calculate and process. Meanwhile, the robot should dynamically update the map data quickly, making it difficult to ensure high real-time when dealing with large grid information[2]. Template matching method is simple in principle. But the fatal flaw of this approach is that it relies on the robot's past experience. If there is not enough path templates in the case library, it can't find a path that matches the current state[3]. Genetic algorithm can get the path quickly. However, because of its inherent limitations, the accuracy of planned path is low[4]. Artificial potential field path planning technology first proposed by Khatib is simple in principle and suitable for real time control[5][6]. In terms of real-time obstacle avoidance path planning and smooth trajectory, it has been widely studied. However, artificial potential field path planning method is easy to fall into local minima and fail to reach the goal[7][8]. This paper solves the problem of local minima well by adjusting the weight of the gaussian-like model obstacle potential field function adaptively.

The paper is organized as follows. The basic principle of artificial potential field method for path planning and a typical traditional artificial potential field method will be introduced briefly in section **II**. In section **III**, this paper will propose a adaptive artificial potential field method to solve the local minima problem. Then in section **IV**, the simulation realized with MATLAB R2010b is to verify the validity of the proposed algorithm. At last, some concluding remarks are given in section **V**.

II. A TRADITIONAL ARTIFICIAL POTENTIAL FIELD METHOD

The basic idea of artificial potential field method for path planning[9] is to make the robot move towards the fastest decline direction of the total potential field by a gradient descent search method. In other words, the method takes the robot in the environment as a kind of robot moving in a virtual manual force field. Obstacles produce a repulsive force on the robot. The goal produces an attractive force on the robot. The total force of the attractive force and the repulsive force controls the moving of the robot. Because of this, the robot can successfully avoid obstacles and reach the goal.

Then a typical traditional artificial potential field method will be introduced to deepen the understanding of the method[9].

Assuming the position of robot is $P_r = (x, y)$ and the position of the goal is $P_g = (x, y)$, then attractive potential function is defined as:

$$U_a = w_a * (P_g - P_r)^2$$

It is easy to find that when the distance between the robot and the goal increases, the attractive potential becomes larger to attract the robot.

The repulsive potential function is defined as:

$$U_{re} = \begin{cases} 0 \\ \frac{1}{2} * \eta * (\frac{1}{\rho} - \frac{1}{\rho_0})^2 \end{cases}$$

Where: η is the constant, which is positive, ρ is the shortest distance between the robot and the obstacle, ρ_0 is the largest impact distance of single obstacle. There is no impact for the robot when the distance between the robot and the obstacle is larger than ρ_0.

It is easy to find that when the distance between the robot and the obstacle decreases, the repulsive potential becomes larger to stop the robot from hitting the obstacle.

Then the total potential field can be expressed as:

$$U_t = U_a + \sum U_{re}$$

The artificial potential field method for path planning is easy to understand and realize. However, this method has the problem of local minima in the following three cases:

(1) In Fig 1, when robot, obstacle and goal are along the same line and the obstacle is at the middle of the robot and the goal. The attractive force may be equal to the repulsive force,

978-1-4799-7005-6/14 $31.00 © 2014 IEEE
DOI 10.1109/ISCID.2014.144

and the force of robot is zero. As a result, the robot will stop at the front of the obstacle or hit the obstacle.

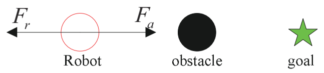

Fig 1: local minima problem

(2) In Fig 2, when the goal is in the front of the robot, there are two obstacles on the robot's left and right sides, respectively, forming a narrow passage. And it leads to the balance of force on the robot and making the robot trapping into local minima.

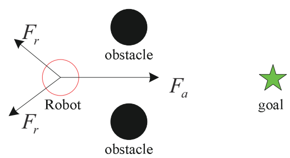

Fig 2: local minima problem

(3) In Fig 3, when the position of the goal is within the range of obstacles, the repulsive field rapidly increases and the attractive field decreases when the robot moves to the goal. Therefore, the robot can never reach the goal.

Fig 3: local minima problem

III. IMPROVED PATH PLANNING ALGORITHM

We consider the robot discrete-time kinematic model is:

$$\begin{cases} P_r(1,i+1) = P_r(1,i) + \lambda * \cos\gamma \\ P_r(2,i+1) = P_r(2,i) + \lambda * \sin\gamma \end{cases}$$

$P_r(1,i+1)$, $P_r(1,i)$ represent the robot's x-coordinate values at time i+1 and time i. $P_r(2,i+1)$, $P_r(2,i)$ represent the robot's y-coordinate values at time i+1 and time i. λ is the step size of the robot. γ is the the yaw angle of the robot in the next step.

A. attractive potential function

The goal potential plays the role of attractive potential, which attracts the robot to the goal. This paper uses the same attractive potential function as the traditional artificial potential field method:

$$U_a = w_a * (P_g - P_r)^2$$

where $P_r = (x, y)$ is the position of robot and $P_g = (x, y)$ is the position of the goal, w_a denotes attractive potential scale factor.

B. obstacle potential function

Obstacle potential plays the role of repulsive potential. We use a Gaussian-like function as the obstacle potential:

$$U_{ob,\mathrm{i}} = w_2 * \exp(-\frac{1}{\sigma^2} * [(x_r - x_{ob,i})^2 + (y_r - y_{ob,i})^2 - R^2 - \mathrm{r}^2])$$

where x_r, y_r represent the robot coordinate values at the current time, $x_{ob,i}$, $y_{ob,i}$ are the coordinate values of the i-th obstacle, σ denotes the standard deviation of the obstacle potential, w_2 represent the obstacle potential scale factor, R is the size of the robot , r is the size of the obstacles.

Supposing that the obstacle potential energy of the n obstacles are $U_{ob,1}$, $U_{ob,2}$, …, $U_{ob,n}$ at one point, we take the maximum of them as the obstacle potential energy at that point, namely U_{ob}=max[$U_{ob,1}$, $U_{ob,2}$, …, $U_{ob,n}$]. That's because the bigger the obstacle potential energy is, the nearer distance between the obstacle and the robot is and the more dangerous the obstacle is to the robot. In other words, we give priority to the most dangerous obstacle. The outline of the algorithm is shown in Fig 3.

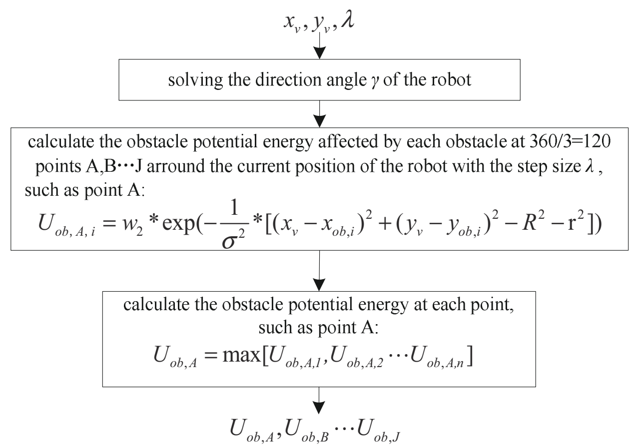

Fig 4: the repulsive potential

We consider the range of the next moving direction of the robot as 360° and every 3° as a direction. Then 120 directions around the robot should be considered when calculating the repulsive potential and we choose the maximum of the repulsive potential produced by different obstacles at each points for the bigger the obstacle potential energy is, the nearer distance between the obstacle and the robot is.

C. total potential function

After the analysis and calculating of the attractive potential and the repulsive potential, we can calculate the total potential around the robot and determine the moving direction of the robot.

The total potential at 120 directions around the robot is:(taken point A as an example)

$$U_{t,A} = U_{a,A} + U_{ob,A}$$

Because the potential of the goal is the minimum, so we choose the direction of the minimum total potential as γ, namely the moving direction of the robot.

D. local minima problem

This paper has introduced about the local minima problems above in part **II**. Now the method to adaptively changing the parameter of the artificial potential field method will be present. First we should judge whether the robot is trapped into the local minima problem. We compare the robot's coordinate values at time t+1 and time t-1. If the difference of the coordinate values is less than a certain value, we consider the local minima problem happened. Then we change the value of the obstacle potential scale factor w_2. Besides, w_2 is restored to its original values if the problems are solved. The outline of the algorithm is shown in Fig 5.

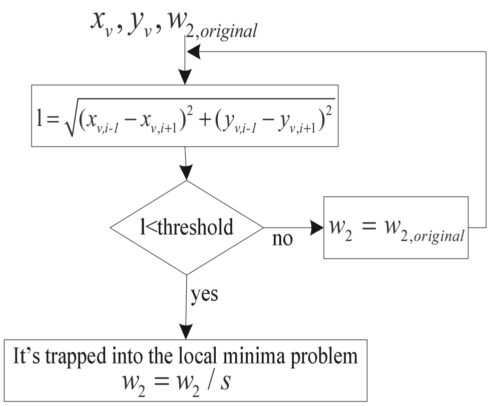

Fig 5

IV. SIMULATION

This paper verified the proposed algorithm with MATLAB R2010b in the three cases of local minima problem introduced in part **II**.

In the first simulation, the initial position of the robot is (2, 6), the position of the goal is (14, 6), and the position of the obstacle is (9, 6). They are along the same line and the obstacle is at the middle of the robot and the goal. Fig 6 displays the total potential energy. x-axis and y-axis are the coordinates of each point. z-axis is the potential energy corresponding to each point. Fig 7 is the path planning result in case 1.

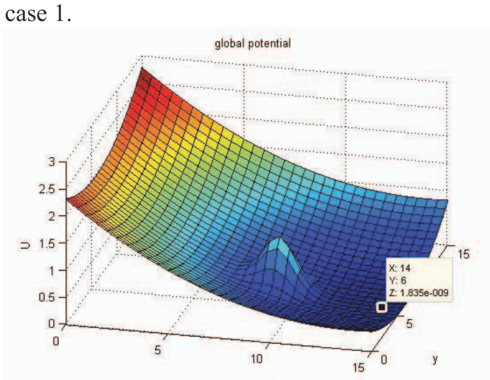

Fig 6: the global potential in case 1

We can see from Fig 6 that the total potential of the goal position (14, 6) is the global minimum and the total potential at the obstacle position (9, 6) is convex obviously. The robot will move towards the fastest decline direction of the total potential field. As a result, the robot can reach the goal without hitting the obstacle.

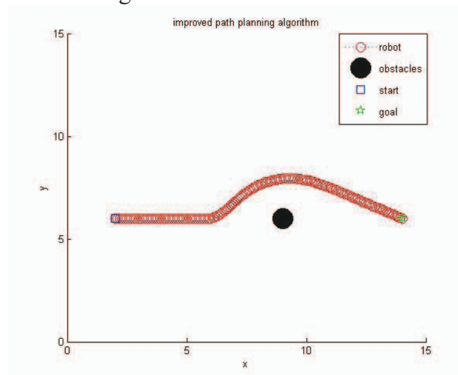

Fig 7: collision avoidance path planning

The red circle represents the robot. The black filled circle represents the obstacle. Fig 7 shows that the robot escaped from the local minima in case 1 and reached the goal successfully without collision with the obstacle.

In the second simulation, the initial position of the robot is (2, 6), the position of the goal is (14, 6), and the position of the obstacles are (9, 4), (9, 7). Fig 8 displays the total potential energy. x-axis and y-axis are the coordinates of each point. z-axis is the potential energy corresponding to each point. Fig 9 is the path planning result in case 2.

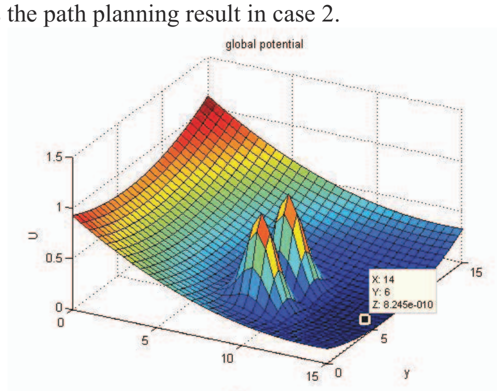

Fig 8: the global potential in case 2

We can see from Fig 8 that the total potential of the goal position (14, 6) is the global minimum and the total potential at the obstacles position (9, 4), (9, 7) are convex obviously. The robot will move towards the fastest decline direction of the total potential field. As a result, the robot can reach the goal without hitting the obstacle.

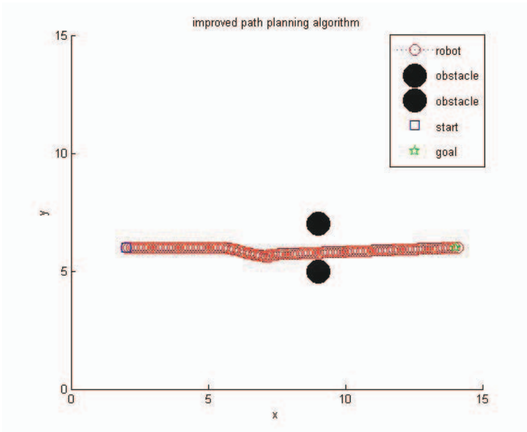

Fig 9: collision avoidance path planning

The red circle represents the robot. The two black filled circles represent the obstacles. Fig 9 shows that the robot escaped from the local minima in case 2 and reached the goal successfully without collision with the obstacles.

In the last simulation, the initial position of the robot is (2, 6), the position of the goal is (10.8, 6), the position of the obstacle is (12, 6) and we increase the obstacle's influence sphere. Fig 10 displays the total potential energy. x-axis and y-axis are the coordinates of each point. z-axis is the potential energy corresponding to each point. Fig 11 is the path planning result in case 3.

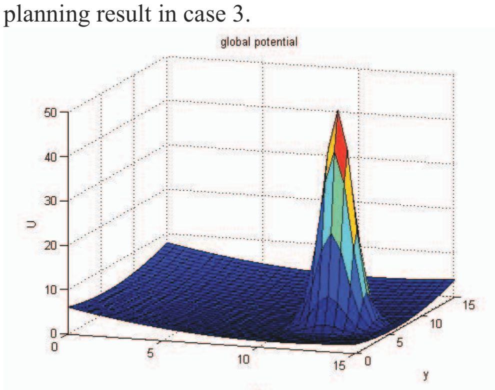

Fig 10: the global potential in case 3

We can see from Fig 10 that the total potential of the obstacle position (12, 6) is the global maxmum and the influence sphere is much larger than other simulations.

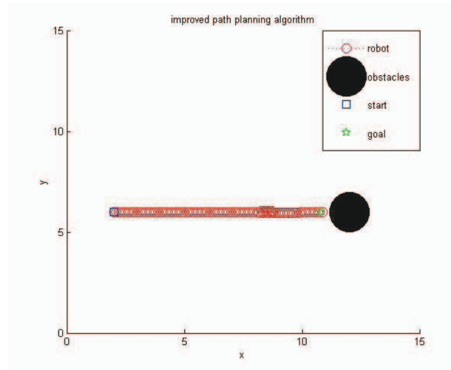

Fig 11: collision avoidance path planning

It can be seen from the simulation results that the proposed algorithm to adaptively changing the parameter of the Gaussion-like artificial potential function can solve the local minima problem well.

V. CONCLUSION

This paper analyzed the advantages of artificial potential field method when planning the obstacle avoidance path for the robot at first. Then the traditional artificial potential field method was introduced and the three cases of local minima problem of the method was analyzed. For the three typical cases of local minima problem existing in the artificial potential field, we propose an adaptive artificial potential field method. And the simulation results in part **IV** show that the proposed algorithm is effective for the three cases of local minima.

REFERENCES

[1] Marwa.T, "Improved Potential Field Controller for Obstacle Avoidance in Mobile Robots", *national radio science conference*, 2012.

[2]Chun. Li, "The improved potential grid method in robot path planning", *Technology and Innovation Conference,* 2009.

[3] Xiao. X, "A Study of Intelligent Searching Mobile Robots under Unknown Environment", *Control Conference,* 2006.

[4] W. Chen, "Path Planning of Mobile Robot Based On Hybrid Cascaded Genetic Algorithm", *World Congress on Intelligent Control and Automation*, 2011.

[5] D. H. Kim, "Local path planning using a new artificial potential function composition and its analytical design guidelines", *Advanced Robotics*, 2005.

[6] J. Vascak, "Navigation of Mobile Robots Using Potential Fields and Computational Intelligence Means", *Acta Polytechnica Hungarica*. 2007.

[7] S. Campbell, W. Naeem, "A Review on Improving the Autonomy of Unmanned Surface Vehicles Through Intelligent Collision Avoidance Manoeuvres", *Annual Reviews in Contro*l, 2012.

[8] C. Petres, M.-A. Romero-Ramirez, "A Potential Field Approach for Reactive Navigation of Autonomous Saiboats", *Robotics and Autonomous Systems*, 2012.

[9] O. Khatib, "Real-time obstacle avoidance for manipulators and mobile robots", *The International Journal of Robotics Research*, 1986.