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Path Planning of Mobile Robot Based on Improved Potential Field

[1]Jinchao Guo, [1]Yu Gao and [2]Guangzhao Cui
[1]Department of Elec. and Info. Engineering, Zhengzhou University of Light Industry, 450002, China
[2]Zhengzhou University, 450052, China

Abstract: The study first describes the problems of slow convergence and Goals Non-Reachable with Obstacles Nearby (GNRON) when using traditional artificial potential field methods for mobile robot path planning. Then, improved artificial potential field are presented which could accelerate the convergence speed and guide the robot to reach the target successfully. However, this method cannot solve the local minimum problem. Another method of robot path planning is navigation potential field method, it has only one minimum point in the movement of robot, so the local minimum problem does not exist, but it has slow convergence and computationally intensive problems. Therefore, this article introduces a strategy which combines the improved artificial potential field and navigation potential field. This method not only accelerates the convergence speed and optimize the path, but also overcomes the local minimum problem. The results of the simulation indicate this method is feasible.

Key words: Artificial potential field, GNRON problem, local minimum, navigation potential field

INTRODUCTION

In recent years, robotic scientists have been developed and improved a lot and it has became a synthesized and advanced subject that includes automatic controller, mechanical engineering, computer technology and signal processing etc. The path planning as an important domain of artificial intelligence in robotics area is one key technology. The goal of the mobile robot path planning is to find a collision-free path from the initial position to the goal position (Hong *et al*., 2011; Hachour, 2008). Examples of successful path planning algorithms include sub-goal network (Sud *et al*., 2008), grids, visibility graph, genetic algorithm (Yazdani *et al*., 2012; Shi and Cui, 2010), neural network methods, traditional artificial potential field (Khatib, 1986) and many others. The artificial potential field method has been widely used in the navigation of mobile robots due to its simplicity, practicality and implement easily.

A significant amount of research has been done using artificial potential field method since it firstly proposed by Khatib (1986). This method is composed of the repulsive potential fields around the obstacles and the attractive potential field around the goal. The repulsive potential field is repelling the robot far away from the obstacles whiles the attractive potential field attracting the robot to the goal position. In general, the artificial potential field can achieve a fast and reactive response in the static environment. However, this method has been widely demonstrated that it suffer from some drawbacks which are very likely for robot to get trapped into a local minimum and Goals Non-Reachable with Obstacles Nearby (GNRON). In order to solve these problems, this article proposes a strategy which combines the improved artificial potential field and navigation potential field. The improved potential function not only can solve the GNRON problem, but also can overcome the local minimum problem.

ARTIFICIAL POTENTIAL FIELD APPROACH AND ITS PROBLEMS

Traditional artificial potential field: The artificial potential field method assumes the robot moving in an abstract artificial force field. The artificial field is consisted of repulsive potential field and attractive potential field in the workspace (Zhao *et al*., 2011). Repulsive field is made up of the synthesis repulsive field of the different obstacles and the direction of the repulsive field is far away from obstacles while the attractive field is produces by the goal and direct to the goal position (Yu *et al*., 2011). Under the superposition influence of the repulsive potential field and the attractive potential field, the robot moves from high to low potential field along the negative of the total potential field. Consequently, the robot moving to the goal position can be considered from a high-value state to a low-value state. The goal position is designed as the lowest potential field in general, so the

Corresponding Author: Jinchao Guo, Department of Elec. and Info. Engineering, Zhengzhou University of Light Industry, 450002, China

movement of the robot will eventually reach this position theoretically. A lot of potential functions have been proposed in this article.

The most commonly used attractive potential function is:

$$U_{att}(q) = \frac{1}{2}\varepsilon d^2(q, q_{goal}) \quad (1)$$

where, ε is a positive scaling factor, $d(q, q_{goal})$ is the distance between the robot q and the goal q_{goal}.

The attractive force is given by the negative gradient of the attractive potential:

$$F_{att}(q) = -\nabla U_{att}(q) = \varepsilon(q_{goal} - q) \quad (2)$$

The attractive force toward zero as the robot approaches the goal.

As we all know, Robot should be repelled from obstacles. However, when robot is far away from obstacles, the motion of robot should not be affected by the obstacles. In this article, we use following repulsive potential function:

$$U_{req}(q) = \begin{cases} \frac{1}{2}\eta\left(\frac{1}{d(q, q_{obs})} - \frac{1}{d_0}\right)^2 & d(q, q_{obs}) \le d_0 \\ 0 & d(q, q_{obs}) > d_0 \end{cases} \quad (3)$$

where, η is a positive scaling factor, $d(q, q_{bos})$ denotes the shortest distance from the robot q to the obstacle, d_0 is the largest impact distance of the obstacle. The negative gradient of the repulsive potential function:

$$F_{req}(q) = -\nabla U_{req}(q) = \begin{cases} \eta\left(\frac{1}{d(q, q_{obs})} - \frac{1}{d_0}\right)\frac{1}{d^2(q, q_{obs})}\frac{q - q_{obs}}{d(q, q_{obs})} & d(q, q_{obs}) \le d_0 \\ 0 & d(q, q_{obs}) > d_0 \end{cases} \quad (4)$$

The total force applied to the robot is: $F_{total} = F_{att}(q) + F_{req}(q)$ which determines the motion of the robot. The robot moves in this field of forces as shown in Fig. 1.

Disadvantage of artificial potential field method: The artificial potential field method is a kind of virtual force method. It has been widely used in real-time obstacle avoidance and trajectory control because of its simple mathematical structure. However, there are some major problems with this method (Sheng *et al*., 2010; Koren and Borenstein, 1991) (1) When the robot is far away target, the attractive force will become very great. It is easily leading robot move too close to the obstacles. Therefore, the robot has the risk of collision to obstacles, (2) Goals Non-Reachable with Obstacle near by (GNRON) (3) When the attractive force and repulsive force is equal or almost equal but on the opposite direction, the potential force of robot is zero, then it will cause robot to be trapped in local minima or oscillations and (4) How to decide the minimal distance from the robot to the obstacles.

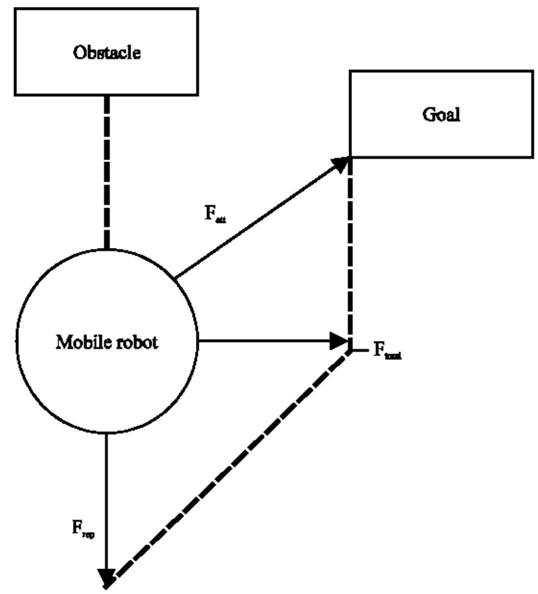

Fig. 1: Force in the artificial potential field

IMPROVED POTENTIAL FIELD METHOD

In order to solve the problems above, we proposed an improved potential field method which combines the improved artificial potential field approach and navigation potential field method.

Improved artificial potential field: Although, the traditional artificial potential field method is more suitable for real-time application and can plan smooth path effectively, it has the risk of collision to obstacles and GNRON problems. Therefore, we propose an improved artificial potential field to solve these questions.

Risk of collision to obstacles: The value of attractive potential field is decided by their distance $d(q, q_{goal})$, as function 1 presented. When robot is far away from target, the attractive force will become very great. That is to say, when $d(q, q_{goal})$ is very great, it is easily leading robot move too close to the obstacles (Shi and Cui, 2010). Therefore, the robot has the risk of collision to obstacles in the real environment. Thus, the attractive potential field is modified as function 5:

$$U_{att}(q) = \begin{cases} \frac{1}{2}\varepsilon d^2(q, q_{goal}) & d(q, q_{goal}) \le d^*_{goal} \\ d^*_{goal}\varepsilon d(q, q_{goal}) - \frac{1}{2}\varepsilon (d^*_{goal})^2 & d(q, q_{goal}) > d^*_{goal} \end{cases} \quad (5)$$

where, ε is the attraction gain, $d(q, q_{goal})$ is the distance between robot and target, d^*_{goal} is the threshold value that defines the distance between the robot and the goal which will be compared for the choice between conic and quadratic potential.

The gradient of the function 6 is obtained as:

$$F_{att}(q) = -\nabla U_{att}(q) = \begin{cases} \varepsilon(q_{goal} - q) & d(q, q_{goal}) \le d^*_{goal} \\ \dfrac{d^*_{goal}\varepsilon(q_{goal} - q)}{d(q - q_{goal})} & d(q, q_{goal}) > d^*_{goal} \end{cases} \quad (6)$$

Goals non-reachable with obstacle nearby: In the above study, it is always assumed that the goal position far away from obstacles. When the robot is near the goal position, the repulsive force is negligible, so the movement of the robot to the goal position will only be determined by the attractive force. However, in some cases, the goal position will be close to an obstacle. When the robot is near its goal position, it also closes to obstacles nearby. According to the attractive and repulsive potentials in formula 2 and 4, the repulsive force will be much larger than the attractive force and the robot cannot reach its goal position (Shi *et al*., 2010; Chuang and Ahuja, 1998). In order to overcome this problem, the repulsive potential functions are modified by considering the relative distance from the robot to the goal (Ge and Cui, 2000). The new repulsive potential function is:

$$U_{req}(q) = \begin{cases} \dfrac{1}{2}\eta\left(\dfrac{1}{d(q, q_{obs})} - \dfrac{1}{d_o}\right)^2 d^n(q, q_{goal}) & d(q, q_{obs}) \le d_0 \\ 0 & d(q, q_{obs}) > d_0 \end{cases} \quad (7)$$

where, $d(q, q_{obs})$ is the minimal distance between the robot q and the obstacles, $d(q, q_{goal})$ is the distance between the robot and the goal q_{goal}, d_0 is the distant of influence of the obstacle and n is a positive constant.

When the robot is not at the goal position, the gradient of the new repulsive potential function is:

$$F_{req}(q) = -\nabla U_{req}(q) = \begin{cases} F_{req1} n_{OR} + F_{req2} n_{RG} & d(q, q_{obs}) \le d_0 \\ 0 & d(q, q_{obs}) > d_0 \end{cases} \quad (8)$$

Where:

$$F_{req1} = \eta\left(\frac{1}{d(q, q_{obs})} - \frac{1}{d_0}\right)\frac{d^n(q, q_{goal})}{d^2(q, q_{goal})} \quad (9)$$

$$F_{req2} = \frac{n}{2}\eta\left(\frac{1}{d(q, q_{obs})} - \frac{1}{d_0}\right)^2 d^{n-1}(q, q_{goal}) \quad (10)$$

$n_{OR} = \nabla d(q, q_{obs})$ and $n_{RG} = -\nabla d(q, q_{goal})$ are two unit vectors and the direction of them is from the obstacle to the robot and from the robot to the goal, respectively.

Navigation potential functions: Although, the improved artificial potential field method can solve the risk of collision to obstacles and GNRON problems, the local minima issue still exists. To solve the local minima problem, a special function to be constructed which has the only minimum at the goal position. These functions are called navigation functions (Yagnik *et al*., 2010). The navigation potential functions can be constructed as follows:

$$\gamma(q) = \frac{d^2(q, q_{goal})}{[d(q, q_{goal})^{2k} + \beta(q)]^{1/k}} \quad (11)$$

Where:

$$\beta(q) = \prod_{i=0}^{n} \beta_i$$

$$\beta_i(q) = \begin{cases} -d^2(q, q_{obs_i}) + r_i^2 & i = 0 \\ d^2(q, q_{obs_i}) - r_i^2 & i > 0 \end{cases}$$

r_i is the radius of the obstacle, q_{obs_0} is the center and r_0 is the radius of the work space, k has an effect of making the navigation function has the form of a bowl near to the goal.

The gradient of the navigation potential function is:

$$\nabla\gamma(q) = \frac{2(q - q_{goal})[d(q, q_{goal})^{2k} + \beta(q)]^{\frac{1}{k}}}{[d(q, q_{goal})^{2k} + \beta(q)]^{2/k}} - \frac{-d^2(q, q_{goal})\dfrac{1}{k}[d(q, q_{goal})^{2k} + \beta(q)]^{\frac{1-k}{k}} s(q)}{[d(q, q_{goal})^{2k} + \beta(q)]^{2/k}} \quad (12)$$

Where:

$$s(q) = 2kd(q, q_{goal})^{2k-2}(q - q_{goal}) + \nabla\beta(q)$$

$$\nabla\beta(q) = \sum_{i=0}^{n} \nabla\beta_i(q) \prod_{j=0, j\ne i}^{n} \beta_j(q)$$

$$\nabla\beta_i(q) = \begin{cases} -2(q - q_{obs_i}) & i = 0 \\ 2(q - q_{obs_i}) & i > 0 \end{cases}$$

Improved artificial potential field approach with navigation potential field: The improved artificial potential field method is very suitable for the bottom of the real-time control due to its explicit physical implication and simple mathematical model, but this method also has the local minima problem. Unlike the improved artificial

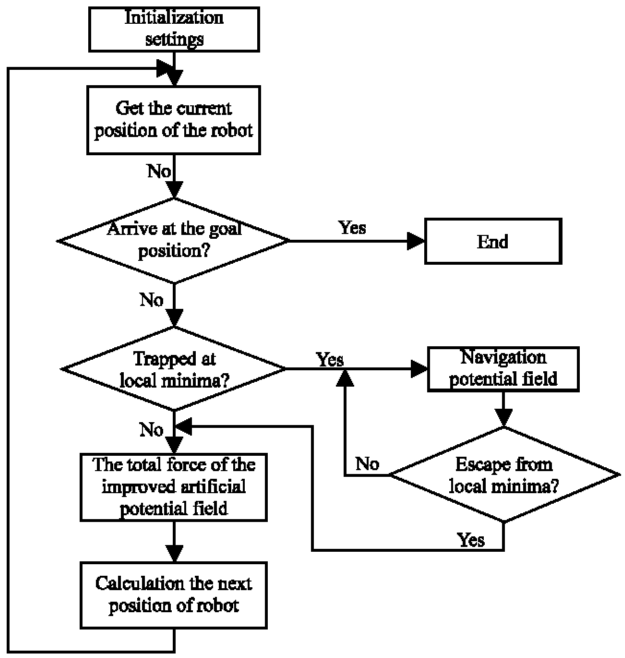

Fig. 2: Improved potential field method

potential field, the navigation potential field only has one minimum point in the workspace, so that there is not any local minimum problem. However, the navigation potential exists computationally intensive and bad real-time performance questions. Therefore, this article introduced a strategy which combines the improved artificial potential field and navigation potential field. This method not only can solve the risk of collision to obstacles and GNRON problems, but also can overcome the local minima problem. The improved potential field method is showed in Fig. 2.

SIMULATIONS RESULTS

Some simulation experiments are carried out for verifying the feasibility of this method using MATLAB R2009a. The environment is setting as sphere world with radius of 10 and the free configuration space is shown in Fig. 3. The positive scaling factor ε of attractive field is 0.5. In order to make the path of robot far away from obstacles, we set the positive coefficient d^*_{goal} is 15. The coefficient η of repulsive field is 1. The largest impact distance of obstacles d_0 is 2. The positive scaling factor of navigation field k is 3. The moving step of robot d is 0.05, the initial position of the robot is (2, 8). The result of the simulation is:

- When the local minima problem does not exist in the movement of the robot, the path planning of the robot can be divided to: Goal Far Away from Obstacles and Goal Close to an Obstacle. In the first simulation study, the goal is far away from the obstacles. The minimum distant from goal to the obstacles, i.e., $r>d_0 = 2$ with the goal at point (5.5, 2). The simulation results are shown in Fig. 3, where Fig. 3a and b paths represent the results obtained using the conventional artificial potential field and the improved artificial potential field, respectively. In the second case, the goal (6.5, 2) is chosen close to an obstacle. The minimum distance from goal to an obstacle, i.e., $r\leq d_0 = 2$. The result of the simulation in Fig. 4

As shown in the Fig. 3, both methods can successfully drive the robot to the goal while avoiding to obstacles. The convergence time for the robot to reach the goal in the traditional artificial potential field method is 0.170966 seconds while the time spend for the improved artificial potential field is 0.160561 seconds. This suggests that the improved artificial potential field method can accelerate the speed of the robot.

When the traditional artificial potential function is used in Fig. 4a, the robot will be trapped at point (6.4, 1.8). When the improved artificial potential function is used in Fig. 4b, the robot can successfully arrive at the goal. The simulation results show the improved artificial potential field can solve the problem of goals non-reachable with obstacles nearby:

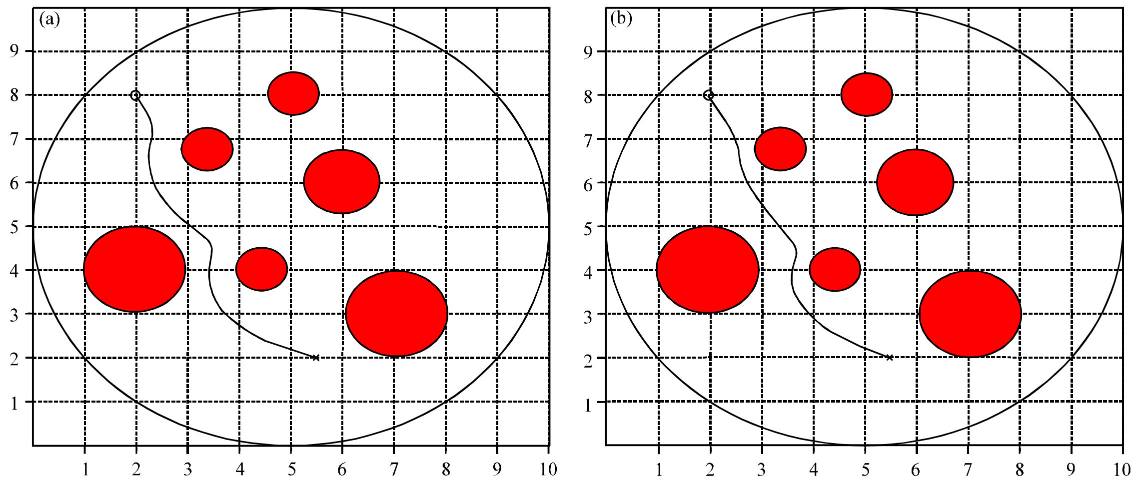

Fig. 3(a-b): Goal far away from obstacles (a) Traditional artificial potential field and (b) Improved artificial potential field

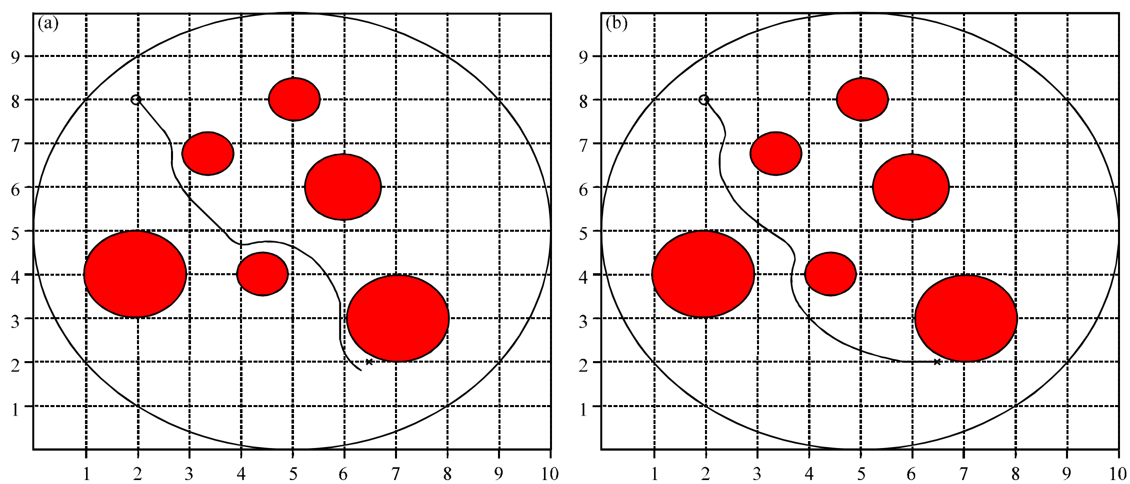

Fig. 4(a-b): Goal close to an obstacle (a) Traditional artificial potential field and (b) Improved artificial potential field

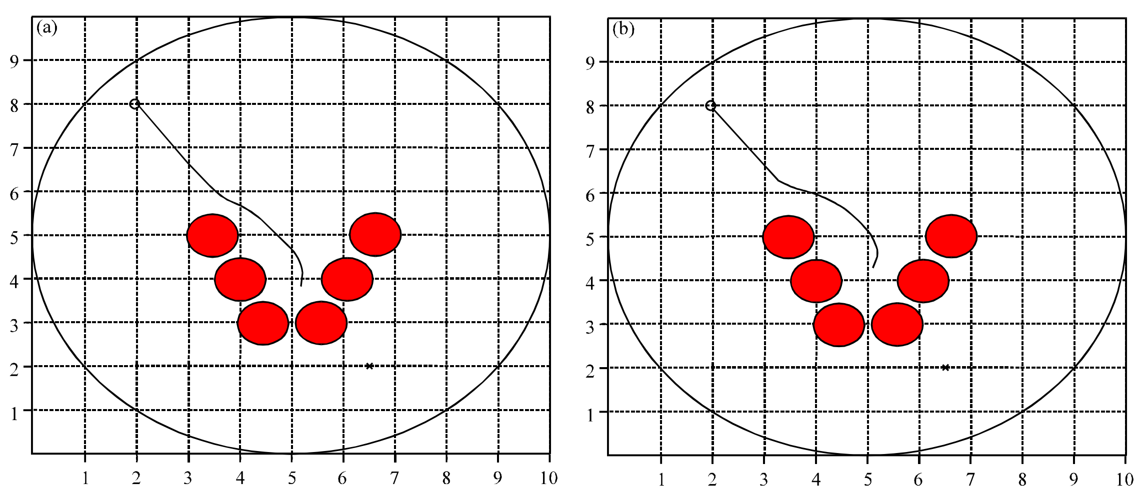

Fig. 5(a-c): Continue

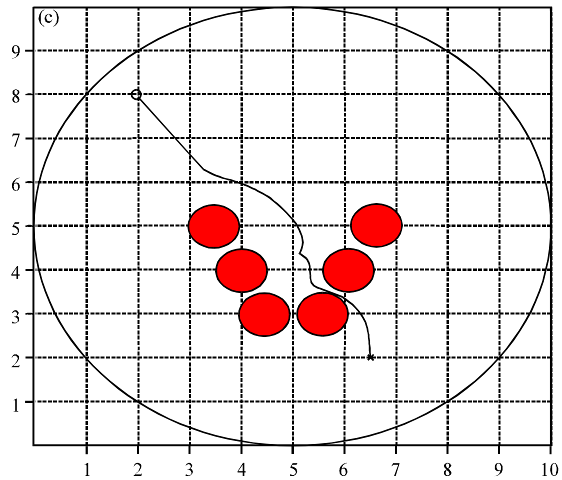

Fig. 5(a-c): Simulation with the local minimum point (a) Traditional artificial potential field, (b) Improved artificial potential field and (c) Improved artificial potential field with navigation potential field

- When the local minimum occurs, the robot is trapped at local minimum and cannot reach the goal (Fig. 5a, b). In this case, navigation potential field should be used to escape local minimum (Fig. 5c). The goal position is (6.5, 2). The simulation results as shown in Fig. 5

As we can see from the Fig. 5, the improved field method can solve the local minimum problem and guide the robot to reach the goal successfully. At the same time, there are several methods to solve the local minimum problem, such as: simulated annealing, regression search method, particle swarm optimization. Compared with these methods, the improved potential field method has some advantages such as simple computation, easy control, real-time working and so on.

CONCLUSION

In this article, we discussed the problems of the artificial potential field method and introduced several methods to solve these problems. Emphatically, the improved potential field methods which integrate the navigation potential field approach into improved artificial potential field path planning was proposed. This method can make the robot escaping from the local minimum. The simulation results show our improved potential field method is very efficiency to solve the robot path planning. In future works, we attend to improve the smoothness of the planning path, utilize the improved potential field method for dynamic environment.

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