Research on Mobile Robot Path Planning in Dynamic Environment

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Abstract—**The traditional artificial potential field method is suitable for stationary environment. In practical application, mobile robot is in a dynamic environment where the target and the obstacles are moving. For the dynamic environment, the relative position and velocity of the moving target with respect to the mobile robot and the mobile robot with respect to the moving obstacles are taken into account in the potential field function. The traditional potential field function is modified with the size of the mobile robot. In the case of a variety of environments with stationary or moving obstacles, the improved artificial potential field method is studied. Finally, the simulation results based on MATLAB platform validates the effectiveness of the algorithm.**

Keywords—mobile robot; path planning; potential field method; dynamic environment; relative velocity

I. INTRODUCTION

Path planning is one of the key technologies of mobile robot navigation [1]. Path planning means how the mobile robot search for an optimal or suboptimal path from the initial point to the target point in the environment basing on a certain performance indicator (the shortest time, the shortest path, the least energy consumption, etc.) [2]. The artificial potential method is widely used because of fast response speed, small computation amount, convenient real-time control and smooth path generation.

The artificial potential field method is usually used in stationary environment. However, in practical applications, the mobile robot environment is not stationary, its target and obstacles may move. In order to solve the problem of dynamic motion planning, many scholars have done a lot of research at home and abroad. In the literature [3], Ge S S proposed a new potential field function considering the relative velocity of mobile robot with respect to target and the relative velocity of mobile robot with respect to moving obstacles. This paper also analyses the local minimum point situation. In the literature [4], Yin Lu et al proposed the relative velocity and relative acceleration of the robot with respect to the obstacles and the robot with respect to the target, which were introduced into the potential function. This algorithm not only tracks the moving target position, but also takes into account the movement tendency of the target. In the literature [5], Qin Ke et al proposed the combination of the genetic algorithm with the artificial potential field method. The traditional stationary potential field is changed into the dynamic potential field by setting the sub-target point, so that the mobile robot can avoid the collision with moving obstacles. In the literature [6], Bi Sheng et al introduced the distance of the target and the obstacles, the velocity vector of the obstacle and the robot and the minimum safe distance in potential field function, which obtained better results compared with the traditional stationary artificial field method. In the literature [7], Chen Li-bin et al proposed an auxiliary repulsive ring method, which changed the repulsive force in the traditional potential field method. It can be more flexible and effective in dealing with obstacle avoidance in dynamic environment. The above studies put forward their own valuable ideas for the dynamic environment, but the size of the mobile robot itself is considered inadequately.

The work is supported by science and technology project of Hebei academy of sciences(No. 14605).

Based on the traditional artificial potential field method, the relative velocity of the mobile robot and the moving target is taken into account in the attractive field function and the relative velocity of the mobile robot and the moving obstacles are taken into account in the repulsive field function. In a variety of environments with stationary and dynamic obstacles, path planning is carried out in conjunction with the size of the mobile robot itself. Finally, the algorithm is experimented in MATLAB platform. The experimental results show that the proposed method can make the mobile robot reaches the target in a variety of environments with stationary and dynamic obstacles.

II. TRADITIONAL ARTIFICAL FIELD METHOD

Khatib first proposed artificial field method in 1986 [8]. The basic principle is to describe the spatial structure using a numerical function called the artificial potential field, which guides the robot in the environment through the force of the potential field. The potential field is divided into two parts, the attractive field of target and the repulsive field of obstacles. The superposition of the two virtual potential field constitutes decides the robot movement. Therefore, the artificial potential field is defined as

$$U = U_a + U_r \tag{1}$$

where U_a denotes the attractive field, U_r denotes the repulsive field. The attractive and repulsive forces are defined as the negative gradient of the attractive field and the repulsive field, respectively. The force F of the artificial potential field can be defined as

$$F = F_a + F_r \tag{2}$$

where F_a denotes the attractive force, F_r denotes the repulsive force.

A. Attractive Potential Function

Define the attractive potential field function as

$$U_a = \frac{1}{2}k(X - X_g)^2 \tag{3}$$

where U_a denotes the attractive field, k denotes positive constant, X denotes the position vector of the mobile robot, X_g denotes the position vector of the target. Therefore, we shall define the corresponding virtual attractive force as the negative gradient of the attractive potential

$$F_a = -grad(U_a) = -k(X - X_g) \tag{4}$$

B. Repulsive Potential Function

For the repulsive potential function, Khatib uses a FIARS (force inducing an artificial repulsion from the surface) function [9]

$$U_r = \begin{cases} \frac{1}{2}\beta(\frac{1}{\rho} - \frac{1}{\rho_0})^2, \rho \le \rho_0 \\ 0, \rho > \rho_0 \end{cases} \tag{5}$$

where U_r denotes the repulsive field, β denotes positive constant, ρ denotes the shortest distance between the mobile robot and the obstacle, ρ_0 denotes a positive constant describing the influence range of the obstacle. Therefore, we shall define the corresponding virtual repulsive force as the negative gradient of the repulsive potential

$$F_r = \begin{cases} \beta(\frac{1}{\rho} - \frac{1}{\rho_0})\frac{1}{\rho^2}\frac{\partial \rho}{\partial X}, \rho \le \rho_0 \\ 0, \rho > \rho_0 \end{cases} \tag{6}$$

The total virtual force can be obtained by $F = F_a + F_r$, which determines the movement of the mobile robot.

III. IMPROVED THE ARTIFICIAL FIELD METHOD

According to the state of targets and obstacles, the dynamic environment is divided into the following five cases: Firstly, the environment just contains the dynamic target. This situation is also called the target tracking; Secondly, the target is moving and the obstacles are stationary; Thirdly, the target is stationary and the obstacles are moving; Fourthly, the target and obstacles are moving; Fifthly, the target is moving, part of the obstacles are moving, the other part of the obstacles are still stationary. For ease of analysis, the paper makes the following assumptions:

Assumption 1: The shape of the mobile robot is circular, the radius R is $20cm$, its position p and velocity v are known.

Assumption 2: the target deems as a particle, its location p_g and velocity v_g are known, $|v_g| < v_{\max}$ [10].

Assumption 3: the dynamic obstacle deems as a particle, its location p_{obs} and velocity v_{obs} can be real-time detected by the sensors, which are equipped on mobile robot [11]. Stationary obstacles shape is circular. Radius is R_{oi}. R_{oi} represents center, where i is the number of obstacles.

A. Improved Attractive Potential Field Function

The traditional attractive potential field function just considers the positional relationship between the mobile robot and the target, but the moving target also needs to consider the velocity. The relative velocity of the mobile robot and moving target is taken into account in the traditional attractive potential field function. The improved attractive potential field function is obtained as follow

$$U_{att}(p,v) = \frac{1}{2}\eta_p(p - p_g)^2 + \frac{1}{2}\eta_v(v - v_g)^2 \tag{7}$$

where $U_{att}(p,v)$ denotes the attractive field. η_p and η_v denote scalar positive parameters. p, p_g, v, v_g are functions about time t, $p = (x_1, x_2)$, $p_g = (x_{g1}, x_{g2})$, $v = (v_1, v_2)$, $v_g = (v_{g1}, v_{g2})$. $(p - p_g)$ is the Euclidean distance between mobile robot and target. $(v - v_g)$ is the magnitude of the relative velocity between the mobile robot and the target.

At this point, the attractive force is

$$F_{att}(p,v) = -\nabla U_{att}(p,v) = -\nabla_p U_{att}(p,v) - \nabla_v U_{att}(p,v) \tag{8}$$

where

$$F_{att1}(p) = -\nabla_p U_{att}(p,v) = -\eta_p(p - p_g)n_{rg} \tag{9}$$

$$F_{att2}(v) = -\nabla_v U_{att}(p,v) = -\eta_v(v - v_g)n_{vrg} \tag{10}$$

where n_{rg} denotes the unit vector pointing from the mobile robot to the target. n_{vrg} denotes the unit vector denoting the relative velocity direction of the target with respect to the mobile robot.

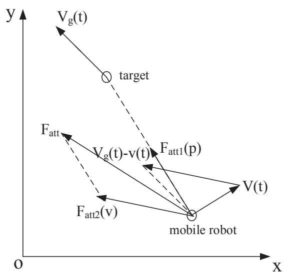

Fig.1. The relationship vectors in the attractive force

B. Improved Repulsive Potential Field Function

In order to avoid the moving obstacles, the relative position and relative velocity of the mobile robot and the moving obstacles are taken into account in the traditional repulsive field function. The relative velocity between the mobile robot and the moving obstacle in the direction from the mobile robot to the moving obstacle is given by

where v_{ro}, v, v_{obs} are function about time t, n_{ro} denotes a unit vector from the mobile robot to the moving obstacle. If $v_{ro} \le 0$, the mobile robot is moving away from the obstacle, no avoidance motion is needed. If $v_{ro} > 0$, the mobile robot is moving close to the obstacle, avoidance motion needs to be implemented.

The improved repulsive potential field function is

$$U_{rep}(p,v) = \begin{cases} \frac{1}{2}\beta_1\left(\frac{1}{\rho - R} - \frac{1}{\rho_0}\right)^2 + \beta_2 v_{ro}, \\ \rho - R \le \rho_0 and v_{ro} > 0 \\ 0, else \end{cases} \quad (12)$$

where $U_{rep}(p,v)$ denotes the repulsive field. β_1 and β_2 denote positive constants. ρ denotes the distance between the mobile robot and the obstacle boundary. R denotes the mobile robot radius. ρ_0 denotes the influence scope of the obstacle.

At this point, the repulsive force is

$$F_{rep}(p,v) = -\nabla U_{rep}(p,v) = -\nabla_p U_{rep}(p,v) - \nabla_v U_{rep}(p,v) \quad (13)$$

From (11) can be introduced

$$\nabla_v v_{ro} = n_{ro} \quad (14)$$

$$\nabla_p v_{ro} = \frac{1}{\|p - p_{obs}\|}\left[v_{ro}n_{ro} - (v - v_{obs})\right] \quad (15)$$

Let $v_{ro\perp}n_{ro\perp}$ denotes the velocity component perpendicular to $v_{ro}n_{ro}$ as given in the following equation

$$v_{ro\perp}n_{ro\perp} = v - v_{obs} - v_{ro}n_{ro} \quad (16)$$

Then

$$F_{rep}(p,v) = \begin{cases} F_{repp} + F_{repv}, \rho - R \le \rho_0 and v_{ro} > 0 \\ 0, else \end{cases} \quad (17)$$

where

$$F_{repp} = -\beta_1\left(\frac{1}{\rho - R} - \frac{1}{\rho_0}\right)\frac{n_{ro}}{(\rho - R)^2} + \beta_2\frac{v_{ro\perp}}{\|p - p_{obs}\|}n_{ro\perp} \quad (18)$$

$$F_{repv} = -\eta_2 n_{ro} \quad (19)$$

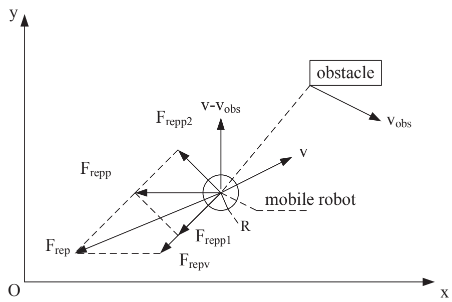

Fig.2. The relationship vector in the repulsive force

In the figure 2, F_{repp1} keeps the mobile robot away from the obstacle. F_{repp2} acts as a steering force for detouring.

IV. SIMULATION EXPERIMENTS AND RESULTS

In order to verify the validity and feasibility of the proposed method, the experiments are carried out in the MATLAB platform. Simulation environment is in the $300cm \times 300cm$ area. The target is moving from point $p_g = (200,80)^T$ at constant velocity $v_g = (0,2)^T$ .The initial position of the mobile robot is $p = (0,0)^T$, its initial velocity is $v = (0,0)^T$.

In figure 3-7, red line denotes the mobile robot trajectory, green line denotes the target trajectory, blue line denotes the moving obstacles trajectory. Figure 3 shows the target tracking without any obstacle. Adjusting the parameters to: $\eta_p = 0.05, \eta_v = 0.1$, the mobile robot can follow the target with a smooth path. Figure 4 shows the stationary obstacles under the target tracking. The parameters are still $\eta_p = 0.05, \eta_v = 0.1$.The influent scope of the obstacle is

$\rho_0 = 60cm$. The mobile robots can avoid obstacles and reach target. Figure 5 shows two moving obstacles and the stationary target. The obstacles parameters are $P_{obs1} = (30,20)^T$, $v_{obs1} = (6,6)^T$, $p_{obs2} = (150,85)^T$, $v_{obs2} = (6,0)^T$.The simulation results show the mobile robot can escape the moving obstacles and reach the target. Figure 6 shows the target tracking with moving obstacles, the parameters are adjusted as above. The simulation results show that the mobile robot can reach the target successfully. Figure 7 shows a moving target with a moving obstacle and two stationary obstacles. The mobile robot can escape the obstacles and reach the target.

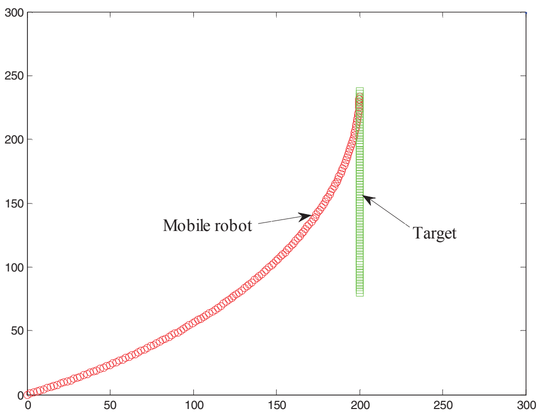

Fig.3. Target tracking without obstacles

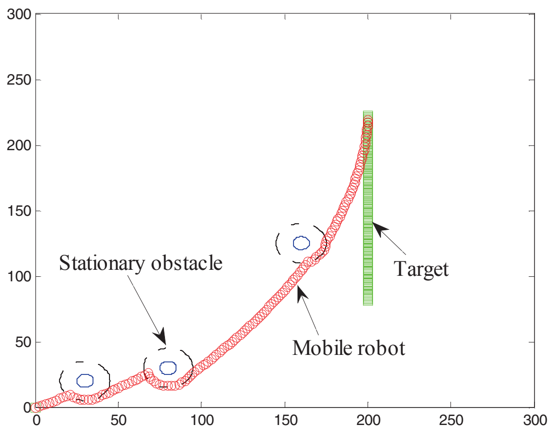

Fig.4. Target tracking under stationary obstacles

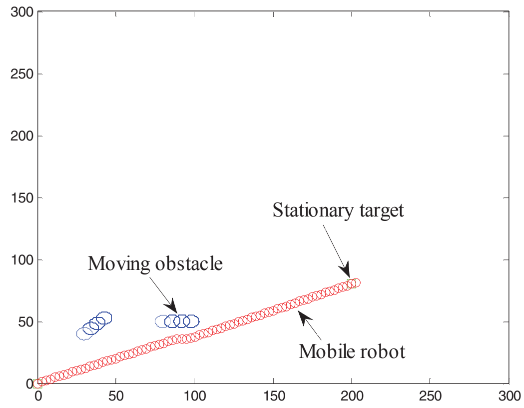

Fig.5. Stationary target under moving obstacles

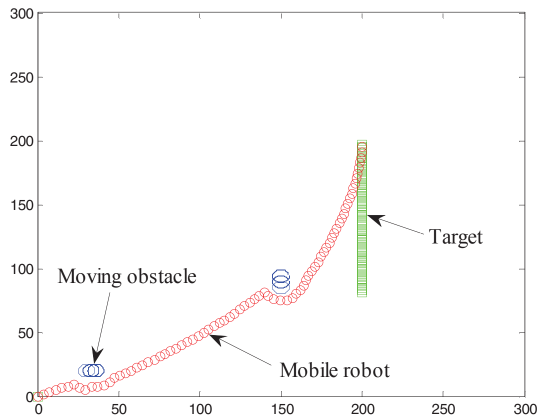

Fig.6. Target tracking under moving obstacles

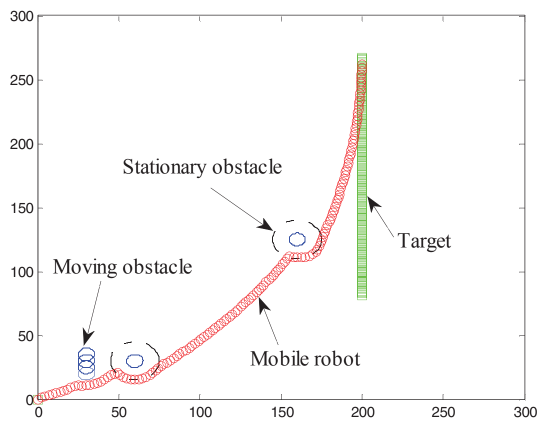

Fig.7. Target tracking under stationary and moving obstacles

V. CONCLUSION

In this paper, the velocity of target and moving obstacles and the size of mobile robots are taken into account in the traditional artificial potential field function. In the environment with dynamic and stationary obstacles, the improved potential field function is studied. In the MATLAB simulation environment, a variety of cases are tested, the simulation results prove the feasibility of this method. However, this method is only under the environment containing less dynamic and stationary obstacles. As for complex environment with many dynamic obstacles, large irregular static obstacles, this method also requires further study.

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