Mobile Robot Path Planning Based on Dynamic Fuzzy Artificial Potential Field Method

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Abstract

Traditional artificial potential field method has the problem of local minimum and can not satisfy the requirements of real-time mobile robot path planning, security and accessibility in dynamic environment. To deal with the problems, through taking the advantage of velocity vector, modifying potential field force function, and integrating with the fuzzy control method, adjusting the factors of repulsion potential field in real time, a new method is proposed to overcome the shortcomings of artificial potential field method. To validate the proposed method, simulation experiments are conducted in MATLAB platform, and experimental results demonstrate that the performance of this proposed method is better than the traditional artificial potential field model.

Keywords: *artificial potential field method, fuzzy control, mobile robot, path planning, local minimum*

1. Introduction

Planning methods can be divided into conventional methods and intelligent methods, conventional methods include space method, the grid method and the artificial potential field method, etc.; intelligent methods are genetic algorithms, neural networks, and fuzzy logic path planning method. Artificial potential field method is simple, relatively easy to grasp, easy to do the bottom real-time control, planning a smoother path in general and more security, especially for a static environment. However, this method is a local path planning, there is a local minimum problem. In addition, when the robot is close to the obstacles and the target point, it is difficult to reach the target point; in the situation of closer distribution of the obstacles, the robot will swing in the narrow channel consisted of the barriers. Currently aiming to these problems, a number of improved methods are brought forward; they mainly lead the relative distance between the robot and the target into repulsive potential field function, and do the improvement of the repulsive potential field function, or combining with other intelligent methods to adjust the size of potential field force.

This paper leads into speed factors in a dynamic environment, in order to more accurately track the target and do obstacle avoidance; obstacle location and the complexity of movement require that the timeliness of repulsion is higher. Therefore, design of fuzzy controller can timeliness adjusts the size of repulsion aiming to repulsion component gain coefficient of the repulsion function. The improved method allows the robot can escape the local minimum, according to the motion state of the obstacles and the target point to a more reasonable of obstacle avoidance and target tracking.

2. The Traditional Artificial Potential Field Method

Artificial potential field method proposed by Khatib is a virtual force method. The basic idea is predigesting all of the robots, obstacles, target points into one point, obstacles produce repulsion to robotics, target point produces gravity, the motion direction of the robot in any location of the space is decided by the direction of total field intensity, which is synthesized by the repulsion from obstacles and the gravity of target point.

Traditional gravity, repulsion potential functions are as follows:

$$U_{att} = \frac{1}{2}\xi \rho_g^2(q)\ \rho_0 \tag{1}$$

$$F_{rep} = \begin{cases} -\eta\left(\frac{1}{\rho(q)} - \frac{1}{\rho_0}\right)\left(\frac{1}{\rho(q)}\right)^2 \frac{\partial \rho(q)}{\partial X}, \rho(q) \\ 0, \rho(q) > \rho_0 \end{cases} \tag{2}$$

In the expressions, ξ , η ----the gain coefficients of the gravity and the repulsive, ρ_0 ----the influence distance of the obstacle, $\rho_g(q)$ ----the Euclidean distance from the robot pose to the target point, $\rho(q)$ ----the minimum distance of the influence distance of the obstacle to the robot pose. Corresponding gravity F_{att} and repulsion F_{rep} are the negative gradient of potential field functions of gravity and repulsion.

The expressions of gravity and repulsion are:

$$F_{att} = -\xi \rho_g(q)\ \rho_0 \tag{3}$$

$$F_{rep} = \begin{cases} -\eta\left(\frac{1}{\rho(q)} - \frac{1}{\rho_0}\right)\left(\frac{1}{\rho(q)}\right)^2 \frac{\partial \rho(q)}{\partial X}, \rho(q) \\ 0, \rho(q) > \rho_0 \end{cases} \tag{4}$$

Composition of the forces stressed on robot is $F = F_{att} + F_{rep}$, the force determines movement of the robot, shown in Figure 1.

Artificial potential field method is a very effective method of static path planning, but there are certain problems in the dynamic environment with many obstacles. Experimental results show that the problem of artificial potential field method mainly represented in the case of the special motion state and the special position relationship among the robot, obstacles, and the target point.

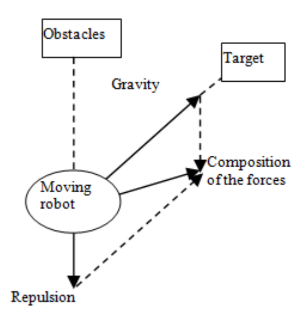


Figure 1. Stress Analysis of the Traditional Artificial Potential Field Method

The following several special and typical position relationships will make the robot can not reach target point under the artificial potential field method:

When the target point is within the sphere of influence of obstacles, the obstacle repulsion is rapidly increasing, and the gravity is decreasing;

When the robot does not reach the target point, the composition of force is zero which consists of repulsive by number of obstacles and the gravity of target point, which is the local minimum problem.

As the irregular movement of the obstacles and goals, the adaptability of artificial potential field is relatively poor; the robot is easy to collide with the obstacles. The following are several typical special motion states which will make path planning fail:

- Obstacles are head-on collision; the robot cannot avoid them on time;
- Obstacles are blocking the side; the robot cannot avoid them on time;
- Obstacles track targets in the same direction in front of the robot; robot can not be advanced to reach the target because of the obstacles avoidance.

3. The Method of Dynamic Fuzzy Artificial Potential Field

Aiming to the shortcoming of the traditional method of artificial potential field in the dynamic environment, modifying the potential field force function will increase its components affected by the speed; using fuzzy control method adjusts the coefficients of repulsive force field, to overcome the problems mentioned above, and improve the planning timeliness. Specific methods are shown in Figure 2.

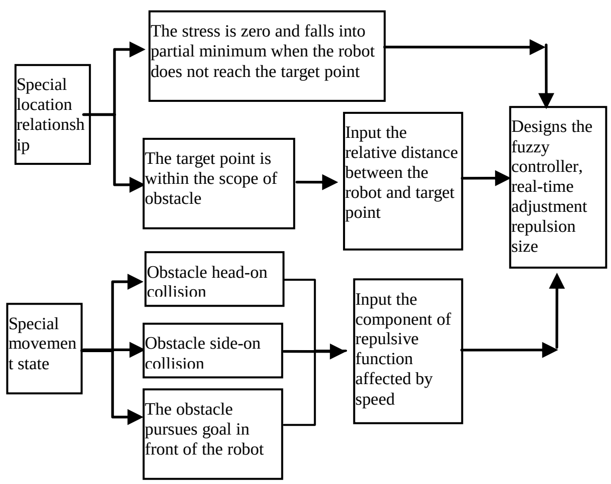


Figure 2. Improved Artificial Potential Field Method

3.1. Modifying Potential Field Force Function

Aiming to the problem caused by the special position, leading in the relative distance between the robot and the target point can improve it in the repulsion potential field function. For the problems caused by a special motion state, leading in the component affected by the speed can solve it in the potential field force function.

If the target is within the scope of the effect of obstacle, using traditional potential field function, the robot may never reach the destination. To do this, the repulsive potential function is modified as follows:

$$U_{rep}(\mathrm{X}) = \begin{cases} \frac{1}{2}\eta(\frac{1}{\rho(q)} - \frac{1}{\rho_0})(\frac{1}{\rho(q)})(\mathrm{X}-\mathrm{X}_g)^n, \rho(q) & \rho_0 \\ 0, \rho(q) > \rho \end{cases} \quad (5)$$

The regulatory factor $(\mathrm{X}-\mathrm{X}_g)^n$ is added in the improved model, $\mathrm{X}-\mathrm{X}_g$ is the distance from robot to the target point, n is real number greater than zero. In the process of robot approaching the target, at the same time the gravitational potential field decreases, a repulsive potential field $U_{rep}(\mathrm{X})$ is decreased, and maintains gravitational potential field is always greater than the repulsive potential field, until the robots reach the target point, the potential field of gravity and repulsion reduced to zero.

Corresponding repulsion expression is

$$F_{rep} = \begin{cases} F_{rep1} + F_{rep2}, \rho(\mathrm{X},\mathrm{X}_0)\rho_0 \\ 0, \rho(\mathrm{X},\mathrm{X}_0) > \rho_0 \end{cases} \quad (6)$$

In the expression, F_{rep1} , F_{rep2} ---------they are two components of F_{rep} , the direction of F_{rep1} is from the nearest point to the robot which is closest from obstacles, the direction of F_{rep2} is from the robot to the target point. Their sizes were

$$\|F_{rep1}\| = \eta(\frac{1}{\rho(q)} - \frac{1}{\rho_0})(\frac{1}{\rho(q)})^2(\mathrm{X}-\mathrm{X}_g)^n \quad (7)$$

$$\|F_{rep2}\| = \frac{n}{2}\eta(\frac{1}{\rho(q)} - \frac{1}{\rho_0})^2(\mathrm{X}-\mathrm{X}_g)^{n-1} \quad (8)$$

To consider the relative speed of the robot and obstacles, when obstacles block the robot, the collision occurs; when the obstacles track the target with faster speed in front of the robot, the robot will make unnecessary obstacle avoidance and can not reach the target ahead of obstacles. Aiming to such problems, the velocity vector is introduced, and the new gravity and repulsion functions were

$$F_{att} = -\xi\rho_g(q) + K_V(v_g - v) \quad \rho_0 \quad (9)$$

$$F_{rep} = \begin{cases} F_{rep1} + F_{rep2} + K'_V(v - v_0), \rho(q) \\ K'_V(v - v_0), \rho(q) > \rho_0 \end{cases} \quad (10)$$

In the expression, V, V0, Vg are the speed of robots, obstacles and target, KV, K'_V are the gain coefficient of the gravitational function and repulsion function affected by the speed.

3.2. The Adjustment of Coefficient of Repulsive Field

Revised repulsion function has two components; one component is affected by the distance, and the other component is affected by the speed. Two components are real-time adjusted by the respective gain coefficient. This paper uses fuzzy control method to design two pieces of double input and single output fuzzy controller, in order to achieve the repulsive factor adjustment.

The position relationship between obstacles and the robot can be determined by using the distance d between them and the angle θ of the directions of movement, the relationship of movement is determined by velocity deviation △V and the movement direction angle θ between them. Therefore, the controller 1 inputs d and θ, gain coefficient η of the repulsion component affected by the distance is its output; controller 2 inputs △V and θ, the repulsive component coefficient K_V' affected by the speed is its output. Fuzzy control method can adjust the two gain coefficients of repulsion, real-time adjust the repulsive size, and optimize the path planning.

Each variable uses continuous theory field, and adopts a simple linear approach, all the membership grade functions are the Gaussian function. The theory field (0,2) between variable d and obstacle can be divided into (ZD, SD, MD, BD) (Z: zero, S: small, M: middle, B: big); the theory field (-π, π) of input variable θ of obstacle direction angle is divided into (NH, NB, NM, NS, Z, PS, PM, PB) (N: negative, H: huge, P: positive); the theory field (-1,1) of speed input variable △V is divided into (NBV, NMV, NSV, ZV, PSV, PMV, PBV). The theory field (1,100) of the first coefficient affected by repulsion and the second coefficient affected by the speed, are divided into (NA, SA, MA, BA) (N: none, A: affect). The fuzzy rules of two fuzzy controllers are shown in Table 1, Table 2. The input and output curved surface of the fuzzy control systems are shown in Figure 3.

Table 1. The Fuzzy Rules of Controller 1

d	***θ***							
	NH	NB	NM	NS	Z	PS	PM	PB
ZD	NA	SA	SA	MA	LA	NA	SA	SA
SD	NA	NA	NA	SA	LA	MA	SA	NA
MD	NA	NA	NA	SA	MA	SA	NA	NA
FD	NA	NA	SA	SA	SA	SA	NA	NA

Table 2. The Fuzzy Rules of Controllers 2

△V	***θ***							
	NH	NB	NM	NS	Z	PS	PM	PB
NBV	LA	MA	SA	NA	NA	NA	SA	MA
NMV	MA	SA	NA	NA	NA	NA	SA	SA
NSV	SA	NA	NA	NA	NA	NA	NA	NA
ZV	NA	NA	NA	NA	NA	NA	NA	NA
PSV	NA	NA	NA	SA	SA	SA	NA	NA
PMV	NA	NA	NA	SA	MA	SA	NA	NA
PBV	NA	NA	NA	MA	LA	MA	NA	NA

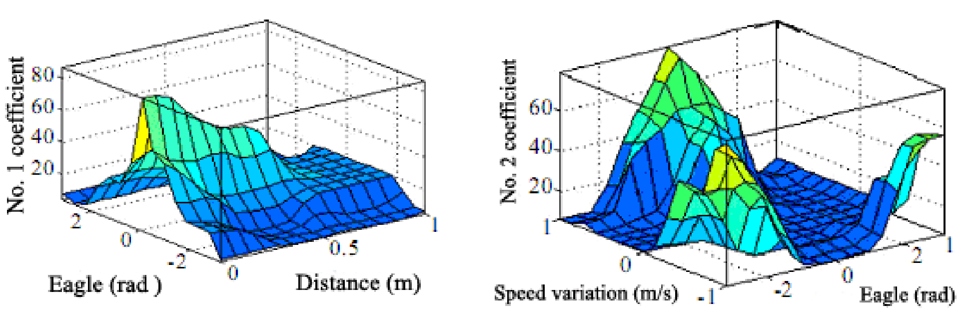


Figure 3. The Input and Output Curved Surface of Fuzzy Control System

4. Simulation Experiments and Results

In order to verify the effect of fuzzy artificial potential field effect, simulation experiment is designed in the MATLAB environment. In the special case of the traditional artificial potential field, the improved results can be observed. In rectangular plane coordinate system, each unit corresponding to the actual physical distance is 10cm. Robot's starting position is (0, 0), the initial position for the target point is (35, 36), the effect distance of obstacles is 50cm.

4.1. The Mobile Robot Path Planning with the Typical Location Relationship

The robot path planning while the target points is within the role range of obstacles: When the obstacle moves to the position (34,34), the target point is very close within the role range of robot, from the starting position the robot does obstacle avoidance and track targets, the experimental results are shown in Figure 4.

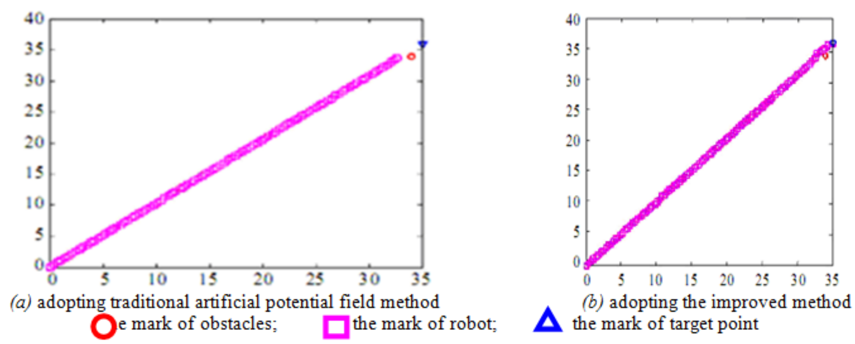


Figure 4. The Robot Path Planning within the Role Range of Obstacles for the Target Point

Experimental results show that after adopting the improved method, the robot smoothly bypass the obstacles to track the target in a special place relationship.

The robot passes through a narrow passage with many obstacles: The starting positions of four obstacles are (14, 14.5), (16.5, 11.5), (19.5, 17), (23.5, 17), forming a narrow channel. From the starting position robot moves through a narrow channel and obstacle avoidance to track the target, experimental results are shown in Figure 5.

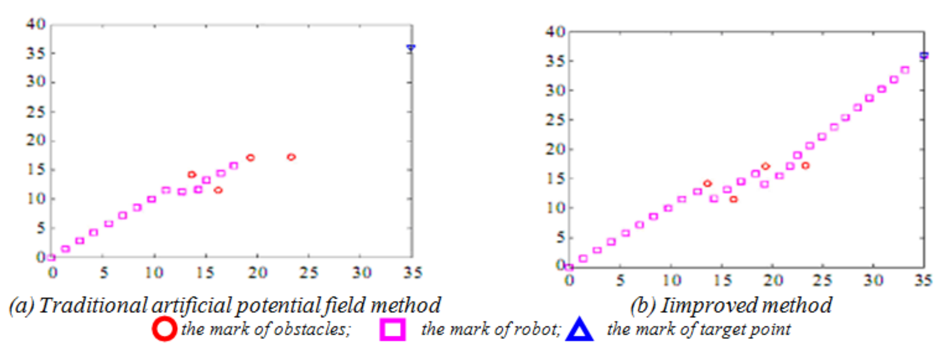


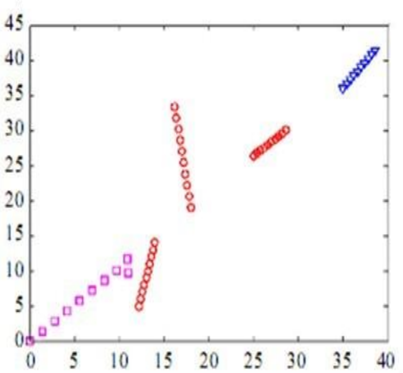
Figure 5. The Robot's Path Planning Passing a Narrow Channel with many Obstacles

The experiment results show when the obstacles form a narrow channel, the robot can overcome the local minimum and reasonably adjust the size of potential field, avoid obstacles and successfully track the target.

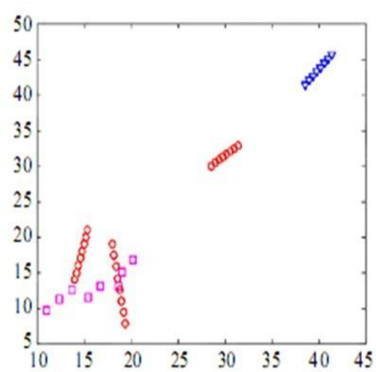
4.2. The Robot Path Planning in Special Movement State

This three locations of obstacles are (12, 4), (16, 35) and (25-26), the corresponding speed are V0(1)=[0.1 0.5]； V0 (2)=[0.1 -0.8]; V0 (3)=[0.2 0.3]. The speed of target point Vg = [0.2 0.3]; the robot with speed V = [0.2 0.4] does obstacle avoidance and target tracking. ξ= 100 , Kv= 60, using the improved method, the experimental results are shown in Figure 6.

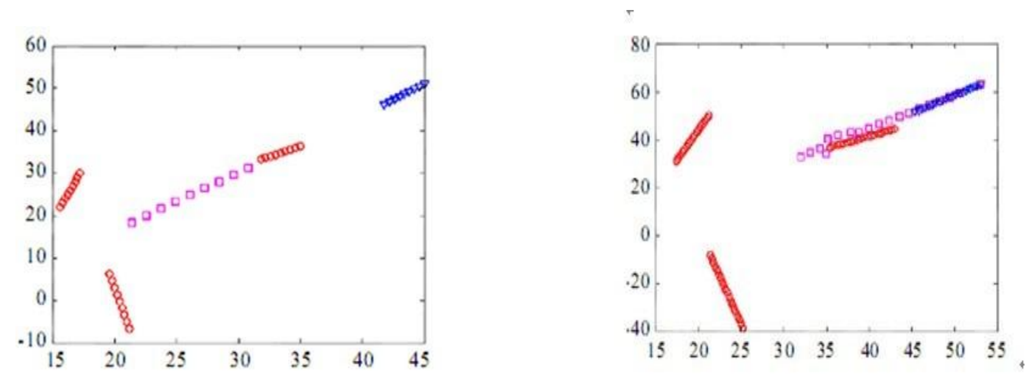
Experimental results show that in the stage 1 of movement, the obstacle with initial position (12,4) intercepts in the front of the robot, the robot can avoid a collision with anti-around to the rear of the obstacle; in the stage 2, the obstacle with initial position (16,35) moves in the front of the robot, the robot can do obstacle avoidance in advance, real-time adjust the direction of movement, and successfully bypass the obstacle; in the stage 3, the obstacle with initial position (25,26) in the robot moving direction tracks the target at the same time, robot regulates repulsion and do not to avoid obstacles, saving the time of reach the goal; in the stage 4 of movement, as the movement relationship between robot and the obstacle tracking the goal at the same time, the robot will hit the obstacle, at this time, the robot does obstacle avoidance reasonably; Since then, due to changes in relationship of the movement, the robot walks parallel to the direction of the obstacle and does not collide. At this time, the robot ignores the role of obstacles along the shortest straight line to track target. These four-stage path planning of the robots show that adopting dynamic fuzzy artificial potential field should take into account the effect of movement relationship to robot path planning.



(a) The robot path planning in stage 1.



(b) The robot path planning in stage 2.



(c) The robot path planning in stage 3. *(d) The robot path planning in stage 4.*

the mark of obstacles; the mark of robot; the mark of target point

Figure 6. The Robot Path Planning in a Special Motion State

5. Conclusions

In the study of mobile robot path planning, based on the traditional idea of artificial potential field, by changing the potential field function and combination with fuzzy control method, the artificial potential field method has been improved. Simulation results show the effectiveness of the introduction of fuzzy methods. In a typical location and movement condition, the improved method has some adaptability and timeliness. This algorithm is simple and good effective path optimization. But the artificial potential field method is an iterative algorithm; inputting the fuzzy control method increases the planning time. In the research, only the impact of speed on path planning is considered, but in practical applications, the trend of movement of objects, that is, the impact of acceleration, also should be considered, which will become the next focus of study.

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