A Novel Potential Field Method for Obstacle Avoidance and Path Planning of Mobile Robot

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***Abstract*—This paper presents a novel artificial potential field method for obstacle avoidance and path planning of mobile robots. By analyzing the shortcoming of the artificial potential field methods for robot path planning, we propose an obstacle avoidance method based on gravity chain. Suppose that there is a rubber band which connects with the beginning and the ending in the obstacle potential field space. As the rubber band will be the role of potential field power, we can build a model to simulate the shape of the rubber band. Then this method will generate a steer angle tangent to the rubber band instead of the angle of artificial potential field. By putting effective obstacle avoidance information into potential field through gravity chain, we solve the problems that the artificial potential field method often converges to local minima, as well as it hardly reach the ending and oscillatory movement. The Simulation results show that the method proposed is correct and effective.**

Keywords—obstacle avoidance; path planning; mobile robots; gravity chain; potential field;

I. Introduction

Path planning is an important branch in mobile robot research. It refers to how a robot search an uncollided path from the original to the target place based on some certain evaluation standards. [11]

Till now, a large number of research results have been achieved in the path planning, such as: artificial potential field [2], D*arithmetic [4], genetic algorithm [3, 13].

The artificial potential field (APF) method is widely used for autonomous mobile robot path planning due to its efficient mathematical analysis and simplicity [12]. The application of this method, however, is often associated with the local minima problem which occur when the total force acting on a robot is summed up to zero although the robot has not reached its goal position yet [10,13]. In order to solve the problem, some previous researches have been done in constructing potential fields free from local minima problem. Such as transforming the Gaussian function of potential [8]. Another solution is to develop the strategies of APF [5-6]. A random sampling scheme that applies random APF force vectors to move away from local minima. But that may cause the robot follow a longer path or does not guarantee to get rid of local minima in one shot [7].

As total force acting on the robot is calculated by summing up all the force components of the environmental effects. The calculation method always causes some oscillations in the motion of mobile robots. And sometimes it makes the robots can't reach the aim because the robots will suffer the great repulsion when the obstacle is near the aim. However, if the potential field force is not directly operated on the robots, all the problems can be easily solved. The method that builds a model to simulate steady state heat transfer with variable thermal conductivity solve this problem is effective [9].

In this paper, we propose a novel artificial potential field method base on gravity chain that connects with the beginning and the ending. Based on the electric charge modeling, the repulsive potential of obstacles is defined as a function of the relative position and electric charge. At the same time, the chain is described as a rubber band which carries uniform positive charge. According to the original electrostatic, the path is generated by following the gradient of a weighted sum of potentials. And the optimal path problem is then the same as to solving a geometric configuration problem of the rubber band.

A key feature of this method is the potential field force dose not directly operated on the robot, and the gravity chain only plays a guiding role to the robot. Therefore, this new potential field method solves the problem of local minima and finally avoids oscillatory movement and unreachable problems. The simulation results show that it is an effective method for obstacle avoidance and path planning of mobile robots, which can overcome the disadvantages of the artificial potential field method.

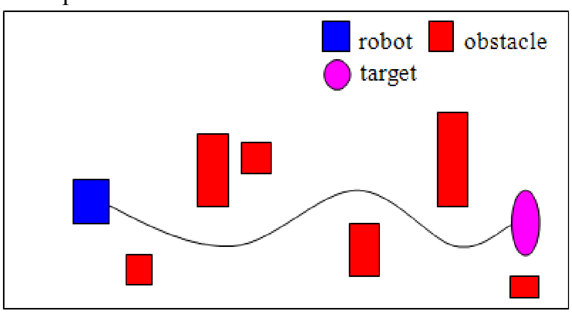

Figure 1. shows the Imaginary path of rubber band

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II. THE REALIZATION OF THE NOVEL APF METHOD

A. the basic principles of Artificial potential field

The artificial potential field method is commonly used for autonomous mobile robot path planning, because of its elegant mathematical analysis and simplicity. This method is first proposed by Khatib [1] in his Doctor's dissertation, and the real time obstacle of the robot arm has been realized in 1985. In contrast to many methods, robot motion planning based on an APF is able to consider the problems of collision avoidance and trajectory planning simultaneously. And this approach can drive the robot to its goal while keeping it from colliding with obstacles present in the workspace.

B. The realization of the novel artificial potential field method

1) environment modeling

Extend the obstacle border to half of the size of the robot both in length and width, by doing so the robot can be seen as the quality point and its quality can be ignored. Besides, if there is the convex polygon obstacle, it can be divided into many concave polygons.

2) the establishment of the gravity chain modeling

a) the choice of the original gravity factor

When there is no obstacle, the gravity chain is a chain connects with beginning and ending. Building a coordinate system based on the "X" of the beginning and ending, chooses a series of point in this "X" axes at the same interval, and put the gravity factors in it. Suppose that the X coordinate of gravity factors are invariable, when the potential field is built, the gravity factors will keep balance because of the interaction of the gravitation and repulsion. At this time, the path caused by the gravity factor is the path which the robot will move. The more points are chosen, the smoother the path is.

b) the establishment of the potential field

Suppose that the gravitation comes only from the beginning and the ending point. The gravitation is proportional to the distance and gravity factors. According to different mathematic modeling, this new potential field method can be expressed in different functions. Based on the electric charge modeling, the following functions can be got:

$$U_{att}(L)=\frac{1}{2}KQ_nQ_sL_n{}^2 \tag{1}$$

We can obtain the gravitation from gravitational potential:

$$F_{att}=KQ_nQ_sL_n \tag{2}$$

Q_n, Q_s (Q_g) stand for charge amount that No. n gravity factor and beginning (or endings).

K is a constant which is similar to the progress coefficient of springs. The greater the K is, the closer the shape of the gravity chain to a line.

L_n stands for the distance between the start point $p(x_s,y_s)$ and No. n gravity factor.

Being similar to the artificial potential field method, obstacle producing repulsion potential leads to repulsive interaction to gravity factor. Repulsion potential based on electrostatic potential field model:

$$U_{rep}(S(p_{(x_i,y_i)},p_{(x_b,y_b)}))=\begin{cases}\eta(\frac{1}{S(P(x_i,y_i),P(x_b,y_b))}-\frac{1}{\rho_0}) & S(P(x_i,y_i),P(x_b,y_b))\le\rho_0\\ 0 & S(P(x_i,y_i),P(x_b,y_b))>\rho_0\end{cases} \tag{3}$$

Negative gradient of repulsion potential is repulsive force to gravity factor:

$$F_{rep}(S(P(x_i,y_i),P(x_b,y_b)))=\begin{cases}\eta\frac{1}{S(P(x_i,y_i),P(x_b,y_b))^2} & S(P(x_i,y_i),P(x_b,y_b))\le\rho_0\\ 0 & S(P(x_i,y_i),P(x_b,y_b))>\rho_0\end{cases} \tag{4}$$

ρ_0 is the maximum scope of the effect of the obstacle to the robot. $S(p(x_i,y_i),p(x_b,y_b))$ stands for the distance between No. n gravity factor and the obstacle. And η is a positive proportion constant.

c) The formation of gravity chain

To simplify the model of this new potential field method, the simulation studies are carried out under those realistic assumptions. First: suppose lead forces of every gravity factors are equal to 1. Second, with coordinate system establishing, the gravity factors can only move in the Y coordinate.

Gravity representation based on the above assumptions:

$$\begin{cases}F_{atsi}=KL_{si}\\ F_{atgi}=KL_{gi}\end{cases} \tag{5}$$

L_{si} and L_{gi} stand for the Euclid's distance between beginning $p(x_s,y_s)$ and ending $p_{(x_g,y_g)}$ and No. i gravity factor.

$$L_{si}=\sqrt{(x_i-x_s)^2-(y_i-y_s)^2}$$
$$L_{gi}=\sqrt{(x_i-x_g)^2-(y_i-y_g)^2}$$

Repulsive force to gravity factors:

$$F_{rep}(S(p_{(x_i,y_i)},p_{(x_b,y_b)}))=\begin{cases}\eta\frac{1}{S(P(x_i,y_i),P(x_b,y_b))^2} & S(P(x_i,y_i),P(x_b,y_b))\le\rho_0\\ 0 & S(P(x_i,y_i),P(x_b,y_b))>\rho_0\end{cases} \tag{6}$$

The gravity factor will eventually reach equilibrium under the action of force (Fig. 2), so it can be expressed as following:

$$F_{atsi}\sin\theta_{si}+F_{atgi}\sin\theta_{gi}=F_{rep}(S(p_{(x_i,y_i)},p_{(x_b,y_b)}))\sin\theta_{bi} \tag{7}$$

$$K(L_{si}\sin\theta_{si}+L_{gi}\sin\theta_{gi})=\frac{\eta\sin\theta_{bi}}{S(p(x_i,y_i),p(x_b,y_b))^2} \tag{8}$$

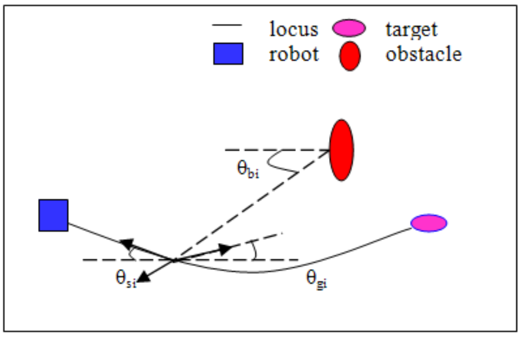

Figure 2. shows the Force diagram of the robot. Square represents robot, Elliptic represent obstacles and the circle represents the target

It is an equation on y_i, since X coordinates are known. If gravity factors are put into the above equation, we will get a point set $P\left\{p_{(x_1,y_1)}, p_{(x_2,y_2)} \cdots\cdots p_{(x_{n-1},y_n)}\right\}$; these points constitute the path that the robot will move. But the Path will not always be as smooth as your imagination. So in this new method the robot will always run the angle between two points as it can make locus smoother. If the point is enough, the direction of robot movement will always be the tangent direction of gravity chain.

Evaluation parameter

As the balance equations have many answers, which mean there will be more than one path under a certain binding condition. For example: in Fig.2, the robot can bypass the obstacle from the top or below .So we need to choice the optimal path. Evaluation parameter referred:

d) Distance to the ending s, v_l is toll costs and S's function, which is positive to the distance.

e) Distance to the obstacle L, v_b is obstacle costs and L's function, which is negative to the distance.

$$V_m = v_b + v_l$$

III. Simulation Studies

In order to verify the feasibility of this method, The Robot Soccer System platform is used to put out the simulation results and given the path in figure with MATLAB. A simple program structure shows in Fig.3.

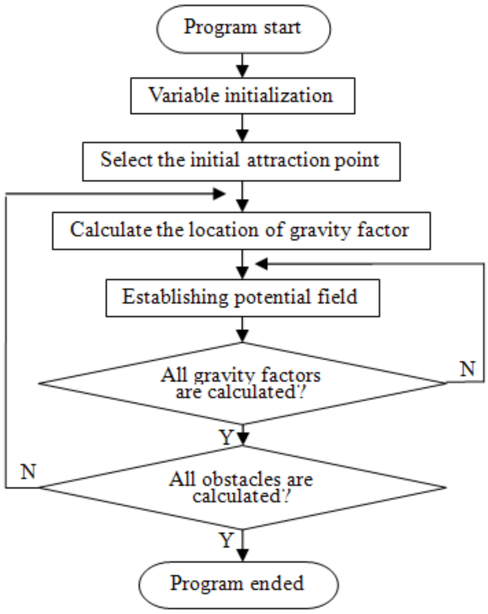

Figure 3. The block diagram of this new potential field

Some process parameters shown in Table.1 and the unit of data are inches.

TABLE I. Shows the X coordinate, Y coordinate and the angle of robot

The number of gravity factors			100
The coordinate of obstacle			(50.2256, 41.0436)
Target point coordinates			(79.34, 41.00)
Start point coordinates			(22.0486, 40.9457)
Case	**The simulation data**		
	Robot coordinates	***Gravity factors coordinates***	***Steer angles of robot***
I	(47.3761,32.8205)	(47.2568,33.5988)	-2.52395
II	(49.5680,32.6854)	(49.5484,33.5317)	-0.26486
III	(51.7825,32.6887)	(51.8401, 33.5234)	1.891648
IV	(53.9459,32.7048)	(54.1318, 33.6308)	4.01632
V	(55.0248,32.6344)	(55.2776, 33.7167)	5.084476
VI	(57.1285,32.7804)	(57.5692,33.9530)	7.225002
VII	(59.1961,32.9767)	(59.2880,34.1873)	8.835632

A. *simulation results*

In The Robot Soccer System platform, the robot receives date from host computer and all calculations for strategy and position control of robots are done on the host computer. As the result, we can get the coordinates of the robots from the platform. In the simulation, it is assumed that the goal and the obstacles are fixed. To show the effectiveness and advantages of this new motion planning scheme, Simulation is divided into two groups. First we validate the new potential field. Second make the comparison between two methods.

Path planning of this new method in complicated environment is shown in Fig.4; the triangle indicates the goal position and the solid circle is the obstacles.

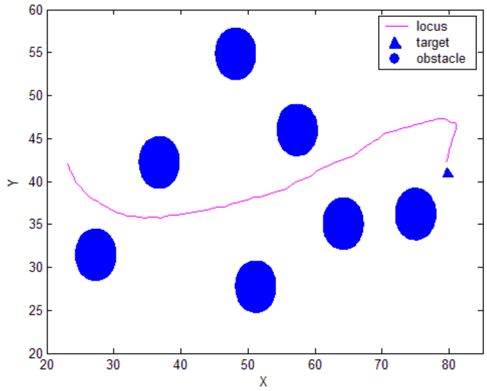

Figure 4. shows the locus, obstacles and the target that drawn based on the new potential field method.

The path is composed of the gravity factor, and the locus show in Fig.4 is the trajectory of robot. The obstacles produce repulsion to reject gravity factor and the target attract it. The proposed path optimization algorithm is verified by the example given in Fig.4.

The path generated by the proposed approach has various favorable features such as freedom from local minima compared with the original APF. Illustrated in Fig. 5, the robot is suffering from local minima problem of artificial potential field. At the same time the path based on new potential field method is shown in Fig.6, in which there is no local minima situation.

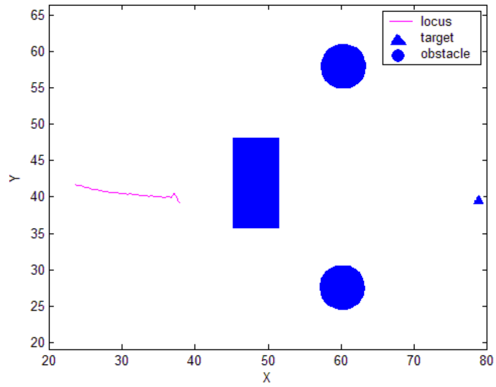

Figure 5. shows the local minimum problem of artificial potential field

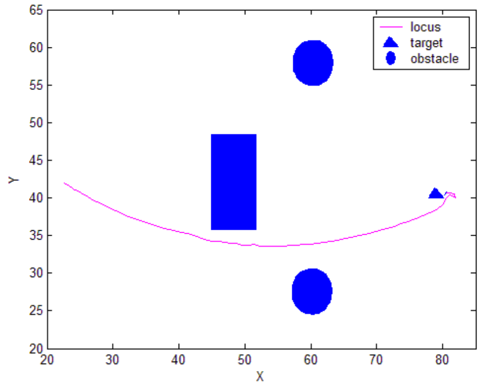

Figure 6. shows the locus based on the new potential field method, which can effectively solve the local minimum problem

Compared with Fig.7 and Fig.8, it is shown that the method of artificial potential field will be inaccessible to target because of large obstacles near the target point. But the new potential field can be very good at avoiding the obstacles to reach the target point in Fig.8. These experiments have been amply demonstrated out the new potential field advantages in resolving these problems.

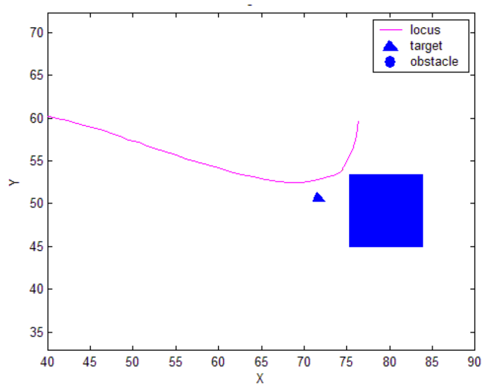

Figure 7. shows the unreachable problem of artificial potential field when the is a large obstacles near the goal

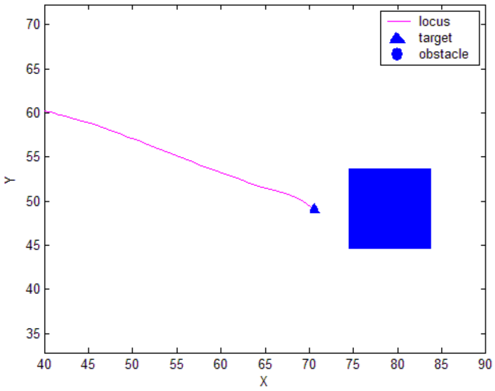

Figure 8. shows the locus based on the new potential field method and the robot can effectively close to the target point

IV. CONCLUSION

In this paper a novel potential field method has been proposed for mobile robot motion planning in a static environment where both the goal and the obstacles are fixed. Once the potential field has been generated, the path proceeds very fast, since it only involves the calculation of gravity factors. The path generated by the proposed approach has various favorable features such as freedom from local minima, no shaking problem, smoothness and collision avoidable. The computer simulations have demonstrated the effectiveness of the mobile robot motion planning schemes based on this new potential field method. Accordingly, this approach can be applied to rich classes of robot path planning in static environments

Because of this method is mainly used to solve the obstacle problem without considering the optimal path, so finding a best or better path are then become a work need to be done in the future.

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