Path planning for mobile robot using the novel repulsive force algorithm

Siyue Sun*, Guoqiang Yin and Xueping Li

School of Mechanical Engineering, Tianjin University of Technology, Tianjin 300384, China

*Corresponding author e-mail: sunsy_503@163.com

Abstract. A new type of repulsive force algorithm is proposed to solve the problem of local minimum and the target unreachable of the classic Artificial Potential Field (APF) method in this paper. The Gaussian function that is related to the distance between the robot and the target is added to the traditional repulsive force, solving the problem of the goal unreachable with the obstacle nearby; variable coefficient is added to the repulsive force component to resize the repulsive force, which can solve the local minimum problem when the robot, the obstacle and the target point are in the same line. The effectiveness of the algorithm is verified by simulation based on MATLAB and actual mobile robot platform.

1. Introduction

Robot path planning is an important part of the discipline of robotics. The idea of a path planning approach is to make the robot move from its starting point towards a destination point, while avoiding obstacles on its way [1]. There are many algorithms for robot path planning; the artificial potential field method is particularly attractive because of its mathematical elegance and simplicity [2].The traditional artificial potential field method assumes that the target point of the robot has a strong appeal, while obstacles applied repulsive force to the robot, and with the robot close to obstacles, the repulsive force will become increasingly large, which means that around obstacles there exists a potential field, hindering the robot proximity[3]. As the target point is designed to be the global minimum of the potential field, the robot will eventually stop at the target point. However, this method has some inherent limitations. When the target point is near the obstacle, the robot cannot reach the goal and reciprocate oscillation around the target point because of the repulsion of the obstacle [4]. Due to the force balance, the robot will fall into local minimum and cannot avoid obstacle when the robot, the obstacle and the target point are in the same line [5].

To overcome the problem of goal unreachable, Krogh [6] proposed a method that is multiply the square of the relative distance between the robot and the target in traditional repulsive potential function, however this method greatly changes the shape of the potential field, which reduces the efficiency of path planning. In order to minimize the distortion of the shape of repulsive potential field. J. Sfeir [7] proposed a new repulsive potential field that ensures the target is the global minimum, but when the robot and the target point is very near, the shape of the potential field will also be greatly changed. Though above these methods can help the robot stop at the target, cannot solve the problem of local minimum when the robot, obstacle and goal in the same line.

In order to improve the efficiency of robot path planning and not change the shape of repulsive potential field, this paper introduces a new repulsive force that is by adding the Gaussian function related to the distance between the robot and the target to the traditional repulsive force to solve the problem of goal unreachable; and adding the variable coefficient in the component of the repulsive force can help the robot escape the local minimum.

2. The model of the artificial potential field

The attractive potential field function of the target is:

$$U_{att} = \frac{1}{2}\xi\left[(x - x_g)^2 + (y - y_g)^2\right] \tag{1}$$

Where ξ is a positive gaining factor, $[x, y]$ is the coordinate of any point in the process of robot movement, $[x_g,y_g]$ is the target point.

The repulsive potential function of the obstacle takes the following equation by Khatib [8]:

$$\Phi = \begin{cases} \frac{1}{2}\eta\left(\frac{1}{\rho} - \frac{1}{\rho_0}\right)^2 & \rho < \rho_0 \\ 0 & \rho \geq \rho_0 \end{cases} \tag{2}$$

Where η is a positive gaining factor, ρ is the distance between the robot and the obstacle, ρ_0 is a positive constant denoting the distance of influence of the obstacle, when $\rho < \rho_0$, the obstacle produces the effect of repulsion to the robot.

The negative gradient of the potential field is used as the virtual force acts on the robot, so the repulsive force is given by (3):

$$Frep = -grad(\Phi) = \frac{\eta}{\rho^2}\left(\frac{1}{\rho} - \frac{1}{\rho_0}\right)\left[\frac{\partial\Phi}{\partial x}, \frac{\partial\Phi}{\partial y}\right] \tag{3}$$

The size of repulsive force is as follows:

$$|Frep| = \begin{cases} \frac{\eta}{\rho^2}\left(\frac{1}{\rho} - \frac{1}{\rho_0}\right) & \rho < \rho_0 \\ 0 & \rho \geq \rho_0 \end{cases} \tag{4}$$

The calculation of the angle between the robot and the obstacle is given by (5):

$$\theta = arccos\left(\frac{x - x_0}{\sqrt{(x-x_0)^2 + (y-y_0)^2}}\right) \tag{5}$$

Where $[x_0, y_0]$ is the coordinate of the obstacle.

The components of repulsive forces in the X and Y axes are given by (6) and (7):

$$|FrepX| = \begin{cases} |Frep| * cos\theta & \rho < \rho_0 \\ 0 & \rho \geq \rho_0 \end{cases} \tag{6}$$

$$|FrepY| = \begin{cases} |Frep| * sin\theta & \rho < \rho_0 \\ 0 & \rho \geq \rho_0 \end{cases} \tag{7}$$

However, according to the equation (2), when the target point is in the distance of influence of obstacle, the robot will be also subjected to the rejection of obstacle at target point, it lead to the robot vibrates around the target point, as shown in Fig. 1; and when the robot, the obstacle and the target are in the same line, the robot is trapped in local minimum and cannot avoid the obstacle to reach the target point, as shown in Fig.2.

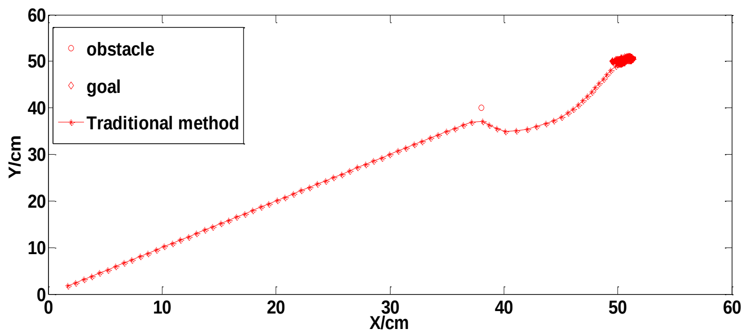

Figure 1. The problem of goal unreachable

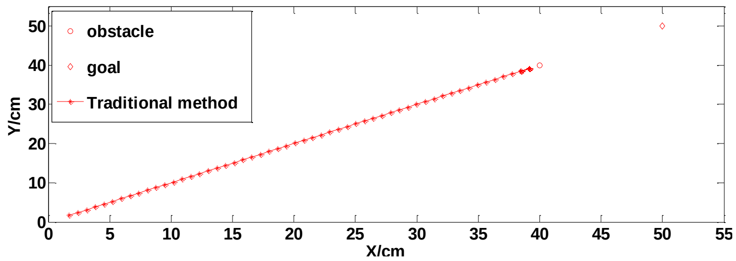

Figure 2. The problem of local minimum

In order to solve the problem of goal unreachable, we introduce a novel repulsive function based on equation (4), the Gaussian function that is related to the distance between the robot and the target is added to the traditional repulsive force (8).

$$|Frep|_{modified} = \begin{cases} \frac{\eta}{\rho^2}\left(\frac{1}{\rho} - \frac{1}{\rho_0}\right)\left[1 - e^{-\frac{(x-x_g)^2+(y-y_g)^2}{R^2}}\right] & \rho < \rho_0 \\ 0 & \rho \geq \rho_0 \end{cases} \tag{8}$$

In order to help the robot escape from the local minimum, the variable coefficients are added to the components of the repulsive force in the X and Y axes based on (6)and (7), the equations are given by (9) and (10).

$$|FrepX| = \begin{cases} (1+\alpha)|Frep|_{modified} * cos\theta & \rho < \rho_0 \\ 0 & \rho \geq \rho_0 \end{cases} \tag{9}$$

$$|FrepY| = \begin{cases} (1+\beta)|Frep|_{modified} * sin\theta & \rho < \rho_0 \\ 0 & \rho \geq \rho_0 \end{cases} \tag{10}$$

Where α and β are the constants of -1 to 1, (9) and (10) are designed to change the direction of the repulsive force through altering the size of the repulsive in the X axis and the Y axis. Such a change is able to transfer the direction of the robot's resultant force, leading the robot to march to the target and escape the local minimum point avoiding the obstacles. It can be concluded that α and β should not be given the same value, otherwise, the direction of the repulsive force will not be changed and the robot cannot escape from the local minimum.

3. Simulation

In order to verify the effectiveness of the algorithm, this paper uses MATLAB to carry out the simulation experiment. Firstly, verify that the improved repulsive force algorithm can stop the robot at the target point. Then verify that changing the components of the repulsive force can make the robot escape from local minimum. At last, verify the feasibility of the method combing above the two cases.

In this paper, the traditional artificial potential field has been improved two times, the equation (8) is to ensure the robot stop at the target and not be subjected to the exclusion of obstacle when the target is in the influence scope of obstacle, but this function cannot ensure the robot escape the local minimum when the robot, obstacle and target in the same line; so we change the components of repulsive force in the X and Y axis based on equation (8) to ensure the robot can escape from local minimum, the simulation results are shown in Fig. 3.

We set the position of the goal is (50, 50), the obstacle is (38, 40), the distance of influence of obstacle $\rho_0 = 30$; $\eta = 100$ the radius of the robot is $R = 80$, the results are shown in Fig. 4.

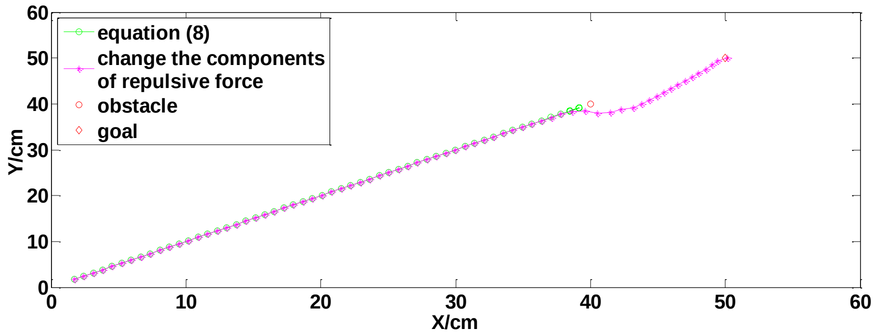

Figure 3. The comparison of two times improvement

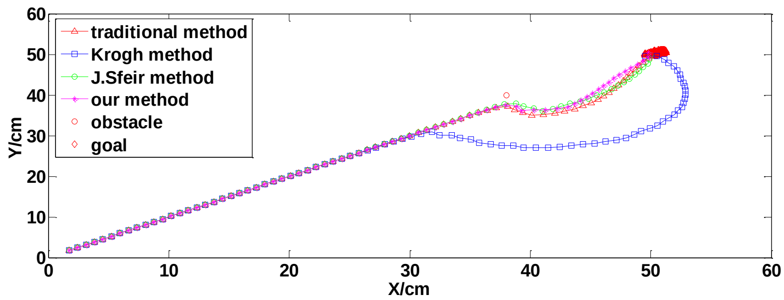

Figure 4. Solved the problem of goal unreachable

In comparison with traditional artificial potential field, it can be seen from Fig. 4 that the modified repulsive force algorithm has solved the problem of goal unreachable; the robot is not affected by the obstacle (38,40), and the path of our method is shorter and smoother. The Krogh's method in [6] was based on the change of equation (2), its equation as (11).

$$\Phi = \begin{cases} \frac{1}{2}\eta\left(\frac{1}{\rho} - \frac{1}{\rho_0}\right)^2 \left[\left(x - x_g\right)^2 + \left(y - y_g\right)^2\right] & \rho < \rho_0 \\ 0 & \rho \geq \rho_0 \end{cases} \tag{11}$$

Although this function can guarantee the robot to stop at the target point, the shape of the repulsive potential field has been greatly changed when the distance between the robot and the obstacle goal is far away in comparison with traditional artificial potential field; it causes the path that the robot to avoid the obstacle become far and reduces the efficiency of path planning. The shape of Krogh's method repulsive potential field and local amplification are shown as Fig. 6; Fig. 5 is the shape of traditional repulsive potential field. By contrast, it can be clearly observed that the shape of the potential field is greatly changed. J.Sfeir's method in [7] reduces the change of the repulsive potential field; its equation as (12), this method has greatly improvement in comparison with Krogh method, but these two method can only ensure the robot stop at the target point, not ensure the robot escape from the local minimum when the robot, obstacle and goal in the same line. The shape of J.Sfeir's method repulsive potential field and local amplification are shown as Fig. 7.

$$\Phi = \begin{cases} \frac{1}{2}\eta\left(\frac{1}{\rho}-\frac{1}{\rho_0}\right)^2\left[1-e^{-\frac{(x-x_g)^2+(y-y_g)^2}{R^2}}\right] & \rho < \rho_0 \\ 0 & \rho \geq \rho_0 \end{cases} \tag{12}$$

In order to not change the shape of potential field and improve the efficiency of path planning, we puts forward the improvement based on the repulsive force to ensure that the robot is stationary at the target point and is not subject to the exclusion of obstacles; and the robot will not be trapped in local minimum when the robot, obstacle, target in the same line. Our method repulsive field is shown as Fig. 8, through comparison with Fig. 5, it can be clearly observed that the shape of the potential field does not change significantly.

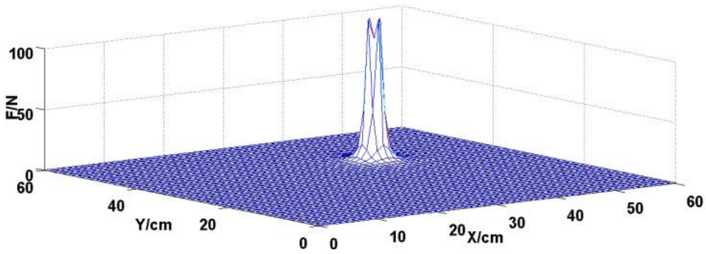

Figure 5. The shape of traditional repulsive potential field

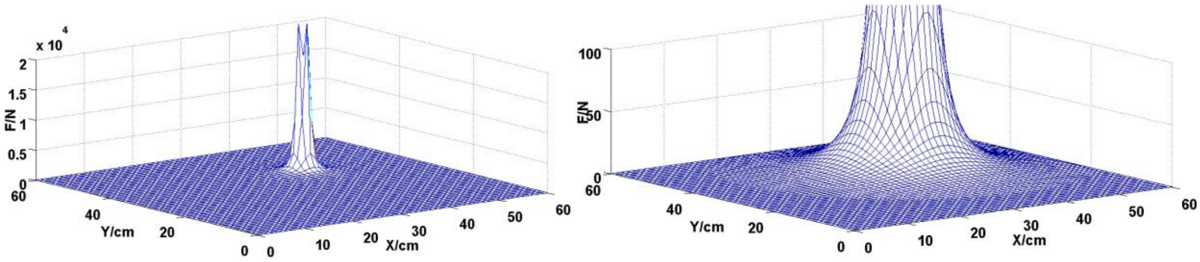

Figure 6. The shape of Krogh's method repulsive potential field and local amplification

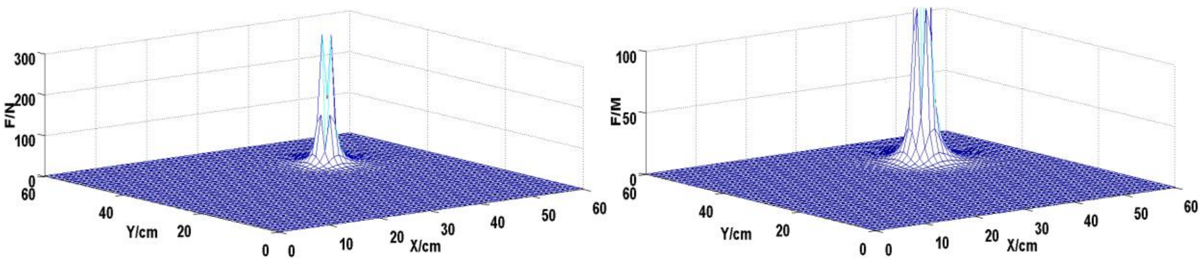

Figure 7. The shape of J.Sfeir's method repulsive potential field and local amplification

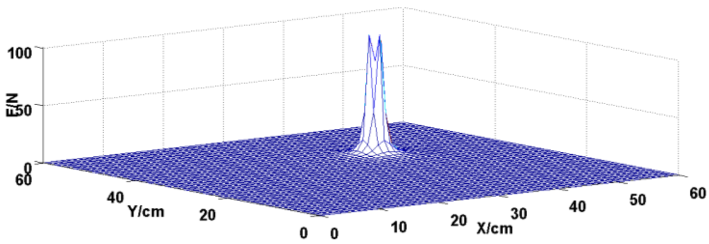

Figure 8. The shape of this paper's method repulsive field

Set the position of the goal is (50, 50), the obstacle is (40, 40) , so that the robot, obstacle, the target point in the same line, in comparison with Fig. 2, it can be seen from Fig. 9 that the method proposed by Krogh and J.Sfeir cannot make the robot escape from local minimum when robot, obstacle and target at the same line; but our method can help the robot escape from the local minimum and avoid the obstacle march to the target, and the path of the robot is very smooth.

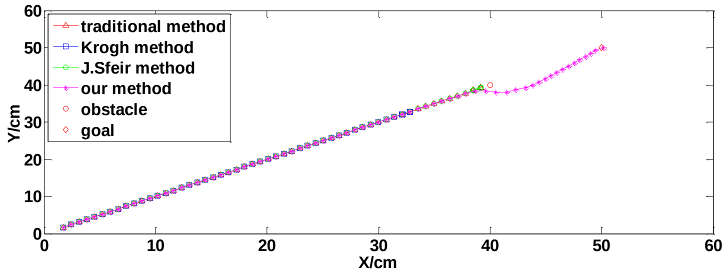

Figure 9. Solved the problem of local minimum

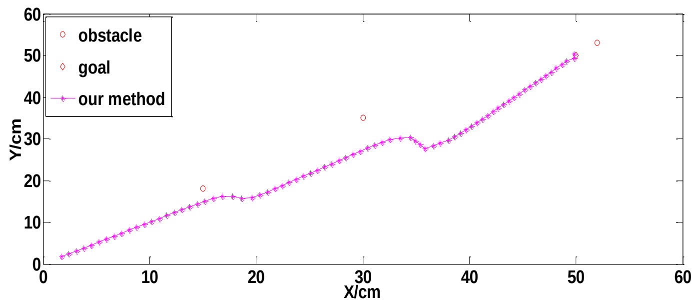

Figure 10. The Path of multiple obstacles

Increase the number of obstacles that are (15,18), (30,35), (52,53), the path of the robot as shown in Fig. 10, it can be seen from Fig. 10 that the method proposed in this paper is feasible in the case of multiple obstacles.

Based on the above analysis, in the case of the same potential field parameters, this paper's method compared with the Krogh's method and J.Sfeir's method, the length of path is shorter and smoother, which greatly improves the efficiency of the path planning.

4. Experiments

In this section, we use the robot to test the feasibility of the proposed algorithm in this paper and compare with the methods proposed by Krogh in [6] and J.Sfeir in [7]. The following are the experimental equipment and experimental results.

Fig. 11 is the experimental equipment and scene; the mobile robot equipped with four step motors for movement, a microprocessor for programming and control, and camera, display screen for color identification, the specification of the robot is 320*360mm and the working space of the robot is

3000*2000mm, the red object represents target and the green object represents obstacle; a mark pen is installed in the robot center to record the walking path of the robot, as shown in Fig. 12, then use Get Data Graph Digitizer to extract data and use origin 8.0 to draw the image of these data, the results are shown in Fig. 13 to Fig. 16. In order to verify the robot can escape from local minima and stop at the target point, we set the influence distance of the obstacle is 800mm,and place the target in the range of obstacles, and make the robot, obstacle, target point in the same line.

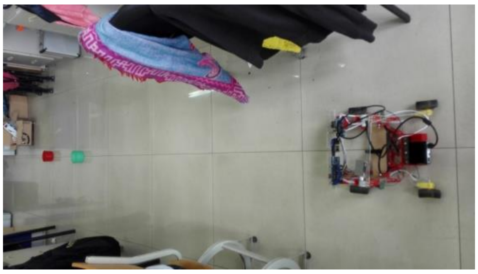

Figure 11. Experimental equipment and scene

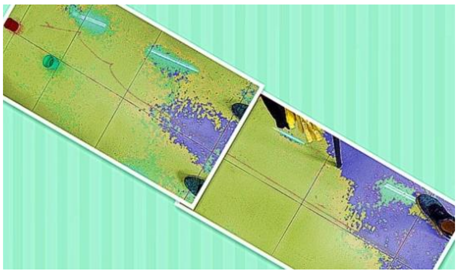

Figure 12.The path of mark pen record

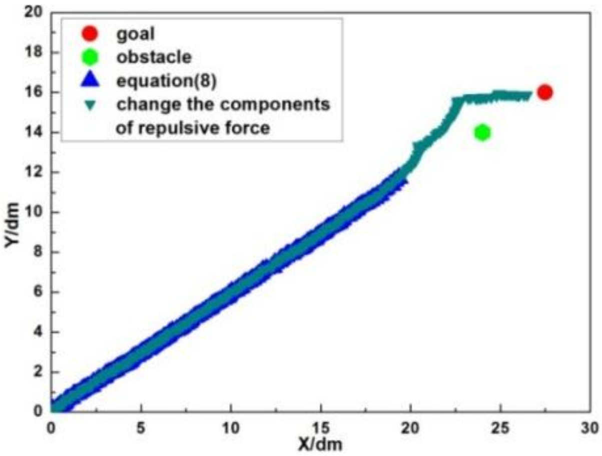

Figure 13. The comparison of two times improvement

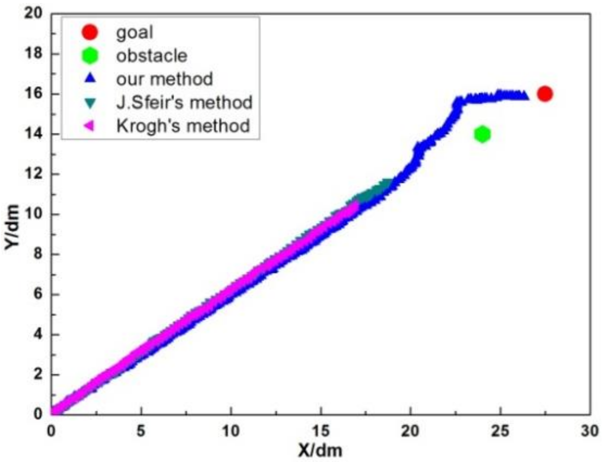

Figure 14. Escaped the local minimum and stop at the target

Fig. 13 shows that when the robot, obstacle and target in the same line, the equation (8) does not change the repulsive force components in X and Y axis, the robot trapped in local minimum, but after change the components of repulsive force, the direction of the robot's movement will be also changed, as a result, the robot can escape the local minimum. In comparison with the methods proposed by J.Sfeir and Krogh, it can be seen from Fig. 14 that the proposed algorithm can help robot escape the local minimum point and stop at the target.

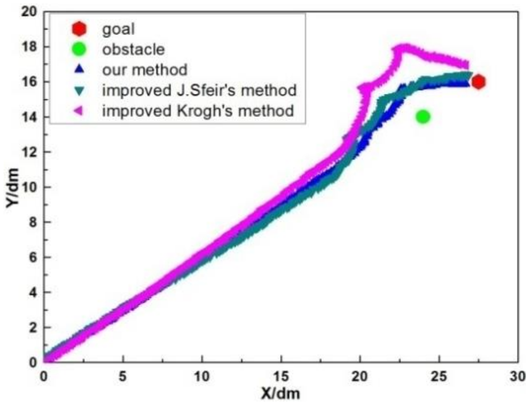

Figure 15. Comparison of three methods

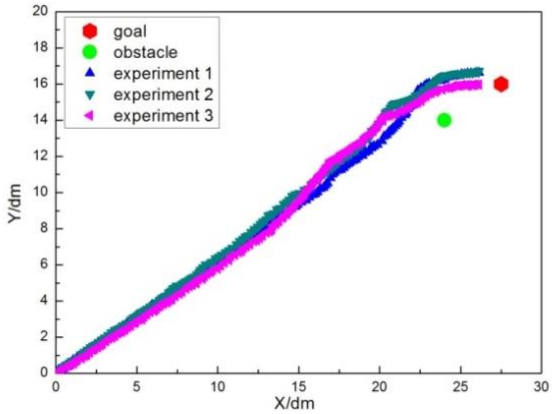

Figure16. Repeated experiments based on our method

In order to highlight the advantages of this algorithm, this paper also changes the other two methods' repulsive force component in the X axis and the Y axis, and then compares the walking path of the robot. As shown in Fig. 15, it can be seen that the path of our method is smoother and shorter, which greatly improves the efficiency of the robot path planning. A number of repeated experiments were carried out to verify the feasibility and effectiveness of the algorithm; the experimental results are shown in Fig. 16.

5. Conclusion

Through the simulation experiments, it can be observed that when the target is in the range of influence of the obstacle; the proposed repulsive algorithm avoids the robot to be affected by the obstacle and solves the problem of goal unreachable. Moreover, by changing the size of the repulsive force in the X axis and the Y axis, we can overcome the problem of the local minimum on the condition that the robot, the obstacle and the target are at the same line. In addition, the variables that are added to the components of the repulsive force will affect the escaping path from the local minimum of the robot, if the value is not appropriate, the path of the robot may have a mutation and easily lead to an oscillation.

Through the experimental results, in comparison with other methods, the path of the proposed algorithm is smoother and shorter; however, due to the lack of performance of the experimental equipment, the robot is greatly influenced by the space environment and its own conditions, and the extraction of data and the path of the robot have some deviation, all above these cause some differences between the actual walking path and the simulation path of the robot.

References

[1] Jinchao Guo, Yu Gao, Guangzhao Cui., Path planning of mobile robot based on improved potential field, J. Inform Technol. 12 (2013) 2188-2194.

[2] S.S.Ge, Y.J.Cui, New Potential Functions for Mobile Robot Path Planning, IEEE T Robotic Autom,16(2000) 615-620.

[3] Hao Wang, Lianyu Zhao, Wei Chen, A Mobile Robot Obstacle Avoidance Method based on Improved Potential Field Method, Appl. Mech. Mater., 467 (2014) 496-501.

[4] Huasong Min, Yunhan Lin, Sijing Wang, Path planning of mobile robot by mixing experience with modified artificial potential field method, Adv Mech Eng., 7 (2015) 1-17.

[5] Li Zhou, Wei Li, Adaptive artificial potential field approach for obstacle avoidance path

planning, ISCID, Hangzhou, 2014, pp.429-432.
[6] Krogh, B., A Generalized Potential Field Approach to Obstacle Avoidance Control, Proceedings of the ASME Conference on Robotic Research, Bethlehem, Pennsylvania, 1984.
[7] J.Sfeir, M.Saad, H.Saliah-Hassane, An improved artificial potential field approach to real-time Mobile robot path planning in an Unknown Environment, IEEE ROSE, Montreal, 2011, pp. 208-213.
[8] O.Khatib. Real-time obstacle avoidance for manipulators and mobile robots, IEEE ICRA, 1985, pp.500-505