APF Obstacle Avoidance in Polar Coordinates for Mobile Robot Based on Laser Radar

YU Zhiqiang, GAO Meng，DENG Xiaoyan, DU Liqiang, HE Chaofeng, DI Jianhong, YANG Yong, SHI Yanhui, HU Liqiang
Shijiazhuang Railway Institute
Shijiazhuang 050043, Hebei Province, China
Yuzhiqiang38381@126.com, gaomeng@sjzri.edu.cn

Abstract—**In order to improve the safety and the reliability of mobile robot, a method for the path planning and the obstacle avoidance is provided based on distance information that laser radar offers. The method used the improved artificial potential field (APF) and set up the real-time variation polar coordinates, whose centre was the place that the laser radar installed in. In the polar coordinates, the robot-to-obstacle relative distance was measured, the direction and the speed of robot were adjusted to avoid obstacles. The simulation results show that this method based on the distance information that laser radar provides can make mobile robot avoid obstacle reliably.**

Keywords- laser radar; path planning; obstacle avoidance; polar coordinates; artificial potential field

I. INTRODUCTION

Environment perception is one of the key technologies in the mobile robot research. The environment information around the robot can be used to navigate, avoid obstacle, plan the path or execute specific task. The path planning of mobile robot is an important component of autonomous mobile robot, its mission is to look for a no-collision path from the start state to the target state according to certain evaluation standard in the obstacle environment. Path planning models can be divided into two types: global path planning based on model, also known as static or offline path planning; and local path planning based on sensor, also known as dynamic or online path planning[1]. This article mainly aims at local path planning, provides a method of dynamic obstacle avoidance in polar coordinates. The robot detects the obstacle distance by the laser radar in the polar coordinates, which is established real-time, calculates its relative speed, and then adjusts the magnitude and direction of its speed to avoid obstacles. It does not need any outside auxiliary positioning system, and solves the problem of path planning in dynamic environment. The simulation results prove the effectiveness of this method.

II. SELECT LASER RADAR

When robot gets environmental information, its sensor not only requires the view field large enough to cover the entire work region, but requires higher sampling frequency to ensure to provide real-time information in dynamic environment. In recent years, laser radar becomes increasing in the application of navigation of mobile robot[2,3]. This is mainly because the distance measurement technology of laser has many advantages, particularly its higher accuracy. Through 2D or 3D scanning laser beams or scanning laser plane, laser radar can provide mass and accurate distance information in higher frequency. Compared with other distance sensors, laser radar can give attention to the requirements of precision and speed. In addition, the laser radar can work both in bright circumstances and in the dark, frees from the constraints of light outside. The basic principle of radar is to measure the time interval from the launched laser beam to the reflected light received (time-of-flight, TOF), and reflection light is reflected from the surface of detected objects, the TOF is proportional to the measured distance. At present, there are three kinds of methods often used to measure the time interval[4]: The first method - TOF, it directly measures the discrete pulse from the launched beam to the reflected beam; the second method is AMCW, which measures time interval by measuring the phase difference of amplitude-modulated continuous wave (AMCW); FMCW is the third method, which does it by measuring the frequency difference of frequency-modulated continuous wave(FMCW). Among these methods, FMCW approach is rarely used because of the higher requirement of laser diode. In practical application, TOF laser radar and AMWC laser radar are often used.

Because of measuring phase by frequency difference, AMCW laser radar has higher accuracy. However, owing to the defect of the principle, there are two main problems of AMCW laser radar: the two-meaning interval problem and the mixed-pixel problem. Therefore, AMCW laser radar is difficult to differentiate more objects in the clutter environment, and its measuring speed is slower than that of TOF laser radar. Moreover, AMCW laser radar is also very sensitive to the temperature of environment and the object reflectivity.

In the process of the autonomous navigation of mobile robot, major detection region is mostly 20m to 150m in front of the robot. So, compared with this range, the accuracy of detection distance is not very important, 10cm that distance resolution can completely meet the need of practical application. On the contrary, the maximum detection range of laser radar is very significant in this case. Therefore, TOF laser radar is more suitable to the autonomous navigation of mobile robot.

978-1-4244-5848-6/10/$26.00 ©2010 IEEE

Authorized licensed use limited to: UNIVERSIDADE FEDERAL DO CEARA. Downloaded on September 06,2020 at 00:24:05 UTC from IEEE Xplore. Restrictions apply.

Through the pretreatment, distance information obtained by three-dimension laser radar can be constructed the CAD model or the three-dimension model. But, the three-dimension information is usually got through scanning scenes by two reflecting mirror that mechanism controls, it will bring additional mechanical control problems. In addition, the amount of data collected by three-dimension laser radar is much greater than that by two-dimension laser radar, so usually more collection time is needed. In the process of autonomous navigation and path planning, data collection time is the key to the real-time control. So, two-dimension laser radar is more suitable to the navigation and path planning of mobile robot.

As above comparison, two-dimension TOF laser radar is the best choice of the autonomous navigation and dynamic path planning of mobile robot. This paper uses laser radar LMS220 that produced by Germany SICK photonics company, its the largest range is 50m~150m, distance resolution is 10mm~50mm, level field of vision is 100°~180°, angular resolution is 0.25°~1°, collection cycle is 13ms~80 ms.

III. OBSTACLE AVOIDANCE MODEL

As above mentioned, according to the perceptive environment information, mobile robot plans the path. The main ways of global path planning are view law, freedom space law, optimal control law, raster law and topological law and so on; the ways of local path planning include artificial potential field law, neural networks law and genetic algorithms law and so on.

Neural network law[5,6] is to process sensor information fuzzy, and to make fuzzy rules, then the fuzzy rules act on the samples and train the neural network, it makes the whole reflect some intelligence. The basic idea of genetic algorithms[5,7]: the individual path is expressed a series of halfway points in the path ,which are converted into binary strings. First path groups are initialized, and then genetic manipulation is carried out, such as the selection, crossover, reproduction and mutation, after several generations' evolution, the best individual is output. Its defect is slow operation speed, because much evolutionary planning is to occupy the larger store space and computing time.

APF law[8~10] is a virtual force method presented by Khatib in the 1980s. The basic idea is to view the movement of mobile robot in the environment as the movement in the virtual manual force field. Obstacles bring repulsion to the mobile robot, the goal point brings the gravitation, and the robot is acted on the abstract force in the potential field and rounds the obstacles. The method is simple, easy to control in real time by the base and is widely used. Its defect is local optimal solution, and it will easily result in deadlock.

On the basis of the above methods, a polar coordinates is set up in this paper, the origin of the polar coordinates is the middle of the front of mobile robot where installs the laser radar, the central axis of the robot's body is as the polar axis, the anti-clockwise is as positive direction. Robot can build the real-time variation coordinates in any control cycle using the distance information that the laser radar detects, the improved APF method is used, robot can make decision by the distance of obstacle-to-itself and goal –to-itself to adjust the speed and direction, plan the path to avoid obstacles.

IV. BUILD THE POLAR COORDINATES

The origin of the polar coordinates is the middle of the front of mobile robot, the central axis of the robot's body is as the polar axis, the polar coordinates set up is shown as figure 1,where, Db is the effective sensing distance of laser radar. Selecting the middle of the front of robot, rather than the center of the front-wheel or rear-wheel of robot as the origin, is based on the following reasons: (1) Laser radar is installed in the middle of the front, the origin of the coordinates accords with the firing point of laser radar. The scanning data of laser radar are also given by polar coordinates form, the location of the obstacle can be very convenient to read out from the coordinates of laser radar, (2) In many cases, the collision between mobile robot and the obstacle occurs in the front of mobile robot possibly. The origin of the coordinates locates in front of mobile robot, which is natural reasonability and convenience in data calculation of the path length and obstacle danger.

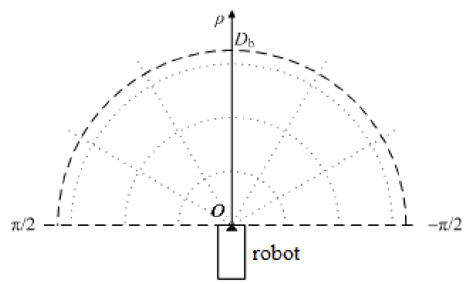

Figure 1. Polar coordinates of mobile robot established

V. APF OBSTACLE AVOIDANCE METHOD IN POLAR COORDINATES

The basic idea of potential field law is to set up an artificial potential field in the environment where the mobile robot moves, it has the effect on mobile robot by the attractive field of the goal point and the repulsion field around the obstacle. Its mathematical formulation is simple and its application is wider. But it has its own flaw, that is, when the goal point is near the obstacles, the robot will never reach it. To overcome this flaw, in the definition of the repulsive force field function, the relative distance between the mobile robot and the goal point should be accounted into. The improved repulsion field function can ensure that the entire potential field in the goal point reaches the global minimum, so that the robot will eventually reach the goal point.

A. *traditional artificial potential field method*

The traditional artificial potential field method is defined as below[11,12]:

$$U_{at}(M) = 0.5\xi\rho^{m}(M, M_{go}) \tag{1}$$

Where, ξ is positive proportion factor, M is the location of the robot in motion space, M_{go} represents the location of the

Authorized licensed use limited to: UNIVERSIDADE FEDERAL DO CEARA. Downloaded on September 06,2020 at 00:24:05 UTC from IEEE Xplore. Restrictions apply.

goal point, $\rho(M,M_{go})$ is the distance between the robot and the point point, the attractive force to the robot that the attractive field generates is the negative gradient of the attractive potential energy; when m = 1, attractive potential field is conical, except the goal point, the attractive force of the other points is constant amplification, $U_{at}(M)$ is monotonous. When m=2, attractive potential field is like parabola, the attraction $F_{at}(M)$ is the negative gradient of the attraction potential field $U_{at}(M)$. The negative gradient of the attractive field is as followed:

$$F_{at}(M) = -\nabla U_{at}(M) = \xi(M_{go} - M) \tag{2}$$

When the robot is near the goal point, attractive potential field is close to zero. The repulsive potential field function commonly used is as followed:

$$U_{re}(M) = \begin{cases} \frac{1}{2}\eta\left(\frac{1}{\rho(M,M_{go})} - \frac{1}{\rho_0}\right)^2, if \rho(M,M_{ob}) \le \rho_0 \\ 0, \quad if \rho(M,M_{ob}) > \rho_0 \end{cases} \tag{3}$$

Where, η is a positive proportion factor, $\rho(M,M_{ob})$ is the shortest distance between the robot and obstacles, ρ_0 is the positive constant of the effect distance of that obstacle, the corresponding repulsive force is:

$$F_{re}(M) = -\nabla U_{re}(M) = \begin{cases} \eta\left(\frac{1}{\rho(M,M_{ob})} - \frac{1}{\rho_0}\right)\frac{1}{\rho^2(M,M_{ob})}\nabla\rho(M,M_{ob}), if \rho(M,M_{ob}) \le \rho_0 \\ 0, \quad if \rho(M,M_{ob}) > \rho_0 \end{cases} \tag{4}$$

So the resultant force acting on the robot is the addition of the attraction and repulsion.

$$F_{to} = F_{at} + F_{re} \tag{5}$$

F_{to} determines the movement direction of mobile robot. When the goal position is very close to obstacle, attractive force is lower and repulsive force is increaser. So the resultant force pushes away the robot and makes it not reach the goal point, it is necessary to amend the form of attraction and repulsion functions in order to make the robot get to the intended point.

B. *Improved repulsion Field Function*

In order to overcome the flaw of traditional repulsion field, in the definition of repulsive force field function[13], the relative distance between the robot and the objective is taken into account, the improved repulsion field function is as followed:

$$U_{re}(M) = \begin{cases} \frac{\eta}{2}\left(\frac{1}{\rho(M,M_{ob})} - \frac{1}{\rho_0}\right)^2 \rho^n(M,M_{go}), if \rho(M,M_{ob}) \le \rho_0 \\ 0, \quad if \rho(M,M_{ob}) > \rho_0 \end{cases} \tag{6}$$

Where, n is a real number greater than zero, the other physical quantities are of the same meaning as above. Compared with the traditional repulsion field function, the relative distance $\rho(M,M_{go})$ is considered between the robot and the goal point to ensure that the entire potential field of the goal point gets to minimum. When m=n=2, $\xi = \eta = 1$, $\rho_0 = 1$, the goal point location is at the origin (0,0) and the coordinates of the obstacle is (1,0), the total potential field distribution is as followed:

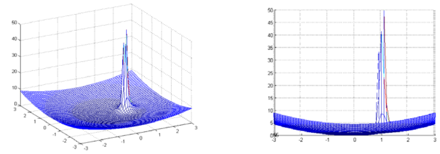

Figure 2. total potential field distribution (3-D and 2-D)

From the figure as above, the total potential field function of the goal point at is the smallest; it gets to the greatest at the location of the obstacle. The corresponding repulsion is as followed:

$$F_{re}(M) = -\nabla U_{re}(M) = \begin{cases} F_{re1}\nabla\rho(M,M_{ob}) + F_{re2}(-\nabla\rho(M,M_{go})), if \rho(M,M_{ob}) \le \rho_0 \\ 0, \quad if \rho(M,M_{ob}) > \rho_0 \end{cases} \tag{7}$$

$\nabla\rho(M,M_{ob})$ and $-\nabla\rho(M,M_{go})$ are two unit vectors, they point to obstacles to robots, robots to the goal point respectively. The Polar coordinates of Repulsion force F_{re} and the total potential field F_{to} is shown in Figure 3.

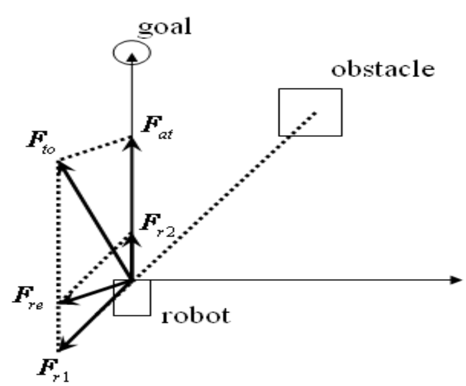

Figure 3. the force diagram of the robot In polar coordinates

VI. COMPUTER SIMULATION COPYRIGHT

in above formula, the locations of the robot, goal point and obstacles are expressed in polar coordinates, the potential field force is the function of distance and phase angle, it is used to adjust moving direction of the robot conveniently. The speed of the robot can be adjusted by measuring the obstacle to robot distance and goal to robot distance by the laser radar. Mobile robot is similar to the shape of car, the circular represents obstacle, the blue triangle and red rectangle indicate the goal point and the start point respectively, laser radar is located in the center of the front of robot, parameters are set as followed: Db = 8, n = 2, ξ = 1, ρ_0 = 2, simulation results are shown in figure 4 to figure 6 , of which, figure 4 is the simulation of no obstacle near the goal point, figure 5 is the simulation of the obstacle in front of the goal point , figure 6 is the simulation of the barrier behind the goal point.

Authorized licensed use limited to: UNIVERSIDADE FEDERAL DO CEARA. Downloaded on September 06,2020 at 00:24:05 UTC from IEEE Xplore. Restrictions apply.

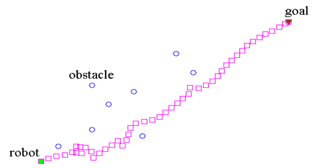

Figure 4. the simulation of no obstacle near the goal point

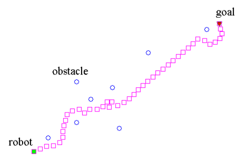

Figure 5. the simulation of the obstacle in front of the goal point

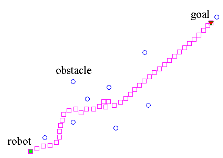

Figure 6. the simulation of the barrier behind the goal point

VII. CONCLUSION

This paper sets up the polar coordinates whose origin is the location of the laser radar installed in front of the robot, uses laser radar to detect the distance information of the obstacles. It uses the idea of APF method and the improved repulsive force field function is used, and the simulation is carried out in different environment. The simulation results show the method provided in this paper can make the mobile robot reach the intended goal point and avoid obstacles in real time. The next-step work is to apply the method to more complex environment, and to accumulate data and experience for the practical application.

REFERENCES

[1] G. Easo Huo Y H, Zhang L M. “A Path Planning Algorithm to Mobile Robot”. Techniques of Automation and Applications. Vol. 22, No. 5, pp.8-10,.2003.

[2] Yang M, Wang H, He K, et al. “Obstacle avoidance using range data in autonomous navigation of mobile robot”. W en T d. Proc. of the 1999 International Symposium on Test and Measurement. Int. Academic Publishers. pp. 929-933,1999.

[3] Ye C, Borenstein J. “Characterization of a 2-D Laser Scanner for Mobile Robot Obstacle Negotiation”.Proc. of the 2002 IEEE Int. Conf. on Robotics and Automation (ICRA2002). pp. 2512-2518,2002.

[4] Hebert M, Kro tkov E. “3D measurement from imaging laser radar: how good are they?”. Image and Vision Computing. Vol. 10, No. 3, pp. 170-178, 1992.

[5] Li L, Ye T, Tan M, et al. “Present State and Future Development of Mobile Robot Technology Research”. Robot. Vol. 24, No. 5, pp. 475-480,2002.

[6] Tzafestas, S.G. “Neural Networks in Robotics: State of the Art”. IEEE International Symposium on Industrial Electronics. Vol. 1, pp.12-20,1995.

[7] Holland J H. “Genetic Algorithms and the Optimal Allocations of Trails”. SIAM of Computing. Vol. 2, No. 2, pp. 88-105,1973.

[8] Khatib O. “Read-time obstacle avoidance for manipulators and mobilerobots”. Proceedings of IEEE International Conference on Robotics and Automation. Piscataway, USA: IEEE. pp. 500-505,1985.

[9] Wang Y F, Chirikjian G S. “A new potential field method for robot path planning”. Proceeding of the IEEE International Conference on Robotics & Automation. Vol. 2, pp. 977-982,2000.

[10] S.S.Ge, Y.J.Cui. “New potential functions for mobile robot path planning”. IEEE Trans on Robotics and Automation. Vol. 16, No. 5, pp. 615 – 620,2000.

[11] RIMON E. “Exact robot navigation using artificial potential function”[J].IEEE Trans on Robotics Automation, Vol. 8,No. 2,pp.501-518,1992.

[12] Alsultan K S,Aiyu M D S. “A new potential field-based algorithm for path planning”[J]. J Intelligent Robotics System,Vol. 17,No. 3,pp.265-282,1996.

[13] Wang H L, Fu W P, Fang Z D,Zhang H Y. “A Path Plann Method for Mobile Robot Based on Improved Potential Field Function”[J]. Machine Tool & Hydraulics,No. 6,pp.67-71,2002.

Authorized licensed use limited to: UNIVERSIDADE FEDERAL DO CEARA. Downloaded on September 06,2020 at 00:24:05 UTC from IEEE Xplore. Restrictions apply.