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OPTIMAL ROUTE PLANNING ALGORITHM OF MOBILE ROBOT

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Abstract

It is one of the important subjects for the intelligent robot that an autonomous robot navigation and route plan, and optimal route planning algorithm of mobile robots is to seek a most suitable path under known environment with obstacles, enable robot to avoid all obstacles from the starting position to the arrival destination in the shortest time.

In this paper, we propose a method of the shortest tangent of the route planning, draw a circle in a safety distance of the obstacle to avoid collision with the robot, and find the possible moving path of several tangent lines among starting position, destination, and the circle of obstacles. Through the computer calculation, select an optimal path as the robotic moving path. The route is modified by using fuzzy logic control to make robot move efficiently and achieve a smooth, perfect curve in the shortest time, and fast arrive the destination. This system achieves the range recognition of obstacles with the laser scanner (SICK LMS291) or ultrasonic sensor, and combines the laser navigation system (NAV 200) to achieve the navigation function. However, all obstacles information can be changed in random under the environment of robot. It makes that the system can adapt oneself to more complicated and unknown circumstances.

Keywords and phrases: path planning, fuzzy logic control, ultrasonic sensor, laser navigation system.

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1. Introduction

The navigation technology of mobile robot is a basic technique in a research field of a robot, and it is also one of the researches of robotics in quite hot domain. No matter any type of the mobile robot, must according to some inference such as the shortest distance of moving path, the least energy consumption, etc. The robot chooses the optimal path to walk in the working environment, and it must calculate itself location through the laser navigation system, and then plan the next motion with a fast speed and avoid collision to arrive the destination.

In recent years, there are several papers to study the navigation and route planning of mobile robot, for instance, the Monte Carlo [7], histogram statistic [1], fuzzy control [11], [8], the genetic algorithm, etc. The fuzzy control has a characteristic that does not to set up the mathematic model for the control plant. It is also used widely to the navigation and control of the mobile robot. Huo and Zhang proposed the shortest tangent path algorithm in [4], this algorithm involves that theory is not complicated to find the shortest tangent path with the geometry. It is simple to calculate and easy to realize, but it is not perfect for its moving path with this algorithm. In this paper, we propose to make the moving path of mobile robot be smoother using the fuzzy logic control theory. The fuzzy rule table is set up to utilize the human experience. Through the look-up table, the robot moving path can be fast and effectively modified.

This paper is divided in five sections. Section 2 describes the motion model of the mobile robot and given parameters. The shortest path algorithm combines with the fuzzy control in order to modify the moving path of mobile robot to be smoother is depicted in Section 3. Section 4 illustrates the simulation and experiment test results to verify that the proposed method is effectual. Section 5 gives some conclusions.

2. Motion Model of Robot

The motion model of the robot is shown in Figure 1. In order to simplify the problem, we suppose the sensor to be working under the ideal state, namely the robot can measure itself position information and the obstacle coordinate. We are divided into three areas at the front of robot 135°, express at the front of the left (L), at the front of the center (F), and at the front of the right (R), respectively. There are installed several ultrasonic sensors and/or the laser range scanner in each area. The range r_A which can be detected from the robot to obstacles with the ultrasonic sensor or laser scanner is used to express as the robot safe collision distance. The angle and distance between the robot position and destination are to express θ_G and D_G, respectively. We suppose that the control values are the speed of robot motion (S) and the rotating angle (θ), where $S \in (0, 0.5\,\mathrm{m/s})$, right and left, respectively, and $\theta \in (-30^\circ, 30^\circ)$. θ is positive when robot turns right, otherwise θ is negative.

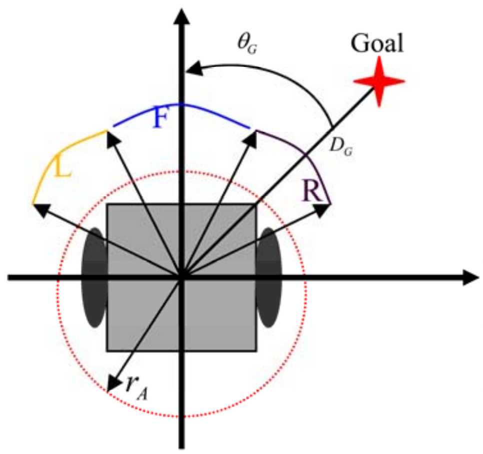

Figure 1. Robot motion model.

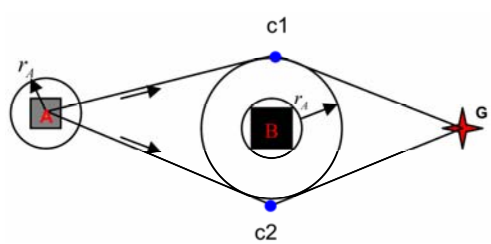

Figure 2. Optimal path planning.

3. Combine the Shortest Path Algorithm and Fuzzy Control

3.1. The shortest tangent path algorithm

First, the robot should confirm whether has obstacles from itself to the destination as shown in Figure 2. Suppose the position of mobile robot and the obstacle are to express A and B, respectively. The position of destination expresses G. These three coordinates can be expressed (x_A, y_A), (x_B, y_B) and (x_G, y_G), respectively. Where the radius outside of obstacle around is to express r_B, the obstacles can be the irregular form, in other words, the round radius of the minimum other circle contact of the obstacles represents r_B, the $\overline{AG}$ straight line equation formulates as follows:

$$\frac{y - y_A}{x - x_A} = \frac{y_A - y_G}{x_A - x_G}. \tag{1}$$

Rewrite equation (1) to $ax + by + c = 0$ in the standard form as follows:

$$(y_A - y_G)x + (x_G - x_A)y + (x_A y_G - x_G y_A) = 0. \tag{2}$$

Suppose d is to express the distance from obstacle to the straight line

$$d = \frac{|ax_B + by_B + c|}{\sqrt{a^2 + b^2}}, \tag{3}$$

where $a = y_A - y_G$, $b = x_G - x_A$, $c = x_A y_G - x_G y_A$.

If $d > r_B + r_A$, then it indicates that robot can arrive at the destination along equation (1) straight line equation without the collision, where B is not an obstacle. If $d < r_B + r_A$, then it expresses that robot arrives at the destination along equation (1) with a probable collision, where B is a probable obstacle. When B is an obstacle, we should find out called the collided circle which has a circular center by B, and the round radius $r_B + r_A$, where r_B is the radius of circle contact outside of obstacle, we can express this circle in the following

$$(x - x_B)^2 + (y - y_B)^2 = (r_B + r_A)^2. \tag{4}$$

Suppose the robot passes through A and the tangent line equation with the collided circle expresses

$$(y - y_A) = m_1(x - x_A). \tag{5}$$

The robot passes through G and the tangent line equation with the collided circle expresses

$$(y - y_G) = m_2(x - x_G). \tag{6}$$

m_1 and m_2 are the slopes to be found. From equation (4) to equation (6), we can find $c1$ and $c2$. Figure 1 shows that there are two paths, $A \to c1 \to G$ and $A \to c2 \to G$. Robot will compare these two paths and choose the shortest one to be the optimal path.

During the process of moving forward, robot finds another obstacles to present, then can replace the original obstacle with the coordinate of this obstacle at that time, and recalculates to obtain that should through midway ($c1$ or $c2$). If there is not new obstacle to appear, then the midway is not changed. If there are several obstacles, while the robot arrives at the first midway, the first midway can be regarded as a start point, and then calculates the second midway again. Following this reason, till the robot arrives the destination. The moving forward strategy of robot is shown in Figure 3.

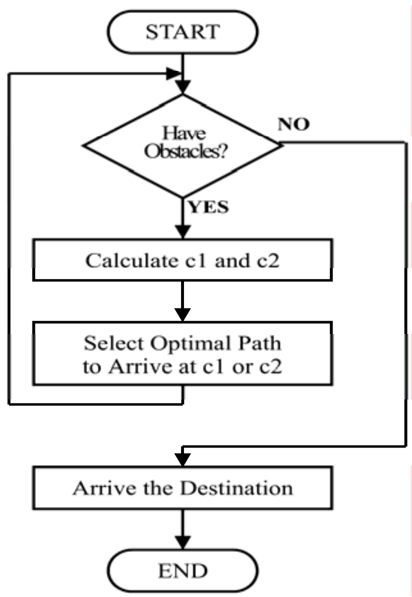

Figure 3. The moving forward strategy of robot flow chart.

3.2. Revise moving path using fuzzy control

From Figure 2, we can find that the optimal path is $A \to c1 \to G$, this path is not very smooth, that can be found out, when the robot arrives at $c1$, it should stop to perform the turn motion then moving forward. It is not only to spend the time but also to consume the energy. Therefore this paper proposes to modify the path of the robot moving using fuzzy logic control (FLC), enable robot moving path be smoother and more efficient to arrive at the destination. Hence, we design an FLC to revise the path, as shown in Figure 4. We define two input variables, namely the error angle (θ_E) and distance (D_G) between the position of robot and destination, and define two output variables, namely the left wheel rotating speed (S_L) and the right wheel rotating speed (S_R). The output of FLC is to control and drive two DC motors (the rotating speed of left and right wheels) by using two PWM controllers, to achieve that robot can move forward with curve.

The membership functions of input variables θ_E and D_G are shown in Figures 5 and 6, respectively. The membership functions of output variables S_L and S_R are shown in Figure 7, where the membership functions of S_L and S_R are the same. The final output value is determined using the look-up table which is previously to set up in database. The fuzzy reasoning rule is shown in Table 1.

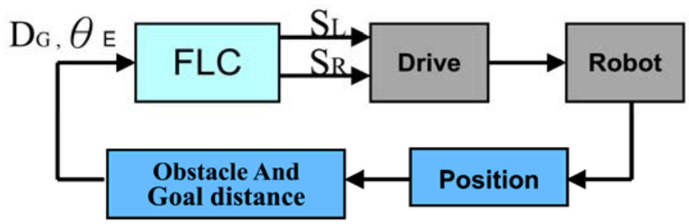

Figure 4. Modify the robot moving path with FLC.

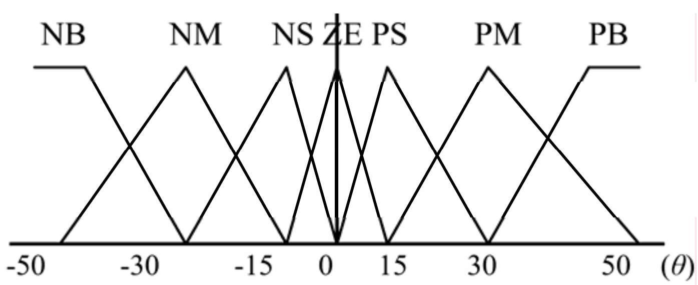

Figure 5. The membership function of θ_E input variable.

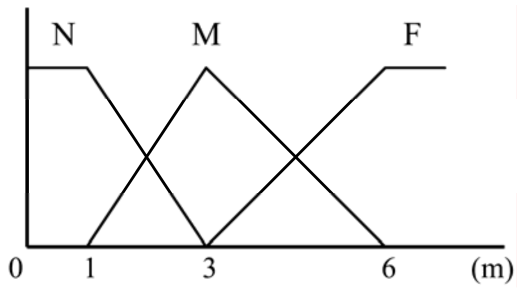

Figure 6. The membership function of D_G input variable.

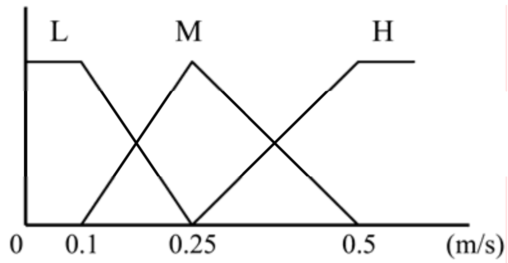

Figure 7. The membership function of S_L and S_R output variables.

Table 1. FLC fuzzy reasoning rule table

S_L/S_R		D_G					
		N		**M**		**F**	
θ_E	**PB**	H	L	H	L	M	L
	PM	M	L	M	L	H	M
	PS	M	L	M	L	M	M
	ZE	L	L	M	M	H	H
	NS	L	M	L	M	M	M
	NM	L	M	L	M	M	H
	NB	L	H	L	H	L	M

Fuzzy reasoning is a core of the fuzzy logical controller, it is to process with the relation of fuzzy logic and reasoning rule. Through the fuzzy reasoning, we obtain a fuzzy quantity and select the center of gravity method to change fuzzy quantity into the actual output quantity.

4. Experimental Results

In order to verify the validity of performance of the proposed algorithm, first, we use the computer to simulate designed algorithm which is developed in Section 3 and revise the optimal route of robot. The simulated environment is divided into a single obstacle and several obstacles to process. Finally, we verify the simulation results by using experimental test via the mobile robot.

4.1. Software simulation results

In order to verify the proposed algorithm is effective, the simulation is set up the motion rule of robot under the environment of Borland C^{++} Builder (BCB). It should not only have a self-locating and the environmental cognition functions (simulation laser navigation system SICK NAV200 and laser scanners system, SICK LMS291), and put the obstacle to prove that the designed fuzzy shortest path algorithm is effective to apply on the robot, not only be able to dodge obstacles, but also can let the robot move with a smoother curve. In simulation, we set up the moving speed of the robot in 0~0.5m/s, right and left, respectively, red point is to express the start of robot, blue point is to express the midway, and yellow point is to show the destination. The coordinate systems unit is 0.5 meter/dose in the figures.

Figure 8 shows the simulation result of without obstacle navigation, the route is by $1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 5,$ the start point coordinate is (1, 1), the destination point coordinate is (10.4, 4.6), the midway points are (5.3, 5), (3.5, 9) and (8.5, 9). From the simulation results, the route is a smoother curve with the designed controller, in other words, the localization of robot can be fixed accurate in destination point and/or midway points.

Figure 9 shows the navigation simulation result of a single obstacle, the start point, destination point and obstacle coordinate are set at (1, 1), (5.5, 6) and (3.6, 4), respectively. Through the computer calculating, the optimal midway point can be obtained. When the robot will reach to the destination, its moving speed will be reduced until the destination arrival.

Figures 10 and 11 show the navigation simulation results of avoiding collision with several obstacles. In Figure 10, the start point, the destination, and the first obstacle and the second obstacle coordinates are set at (1, 1), (7, 5.5), (3.6, 3), and (5, 5). Also Figure 11 shows that these coordinates are set at (1, 1), (9, 2), (3.6, 1.6), and (6, 1.6). Through the simulation results, we can find that the system is adaptive in several obstacles environment with the designed controller, and it can accurately reach the destination.

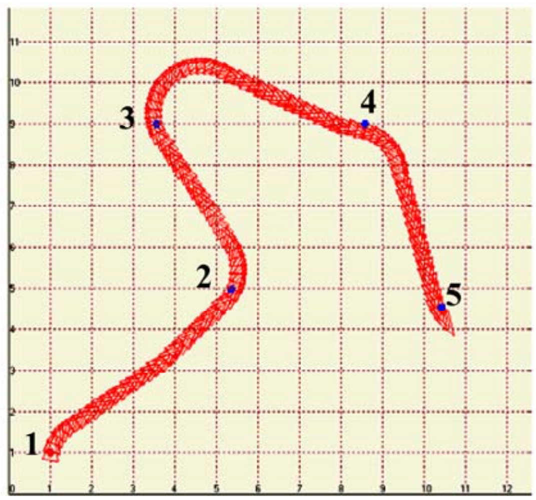

Figure 8. The navigation simulation without obstacles.

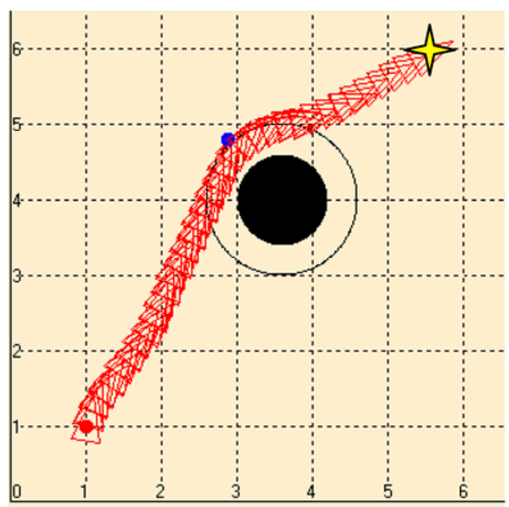

Figure 9. The navigation simulation with a single obstacle.

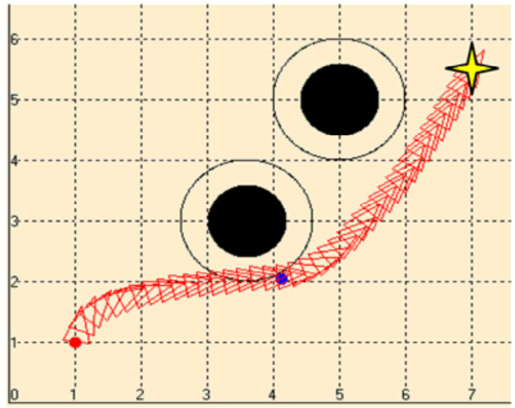

Figure 10. One of the navigation simulations with several obstacles.

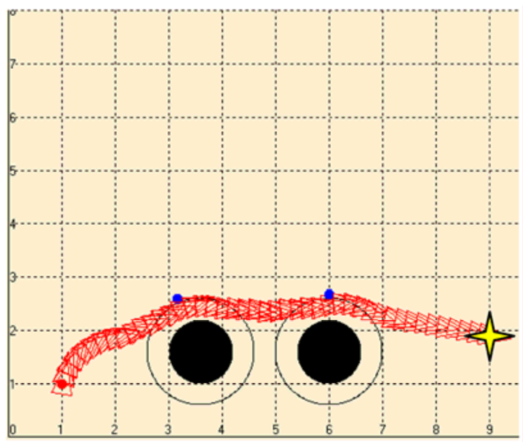

Figure 11. The other of the navigation simulation with several obstacles.

4.2. Experiment test results with real hardware

We draw the real environment into the map by way of manpower, and then perform a real test with the mobile robot. Where the black part is to express an obstacle, the practice moving route of robot shows in red lines, the yellow point expresses the destination coordinate, the coordinate unit is 0.5meter/dose, and set up the moving speed of robot in 0.5m/s, right and left, respectively. SICK NAV 200 is used to fix itself positioning, SICK LMS 291 scanner is selected to regard as scanning the obstacles, and the computer performs to calculate and process. The test platform of the mobile robot is shown in Figure 12. The characteristic of mobile robot can be demonstrated the self-rotating at one point, and a high flexibility.

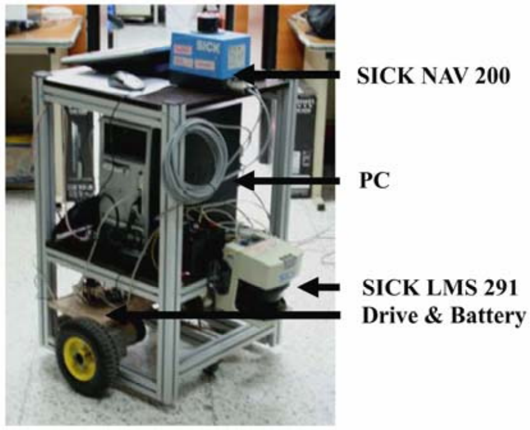

Figure 12. Test platform of the mobile robot.

Figure 13 shows the actual navigation test results without obstacle. The robot moving route is from $1 \rightarrow 2 \rightarrow 3.$ When the robot arrives at point 2, the heading angle of the robot moving towards is 276° at this moment, and the next point position is at the left of the rear of the robot. At this moment, it will spend for a long time by way of curve method than by turning round approach. Therefore, the robot will turn to the direction of the next point by way of rotation, and then moves forward to the next point (destination) by way of straight line.

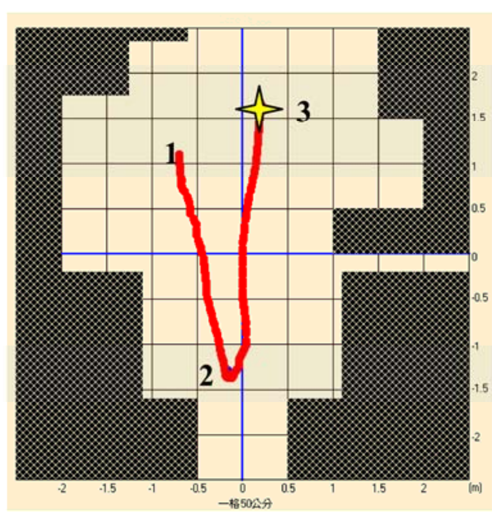

Figure 13. Real navigation test without obstacles.

Figure 14 shows the real navigation test result for single obstacle. In Figure 14, we find that the robot calculates the optimal midway point in real time to dodge the obstacle after the obstacle information is obtained, and arrive at the destination with the smooth curve method.

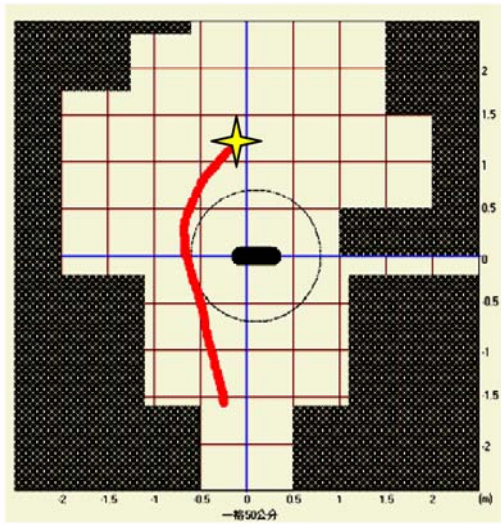

Figure 14. Real navigation test with a single obstacle.

The real navigation test with several obstacles is shown in Figure 15. The robot proceeds from starting point, obtains the first obstacle information and calculates the first midway point, after it arrives the first midway point then finds that there is the second obstacle. At this time, if the robot goes to the destination with original calculated route then maybe collided with the obstacle, so it will calculate the second midway at this moment, and then advance in accordance with the calculated route. From Figure 15, the robot can dodge a lot of obstacles and pass two midway points to arrive at the destination with the optimal route.

4.3. Experimental result analysis

Through the simulation and experiment test results, we cab obtain the optimal route planning with the proposed method. In real-time test, because the DC motor is used without encoder, and the unevenness between the wheels and ground will cause some errors. It is not smoother to compare the real experiment curve with the simulation curve. But its accuracy is within an acceptable range, and locates accurately in midway point and destination. Its error does not exceed ±10cm.

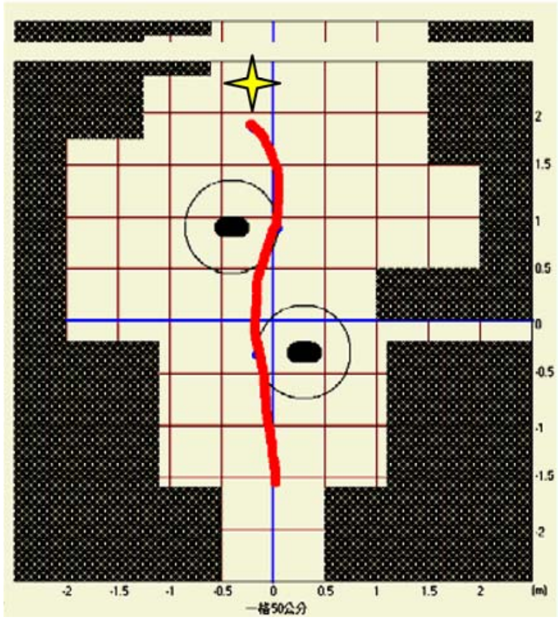

Figure 15. The real navigation with several obstacles.

5. Conclusion

There are a lot of path planning methods of the mobile robot, in general speech, there are some advantages and drawbacks for each approach, and these are not methods which can be suitable for various environments. This paper proposes to utilize fuzzy control method to modify that Ying-Iau Huo et al. proposed the shortest path tangent line algorithm, and obtains the fuzzy control rule table to determine the robot moving path through the simulation sensor characteristic, measurement data and the human experience. With respect to a single obstacle and several obstacles, perform some simulations and verifications in real time under the unknown environment. The mobile robot can also avoid the obstacle and arrive at the destination when a new obstacle presents. Through the simulation and real-time experimental test result of a single obstacle and several obstacles, can prove the designed fuzzy controller to make the robot moving along a smoother curve, and can fast get the control value through the look-up table. The small calculation effort and the real-time results are relatively better. Robot can reach the destination within the shortest time, and reduce the consumption of energy to achieve the purpose of optimal navigation function.

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