Obstacle Avoidance Method Based on the Movement Trend of Dynamic Obstacles

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***Abstract*—Obstacle avoidance is a well-known problem in the field of robotics. In this paper, movement trends of obstacles are proposed to be considered to improve the classical obstacle avoidance method. According to the movement laws of the dynamic obstacle, the movement trends of the obstacle are predicted to help the robot to plan the route and the mode of avoidance. Fuzzy logic technique is applied to predict the movement trend of the obstacle and dominate the linear velocity of the robot. In this paper, movement trend of obstacle are divided into approaching to the robot, moving away from the robot, translating with the robot. According to the three trends, the robot can choose to increase the velocity, decrease the velocity to pass by the obstacle, or stop to wait for the obstacle to pass. Some simulation results show that the proposed method can help the robot to accomplish obstacle avoidance without changing the initial moving path.**

Keywords-movement trends; obstacle avoidance; fuzzy logic technique;mobile robot;

I. INTRODUCTION

Now, more and more robots are applied in real dynamic environment. When mobile robots are moving in the complex environment, possible dynamic obstacles appears and the risk of its conflicts is more probable. Obstacle avoidance is a promising research issue in the field of robotics.

Many approaches have been suggested for the obstacle avoidance of mobile robots with obstacles[1~5]. Such as, Khatib[6] presented a real-time obstacle avoidance approach based on the artificial potential field concept. And many improved artificial potential field approaches are proposed [7][8]. Mohammadi[9] presented an improved A-star motion planning procedure. Caceres[10] used artificial neural networks and genetic algorithms to develop autonomous robotic systems. Ahmadzadeh[11] used particle swarm optimization(PSO) method to finding the proper solutions of optimizations navigation problems.

From those methods, we can conclude that most of the obstacle avoidance methods focusing on the moving trajectory, velocity, or the direction of obstacles. Some focus on if the obstacle avoidance rout is the shortest, or if can get high successful rate. No matter which methods, they all need the detail movement information of obstacles. But, sometimes it's not necessary to get all the information of obstacles, and it's difficult to calculate the movement information precisely. Since it is difficult for sensing system to give the reliable movement information, it is impossible to calculate the velocity and direction of obstacles precisely. However, fuzzy logic technique is good at dealing with time-variable, non-linear, and uncertain condition[12-18]. Here, we'll apply it to deal with the movement information of obstacles to prediction the movement trend.

Furthermore, some obstacle avoidance methods proposed to change the initial path to avoid obstacles. Comparing with the movement modes of human, changing route is not always the best way to avoid obstacles. Usually, people will choose to wait for the obstacle to move by stopping or slowing down. And if the obstacle moves slowly, people will choose to speed up to pass by. Therefore, we will propose to increase or decrease the speed of the robot to avoid the obstacles without changing the initial route of robot.

In conclusion, the movement direction and velocity of dynamic obstacle will influence the obstacle avoidance mode of mobile robot. In this paper, the information of the velocity and direction of obstacles are estimated. Fuzzy logic technique is used to predict the trend of obstacle, based on which the avoidance modes of the robot are chosen.

This paper is organized as follows. In section 2, the formulation of the obstacle avoidance problem is presented. The principle of movement prediction based obstacle avoidance method is introduced. In Section 3, the classification of the mode of obstacle avoidance is given. And the details of fuzzy logic control for predicting the movement of obstacle are discussed in section 4. Simulation results are given in section 5. The conclusion and suggestions are given in section 6.

II. FORMULATION OF THE PROBLEM

The simulation environment is shown in Figure 1.There are obstacles (O1, O2, O3) moving in the environment. Our object is to choose the suitable moving mode for the mobile robot(R) to avoid the obstacles until arrive the destination G.

Figure 2 gives the mobile robot applied to research. It has 8 sensors. 6 sensors in the front can sensor the distance to the obstacle, which are numbered from 0 to 5. 2 sensors are numbered 6 and 7. To simplify the computation, the front 6 sensors are divided into three groups, shown in Figure 3.

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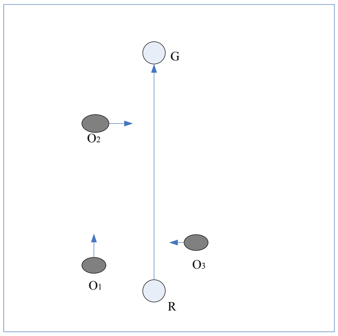


Figure 1. The simulation environment

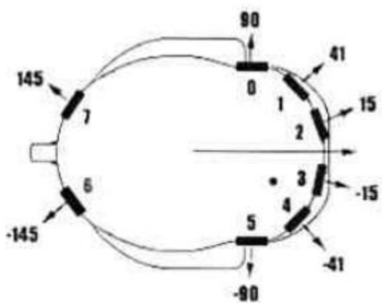


Figure 2. Mobile robot with 8 sensors

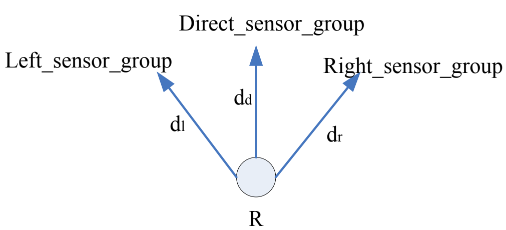


Figure 3. Three groups of sensors

Here, Left_sensor_group gives the fused data from sensor 0 and sensor 1. Direct_ sensor_group gives the fused data from sensor 2 and sensor3. Right_sensor_group gives the fused data from sensor 4 and sensor 5. d_l is the distance to the obstacle measured by the left_sensor_group. d_d is the distance to the obstacle measured by the direct_ sensor_group. d_r is the distance to the obstacle measured by the right_sensor_group.

The previous obstacle avoidance methods used to apply the same avoidance mode to avoid the different obstacles without making a difference between them. In this paper, after the dynamic obstacle is detected, its movement trend will be classified. According to the movement trend, the robot will choose the suitable avoidance mode. This approach will apply different avoidance mode to different obstacles. The typical architecture of the method is shown in Figure 4.

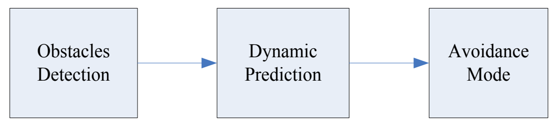


Figure 4. Typical structure of obstacle avoidance

The key parts of the method are how to predict the movement trend of obstacles and how to choose the suitable avoidance mode. The following sections will give the details.

III. The Movement Trend of Obstacles

The principle of the prediction of movement trend is to predict the dynamic movement trend of obstacles according to the distance and direction changes between the obstacles and robot.

Here, the movement trends of obstacles are classified into several modes(shown in Table 1). According to the distance between the obstacle and robot, and the velocity of obstacle and robot, the movement trends of obstacles are classified.

Based on Table 1, the robot can choose to increase, decrease the speed to pass by the obstacle, or stop to wait for the obstacle to pass.

TABLE I. The Classification of the Movement Trend

Movement Trend		**Explanation**
Approaching	Approaching Quickly	The velocity of obstacle is bigger than the velocity of the robot, and the distance between obstacle and robot is becoming smaller.
	Approaching Gradually	The velocity of obstacle is smaller than the velocity of the robot, and the distance between obstacle and robot is becoming smaller.
Moving away	Moving away Quickly	The velocity of obstacle is bigger than the velocity of the robot, and the distance between obstacle and robot is becoming bigger
	Moving away Gradually	The velocity of obstacle is smaller than the velocity of the robot, and the distance between obstacle and robot is becoming bigger
Translating	Translating Quickly	The velocity of obstacle is bigger than the velocity of the robot, and the distance between obstacle and robot remain unchanged
	Translating Gradually	The velocity of obstacle is smaller than the velocity of the robot, and the distance between obstacle and robot remain unchanged

IV. Fuzzy Logic Based Obstacle Avoidance Algorithm

Since fuzzy inference systems can deal realistically with imprecise and uncertain sensing information, fuzzy logic technique has been developed for mobile robot applications. The movement trend of obstacles is presented in the form of fuzzy rules, such that the robot can predict the movement trend of obstacles and can move without colliding with obstacles.

Fuzzy logic control is a valuable tool to deal with the fuzzy relationship between the movement trend of obstacles and the strategies taken by robots. To implement fuzzy logic control requires the following three steps: fuzzification, fuzzy reasoning, defuzzification. The fuzzification converts the input variables into fuzzy data or membership function. The fuzzy reasoning generates fuzzy results from combining membership functions with control rules. The defuzzification converts fuzzy variables to accurate output variables.

A. Fuzzification

The inputs to the fuzzy logic controller are the distance between the robot and the obstacles with respect to the left, direct and right sensors, described by d_l , d_d and d_r . One more input is the linear velocity of the obstacle V_{ob} . The output variable is the increment of the linear velocity of the robot ΔV_{ro} , including increasing, decreasing, unchanged.

Linguistic variable "Near" and "Far" are taken for d_l , d_d and d_r . The membership functions are shown in Figure 5.

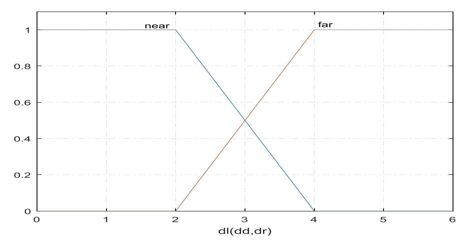


Figure 5. Membership functions of obstacle distance dl,dd,dr

The domain for velocity of obstacle is constructed with slow and fast. The membership function is shown in Figure 6.

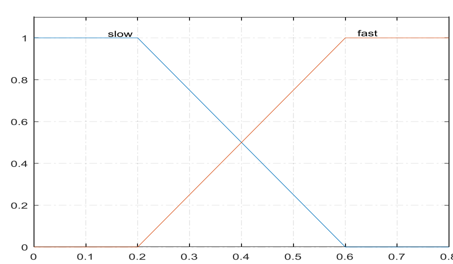


Figure 6. Membership function of Velocity of obstacle

The increment of the linear velocity of the robot is constructed with{SD, SZ, SI}. Here, SD means to decrease the speed, SZ means the speed remains unchanged, SI means to increase the speed. The membership function is shown in Figure 7.

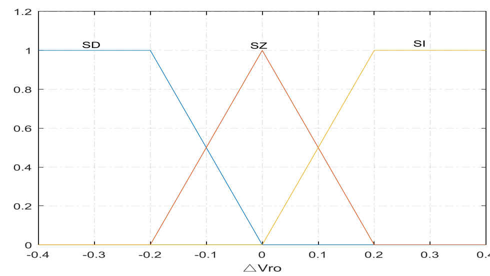
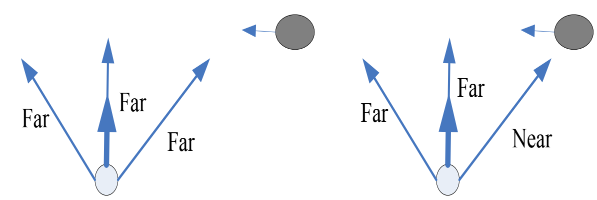


Figure 7. Membership function of the increment of the velocity

B. Control Rules

The impossible situations of the movement of mobile robot are show in Figure 8~14. Several cases will be introduced in the following. The according control rules will be induced by empirical knowledge.

Case1: Approaching to the robot far from right



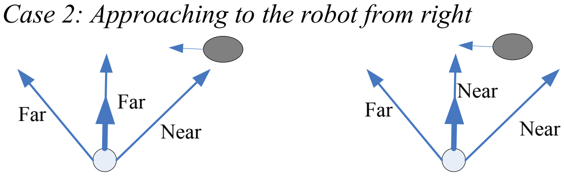
(a) t-1time (b) t time

Figure 8. Approaching to the robot from right

r1 1:If $d_l|_{t-1}$ is Far and $d_d|_{t-1}$ is Far and $d_r|_{t-1}$ is Far and $d_l|_t$ is Far and $d_d|_t$ is Far and $d_r|_t$ is Near and V_{ob} is Slow, then ΔV_{ro} is SI

r2:if $d_l|_{t-1}$ is Far and $d_d|_{t-1}$ is Far and $d_r|_{t-1}$ is Far and $d_l|_t$ is Far and $d_d|_t$ is Far and $d_r|_t$ is Near and V_{ob} is Fast, then ΔV_{ro} is SD

Case 2: Approaching to the robot from right

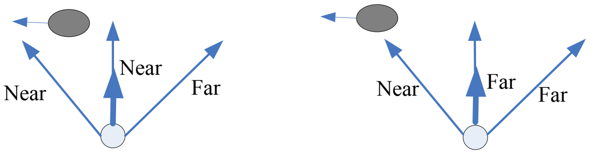


(a) t-1time (b) t time

Figure 9. Approaching to the robot from right

r3:if $d_l|_{t-1}$ is Far and $d_d|_{t-1}$ is Far and $d_r|_{t-1}$ is Near and $d_l|_t$ is Far and $d_d|_t$ is Near and $d_r|_t$ is Near and V_{ob} is Slow, then ΔV_{ro} is SI r4:if $d_l|_{t-1}$ is Far and $d_d|_{t-1}$ is Far and $d_r|_{t-1}$ is Near and $d_l|_t$ is Far and $d_d|_t$ is Near and $d_r|_t$ is Near and V_{ob} is Fast, then ΔV_{ro} is SD

Case 3: Moving away from robot



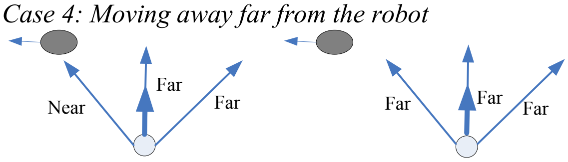
(a) t-1time (b) t time

Figure 10. Moving away from robot

r5:if $d_l|_{t-1}$ is Near and $d_d|_{t-1}$ is Near and $d_r|_{t-1}$ is Far and $d_l|_t$ is Near and $d_d|_t$ is Far and $d_r|_t$ is Far and V_{ob} is Slow, then ΔV_{ro} is SD .

r6::if $d_l|_{t-1}$ is Near and $d_d|_{t-1}$ is Near and $d_r|_{t-1}$ is Far and $d_l|_t$ is Near and $d_d|_t$ is Far and $d_r|_t$ is Far and V_{ob} is Fast, then ΔV_{ro} is SZ.

Case 4: Moving away far from the robot



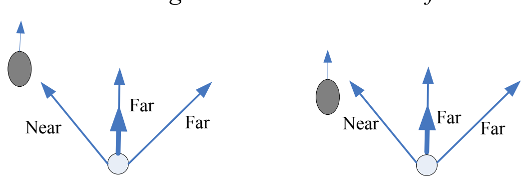
(a) t-1time (b) t time

Figure 11. Moving away far from robot

r7:if $d_l|_{t-1}$ is Near and $d_d|_{t-1}$ is Far and $d_r|_{t-1}$ is Far and $d_l|_t$ is Far and $d_d|_t$ is Far and $d_r|_t$ is Far and V_{ob} is Slow, then ΔV_{ro} is SZ.

r8: :if $d_l|_{t-1}$ is Near and $d_d|_{t-1}$ is Far and $d_r|_{t-1}$ is Far and $d_l|_t$ is Far and $d_d|_t$ is Far and $d_r|_t$ is Far and V_{ob} is Fast, then ΔV_{ro} is SZ.

Case5: Translating with the robot at the left side



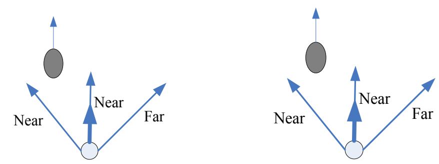
(a) t-1time (b) t time

Figure 12. Translating with the robot

r9: :if $d_l|_{t-1}$ is Near and $d_d|_{t-1}$ is Far and $d_r|_{t-1}$ is Far and $d_l|_t$ is Near and $d_d|_t$ is Far and $d_r|_t$ is Far and V_{ob} is Slow then ΔV_{ro} is SZ.

r10: :if $d_l|_{t-1}$ is Near and $d_d|_{t-1}$ is Far and $d_r|_{t-1}$ is Far and $d_l|_t$ is Near and $d_d|_t$ is Far and $d_r|_t$ is Far and V_{ob} is Fast then ΔV_{ro} is SZ.

Case 6: Translating nearly with the robot



(a) t-1time (b) t time

Figure 13. Translating nearly with the robot

r11: :if $d_l|_{t-1}$ is Near and $d_d|_{t-1}$ is Near and $d_r|_{t-1}$ is Far and $d_l|_t$ is Near and $d_d|_t$ is Near and $d_r|_t$ is Far and V_{ob} is Slow then ΔV_{ro} is SZ.

r12: :if $d_l|_{t-1}$ is Near and $d_d|_{t-1}$ is Near and $d_r|_{t-1}$ is Far and $d_l|_t$ is Near and $d_d|_t$ is Near and $d_r|_t$ is Far and V_{ob} is Fast then ΔV_{ro} is SZ.

Case 7: Leading the robot

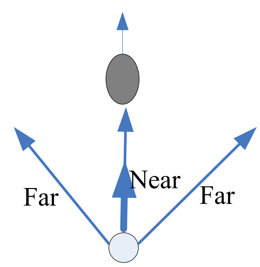


Figure 14. Leading the robot

r13: :if $d_l|_{t-1}$ is Far and $d_d|_{t-1}$ is Near and $d_r|_{t-1}$ is Far and $d_l|_t$ is Far and $d_d|_t$ is Near and $d_r|_t$ is Far and V_{ob} is Slow, then ΔV_{ro} is SD.

r14: :if $d_l|_{t-1}$ is Far and $d_d|_{t-1}$ is Near and $d_r|_{t-1}$ is Far and $d_l|_t$ is Far and $d_d|_t$ is Near and $d_r|_t$ is Far and V_{ob} is Fast, then ΔV_{ro} is SZ.

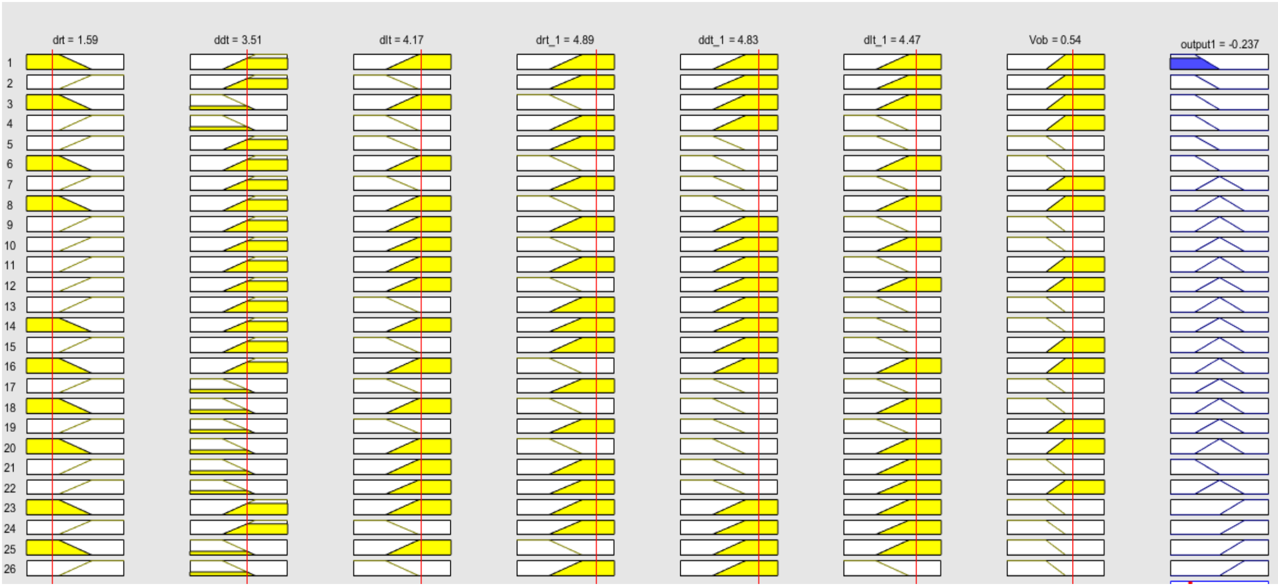


Figure 15. The example of the results of fuzzy rules

Here we give the typical cases and the according fuzzy control rules. Other rules can be deduced by analogy. Figure 15 shows the results after performing fuzzy rules.

C. Defuzzification

Many defuzzification algorithms have been reported. There are several common methods, such as maximum membership grade, median clustering, average maximum membership grade and weighted average method, and etc. Here, we apply the mean of maximum membership method.

Since, it's difficult to apply the output value to the robot directly. Here we discrete the output to three crisp values, shown in (1).

$$\Delta V = \begin{cases} -0.2 & -0.4 \le \Delta V_{ro} < -0.2 \\ 0 & -0.2 \le \Delta V_{ro} \le 0.2 \\ 0.2 & 0.2 < \Delta V_{ro} \le 0.4 \end{cases} \tag{1}$$

Here, ΔV is the increment of the speed.

Then, the linear velocity of the robot will be

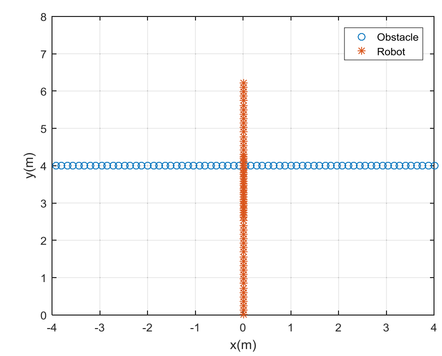
$$V_t = V_{t-1} + \Delta V \tag{2}$$

V. Simulation and Results Analysis

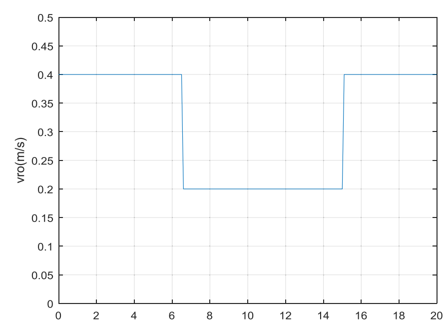
To test the proposed algorithm, several simulation experiments are taken. The velocity of robot is assumed to be able to be modified as required.

In simulation experiment 1(shown in Figure 16.), the obstacle moves at the speed of 0.4m/s, and the robot move at the speed of 0.4m/s. After detected the obstacle, the robot decreased the speed to 0.2m/s until pass the obstacle.

Simulation experiment 2(shown in Figure 17): the obstacle moved at the speed of 0.3m/s, the robot moved at the speed of 0.4m/s. After detected the obstacle, the robot increased the speed to pass the obstacle.



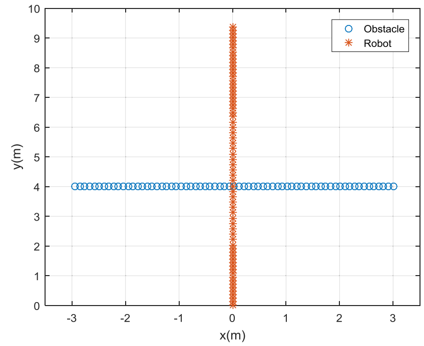
(a)The trajectories of the robot and the obstacle



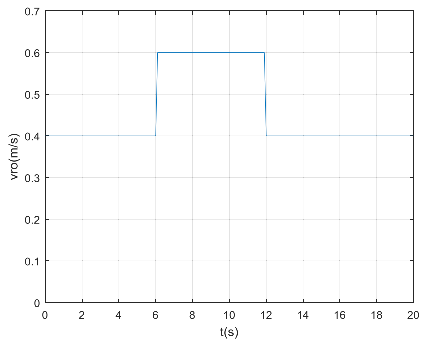
(b)The linear velocity of the robot

Figure 16. The results of the simulation experiment 1

From the simulation results shown in Figure 16 and 17, the fuzzy logic controller can predict the movement trend of the obstacle, and can help the robot to choose the suitable speed to pass the obstacle. Although the method is simple, it can get good results. Comparing to the other obstacle avoidance method, the proposed method is easier to be executed.



(a)The trajectories of the robot and the obstacle



(b)The linear velocity of the robot

Figure 17. The results of the simulation experiment 2

VI. Conclusions

In this paper, we have proposed a fuzzy logic based obstacle avoidance method. According to the movement trend of the obstacle, the robot chooses increasing the speed, decreasing the speed or stop to wait the obstacle to pass. Without changing the initial route, the robot avoided the obstacle just through adjusting the speed in advance.

Here only several typical movement modes of the robot and movement trends of obstacles are discussed. In real environment, the movement trends of obstacles are various and more complex. There are different avoidance modes which can be designed for the robot to choose. For example, if the angle information of obstacle can be sensed, the robot can detour to avoid the obstacle. How to deal with different modes is one of the future works.

Acknowledgment

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