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Intelligent Obstacle Avoidance Control Strategy for Wheeled Mobile Robot

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Abstract: This paper presents intelligent strategies for a wheeled mobile robot to avoid obstacle and move to target location. The obstacle detection for the wheeled mobile robot is carried out by ultrasonic sensors. There are two models in this study, short-distance obstacle avoidance model and target-driven obstacle avoidance model. In short-distance obstacle avoidance model, the wheeled mobile robot utilizes signals of the ultrasonic sensors to avoid obstacle. In target-driven obstacle avoidance model, fuzzy theory with sensor signals is used to control the speed of the wheeled mobile robot and make it move to target location. In this study, software simulations are made on the MATLAB platform. Both obstacle avoidance models are successfully performed.

Keywords: Obstacle avoidance, wheeled mobile robot, intelligent strategy.

1. INTRODUCTION

Automation techniques have been applied to many aspects in recent years. The autonomous mobile robot is one of the applications of the automatic science and technology. By integrating intelligent control method and mobile robot developing platform, a lot of assistant robots and service systems are developed such as human-machine interaction, mobile navigation system, image processing, object recognition, voice recognition, teleoperation, remote sensing, map building and localization, etc. Through artificial intelligence techniques, applications of advanced robot systems can be achieved.

Robot development started in 1970. There are many kinds of robots, wheeled mobile robot (WMR) is one of them. In dynamics models and stability analysis of wheeled mobile robots, BeMent [1] proposed six kinds of models to wheeled mobile robot and controllability was also provided. Leow [2] developed kinematic modeling and analysis of mobile robots with omni-directional wheels. In feedback control, hardware realization and application, Laiou and Astolfi [3] presented chained forms and Andrea [4] constructed dynamic feedback linearization design to control a WMR. Chung [5] proposed a position control by the difference of the WMR's two driving wheels. Lee [6]-[8] developed a fast path planning-and-tracking control for a wheeled mobile robot. Shi [9] utilized fuzzy predictive control with multi-sensors to wheeled mobile robot control.

Fuzzy logic is introduced by Zadeh in 1965 and thereafter its applications in control systems increased quickly. One major feature of fuzzy logic is its ability to express the amount of ambiguity in human thinking and subjectivity in a comparatively literal method. Fuzzy logic is easily used when a mathematical model of the process does not exist, or it is too complex to be evaluated for real-time operation. In recent years, fuzzy logic based approaches have been successfully applied to control ill-defined and nonlinear systems. In early researches, classic control methods such as optimal control, PID controller and adaptive control have been used for wheeled mobile robot control [10], [11]. Subsequently when artificial intelligence methods were introduced, applications of these methods were extended to wheeled mobile robot control. Nowadays, neural networks, fuzzy logic and genetic algorithm methods are used very often to control the wheeled mobile robot [12]-[14]. Among these methods, a simple fuzzy logic system is used in this paper.

In previous study [14], the WMR only works in simple environment, which consists two or three obstacles. The purpose of this study is to design intelligent control strategy for a wheeled mobile robot and make it avoid obstacle and move to target location in complex environment. There are two main parts in this study. They are obstacle avoidance model and target-driven obstacle avoidance model. In obstacle avoidance model, the wheeled mobile robot utilizes signals of the sensors to avoid obstacle accurately. In target-driven model, we utilize the concept of the fuzzy theory and sensor signals to design the fuzzy controller to control the speed of the wheeled mobile robot and make it move to target location.

2. SYSTEM DESCRIPTION

The WMR used in this article is shown in Fig. 1. This system has two wheels which are located at the front two side of the WMR. The radius of the wheels are both 9 centimeters and the wheel axle is 27.4 centimeters. Respective DC motor is used to drive the rotation of each wheel. Rotation speeds of the motors are controlled by the supply voltage. The motor rated voltage is 5 volts. When the voltage increases, the motor rotates faster; voltage decreases, the motor rotates slower. The motor rotation speed is proportional to the input voltage [14]. Outside each wheel, a quadrature encoder is installed to detect the wheel rotation. The movement of the WMR on the ground can be calculated and the quadrature encoder also serves as a robot movement feedback. The rear wheel is only used to support the weight of the mobile robot. Changing direction of the WMR depends on the difference speeds of two front wheels. On the body of the WMR, there are three ultrasound receivers and two movement sensors to collect the surrounding environment data.

The WMR on the two dimensional Cartesian coordinate system is a vector nonlinear carrier. It belongs to a nonholonomic system [4] and its vectors divide into head direction and lateral direction. On lateral direction, the wheels are still.

Fig. 1. Wheeled mobile robot (WMR).

$$\dot{x}\sin\theta - \dot{y}\cos\theta = 0 \tag{1}$$

The first-order kinematic equation is

$$\begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{pmatrix} = \begin{pmatrix} \cos\ \theta \\ \sin\ \theta \\ 0 \end{pmatrix} v + \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} w \tag{2}$$

where the WMR locates on the Cartesian coordinate system. v is the center speed and w is the angular speed of the WMR. Since the speeds of the left and right wheels are the inputs of the system, linear transformation is used to transform left wheel speed to center speed and right wheel speed to angular speed as shown in (3). w_l is the speed of the left wheel and w_r is the speed of the right wheel.

$$\begin{bmatrix} v \\ w \end{bmatrix} = \begin{bmatrix} \frac{\mathrm{r}}{2} & \frac{\mathrm{r}}{2} \\ -\frac{r}{d} & \frac{r}{d} \end{bmatrix} \begin{bmatrix} w_l \\ w_r \end{bmatrix} \tag{3}$$

The coordinate of the WMR on the Cartesian coordinate system is

$$\begin{bmatrix} x_k(i+1) \\ y_k(i+1) \\ \theta(i+1) \end{bmatrix} = \begin{bmatrix} x_k(i) \\ y_k(i) \\ \theta(i) \end{bmatrix} + \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V \\ w \end{bmatrix} * \Delta t \tag{4}$$

Where Δt is the sampled time,i is the current time index,i+1 is the next time index.

In Fig. 2, X and Y are the transverse and longitudinal vectors on the global coordinates, respectively. $X2$ and $Y2$ are the lateral direction and head direction vectors of the WMR's local coordinate. Xk and Yk are coordinate vales of the center of the WMR in global coordinates. Xt and Yt are the coordinate values on the global coordinates of the target position (expected point of position or expected trajectory) . Xt' and Yt' are the coordinate values on local coordinate of target location (expected point of position or expected trajectory). θ is an included angle between the center of the mobile and the transverse axis of the global coordinate. θ_e is an included angle between the head direction and the target position and φis an included angle between the lateral direction and the target location.

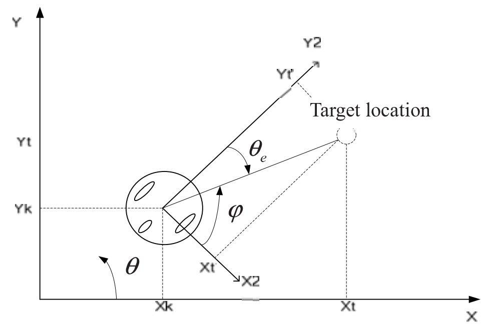

Fig. 2. WMR on global coordinate.

3. FUZZY CONTROLLER DESIGN

The typical architecture of fuzzy logic control comprises four principal components: a fuzzifier, a fuzzy rule base, a fuzzy inference engine, and a defuzzifier. There are six inputs of this system, which are the angle between target location and robot's moving direction and five ultrasound sensors' distance. The output of the system is the turning angle of the wheeled mobile robot. A fuzzy controller is proposed to control the output of turning angle and make the robot reach target location. There are seventy-two rules for robot navigation. Fig. 3 shows membership functions of input distance. The input of variables are *drr*, *dr, dc*, *dl*, *dll* and the fuzzy sets are NEAR and FAR. Fig. 4 shows the membership functions of *tr*, the angle between target location and ultrasonic sensor-3. Five levels of this input are RAB, RAS, TZ, LAB, and LAS. The output of Rule 1 to Rule 33 is *sa* and the fuzzy sets are shown in Fig. 5. There are seven levels of turning degree. They are TRRABB, TRRAB, TRAB, TZZ, TLAS, TLLAS, and TLLASS which represent turning right largest, turning right larger, turning right , going forward, turning left, turning left larger, and turning left largest, respectively. The output of Rule 34 to Rule 72 is *sa1* and the fuzzy sets are shown in Fig. 6. Five levels of turning degree are TRAB, TRAS, TTZ, TLAS, and TLAB, which are similar to Fig. 6 except TRRAB and TLLAS.

If the mobile robot is very close to obstacles, the WMR uses Rule 1 to Rule 32. If the mobile robot is far away from obstacles, it uses Rule 33 to Rule 72. Some examples of the rules are shown below.

Rule 1: if *drr* is FAR and *dr* is FAR and *dc* is FAR and *dl* is FAR and *dll* is FAR, then *sa* is TZZ.

Rule 2: if *drr* is FAR and *dr* is FAR and *dc* is FAR and *dl* is FAR and *dll* is NEAR, then *sa* is TRRAB.

…

Rule 33: if *dr* is FAR and *dc* is FAR and *dl* is FAR and *tr* is LAB, then *sa* is TLAB.

Rule 34: if *dr* is FAR and *dc* is FAR and *dl* is FAR and *tr* is LAS, then *sa1* is TLAS.

…

Rule 72: if *dr* is NEAR and *dc* is FAR and *dl* is NEAR and *tr* is RAB, then *sa1* is TRAB.

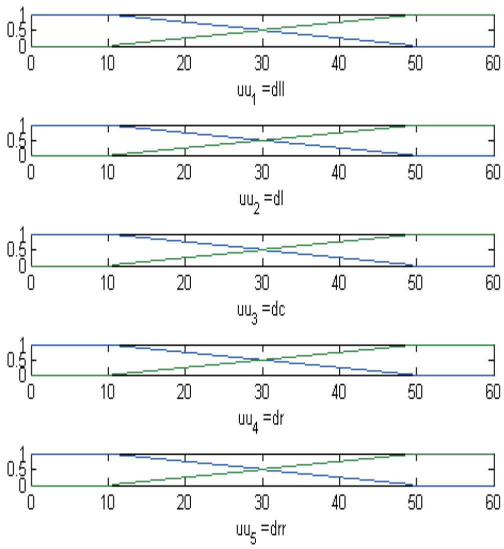

Fig. 3. Membership functions of ultrasonic sensors.

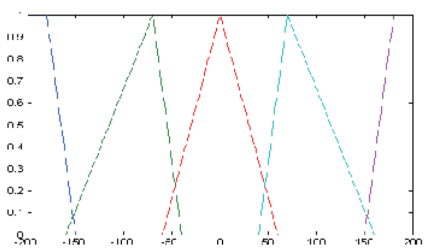

Fig. 4. Membership functions of the angle between target location and ultrasonic sensor.

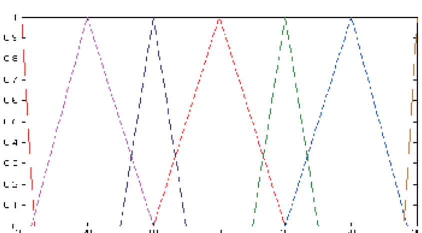

Fig. 5. Membership functions of the output of turning angle *sa*.

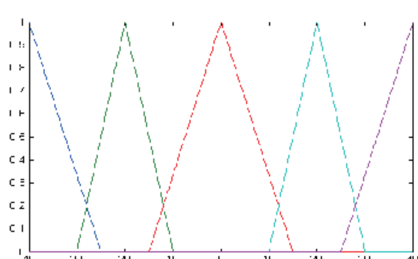

Fig. 6. Membership functions of the output of turning angle *sa1*.

4. CONTROL STRATEGIES AND SIMULATIONS

A. short-distance obstacle avoidance model

By using the ultrasonic sensors in front, right 90-degree, right 45-degree, left 45-degree and left 90-degree sides of the robot, the size of obstacle and distance between robot and obstacle can be detected. The sensors are shown in Fig. 7. Fig. 8 is the control strategy of the short-distance obstacle avoidance model. We have identified and implemented the obstacle avoidance behaviors as follows:

1. If the detected distance between obstacle and WMR is shorter than 60cm, then the robot uses short-distance obstacle avoidance model.
2. If the distance from obstacle is detected larger than 60cm, then the robot uses target-driven obstacle avoidance model.

The operation of the WMR depends on the distance information. Examples of short-distance obstacle avoidance model are shown in Fig. 9 and Fig. 10. Fig. 10 shows the WMR is in simple environment. The robot uses short-distance obstacle avoidance model. In this case, the robot moves into a trap and keeps moving along a square pattern. The case in Fig. 10 has more obstacles. The WMR can not reach the target location.

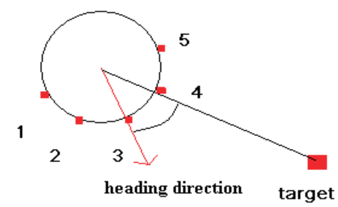

Fig. 7. Deployment of ultrasonic sensors.

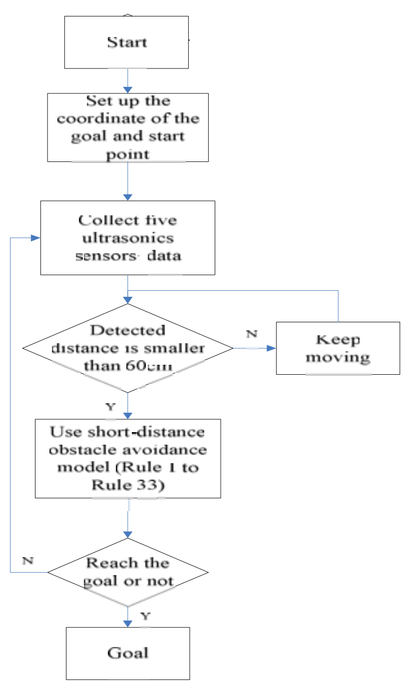

Fig. 8. Short-distance obstacle avoidance model.

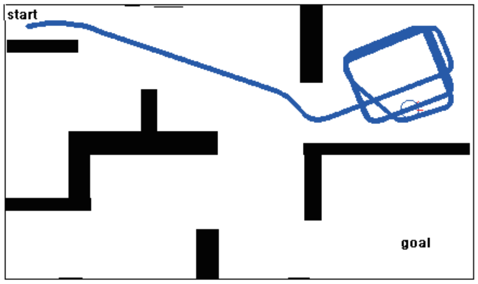

Fig. 9. Short distance obstacle avoidance model-ex1.

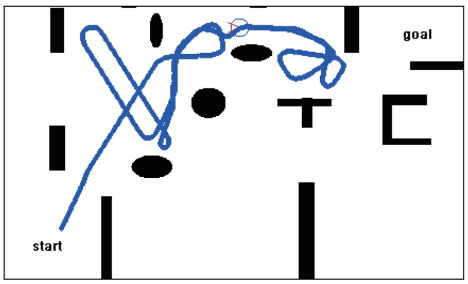

Fig. 10. Short distance obstacle avoidance model-ex2.

B. Target-driven model

Fig. 11 is the control strategy of the target-driven model. There are four inputs and one output of the system, which are the angle between target location and robot's heading direction and obstacle distances of ultrasonic sensors in front, right 45-degree, left 45-degree sides of the robot, and turning angle of the wheeled mobile robot, respectively. A fuzzy controller is proposed to control turning right or left and make the robot reach target location. The simulation result is shown in Fig. 12. With goal given, the WMR can move from starting point to target location successfully.

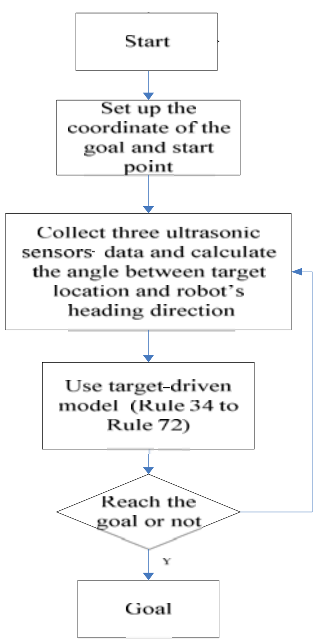

Fig. 11. Flow chart of the target-driven model.

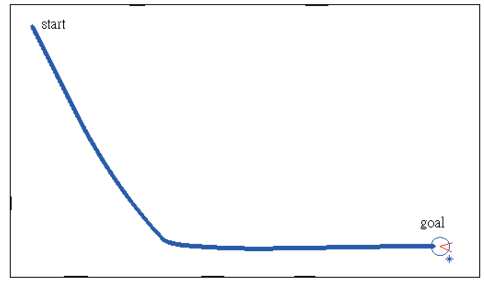

Fig. 12. Target-driven model without obstacle.

C. Target-driven obstacle avoidance model

Fig. 13 is the control strategy of target-driven obstacle avoidance model. Figs. 14~16 show the performances of using combined short-distance obstacle avoidance and target-driven strategy in different environments. This intelligent control strategy can provide superior route from starting point to the goal in different environments than previous work [14]. Fig. 17 shows the situation that the robot may take some unnecessary routes. We can set a midway point outside the circle route and make the robot avoid the unnecessary route and reach the goal as shown in Fig. 18. Fig. 19 and Fig. 20 show the results by setting different midway points. The midway point can be generated automatically from the intelligent strategy as shown in Fig. 21. In Fig. 22, by setting midway points, the robot reaches the point 1 first and then reaches the point 2 and so on. This approach can make the robot reach hidden goal.

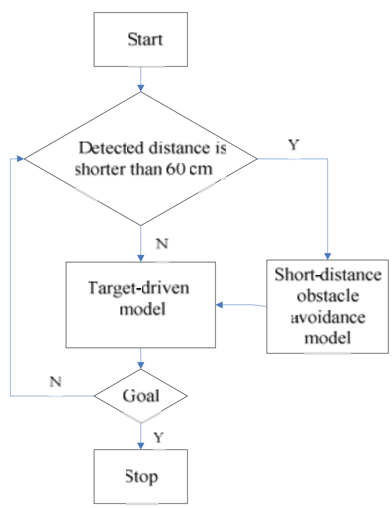

Fig. 13. Target-driven obstacle avoidance model.

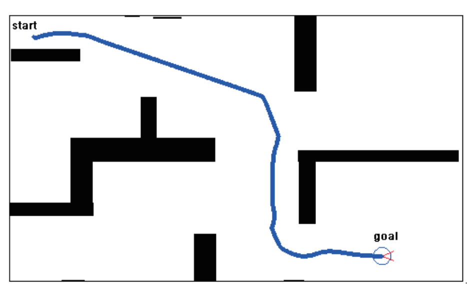

Fig. 14. Target-driven obstacle avoidance.

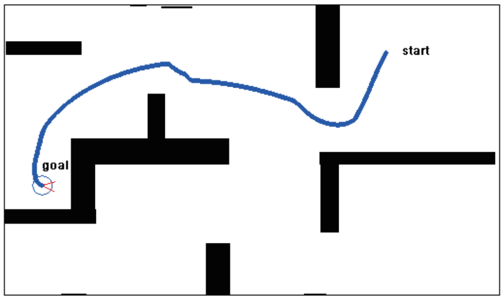

Fig. 15. In simple environment with different starting and ending points.

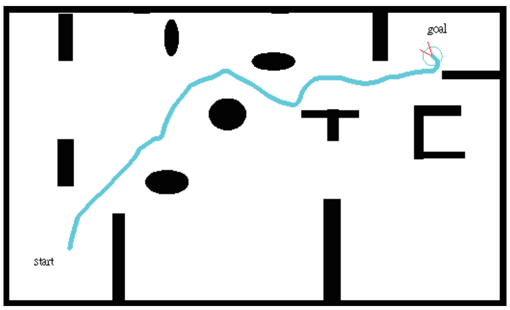

Fig. 16. In complex environment.

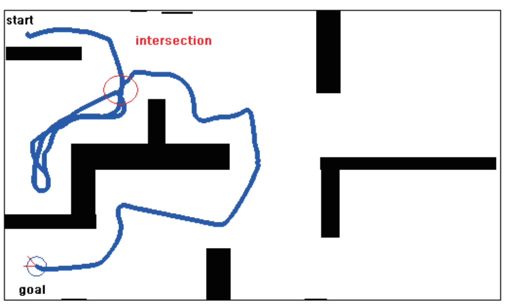

Fig. 17. Robot movement with unnecessary route.

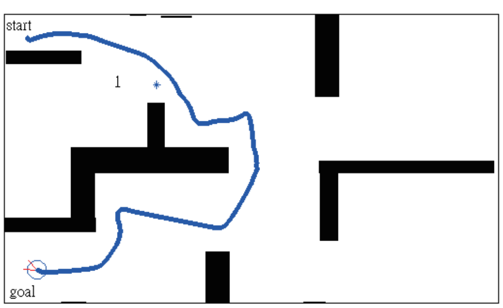

Fig. 18. Set a midway point to guide the robot to reach the goal.

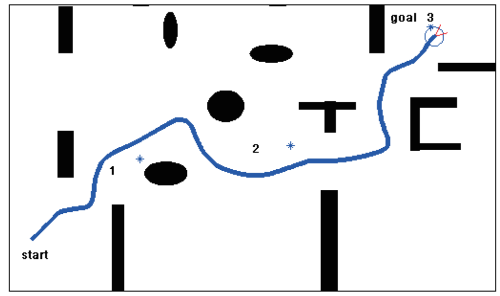

Fig. 19. Set two midway points to guide the robot to reach the goal.

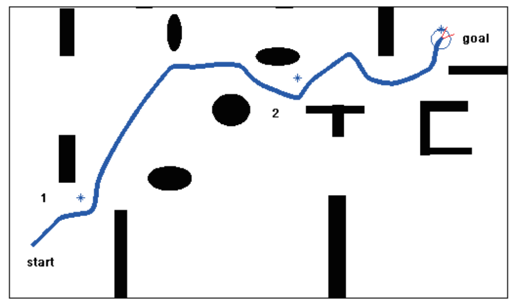

Fig. 20. Set different midway points to guide the robot to reach the goal.

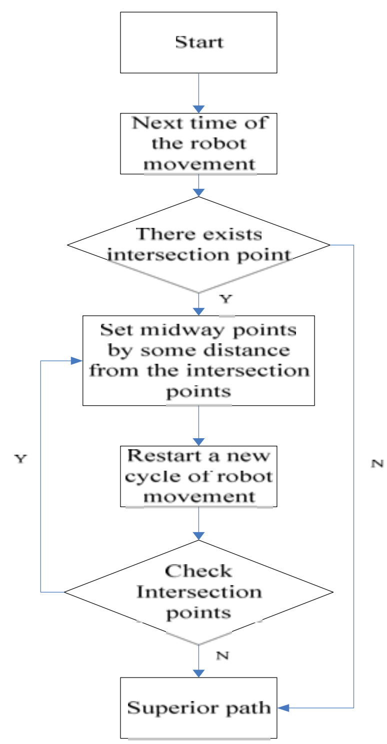

Fig. 21. Flow chart of setting midway points.

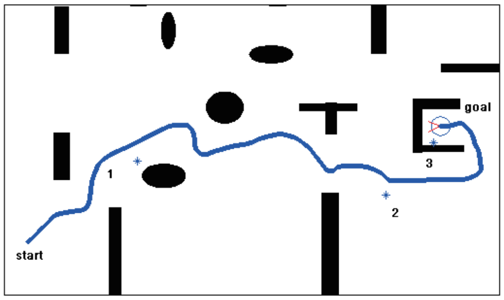

Fig. 22. Robot reaches a hidden goal in complex environment.

5. CONCLUSION

In this study, several intelligent obstacle avoidance strategies to a wheeled mobile robot are proposed. Software simulations are made on the MATLAB platform. The wheeled mobile robot is put in different complex environments. Obstacle avoidance and target-driven models are performed successfully. In the future, the proposed control scheme can be applied to indoor service robots such as medical files delivery robot in the hospital, food delivery robot in the restaurant, etc.

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