Behavior-Based Hierarchical Fuzzy Control for Mobile Robot Navigation in Dynamic Environment

Wang Dongshu, Zhang Yusheng, Si Wenjie

Abstract—**It is of high significance to investigate the mobile robot navigation under dynamic unknown environment. In order to realize the non-collision movement of mobile robots in dynamic unknown circumstance, behavior-based hierarchical fuzzy logic controller to solve the robot navigation and priority-based behavior control are proposed in this paper. First, four basic behaviors, goal seeking, obstacle avoidance, wall following and deadlock disarming, for mobile robot navigation are proposed, and the former three basic bahaviors are implemented through a fuzzy logic controller. To the 'U' or 'V' shaped acute obstacles where mobile robot may be trapped, path remembering behavior is employed to protect robot from re-entering the similiar areas through constructing the Virtual Wall. Matlab simulation results show that the proposed approach is effective in navigating mobile robots in a dyanminc unknown circumstance.**

Key words: Mobile robot, Navigation, Fuzzy Logic controller, Path remembering, Virtual wall

I. Introduction

MOBILE robot is a kind of robot which has self-planning, self-organizing, self-adapting abality and working in complex environments. In the correlative techniques researches, , the mibile robot navigation techinque is the core, as well as is the key technique to realize real intelligence and totally autonomous moving. Research aim of navigation is making robot move to the goal and accomplish certain tasks or operations without human interference. In order to achieve real-time autonomous navigation, the mobile robot must be capable of sensing its environment, interpreting the sensed information to refine the knowledge of its position and the environment's structure, planning a route from an initial to a goal position with obstacle avoidance, and controlling the mobile robot's turning angle and linear velocity to reach the target[1].

The robot navigation can be accomplished through behavior arbitration[2] and hierarchical behavior control[3]. Some of these basic behaviors are Goal Seeking, Obstacle Avoidance and Wall Following[4]. Behavior-based methods have been widely used for mobile robot navigation[5-6].It can not only cope with uncertainties due to the environments and sensors, but also deal with various situations without the model or environment map. In 1985, Brooks proposed the famous subsumption architecture that has been successfully applied to mobile robot[7]. With this architecture, one can decompose complex navigation tasks into several well-specified behaviors, each of which is connected directly to sensors and actuators and operates in parallel, all behaviors are connected together by an arbitrator to determine control action of the robot. The behavior arbitrator resolves any conflicts arising from multiple behaviors attempting to control the same actuator simultaneously [8].

In mobile robot navigation, some artificial intelligence techniques, such as Fuzzy Logic (FL)[9], Artificial Neural Network (ANN), Genetic Algorithm (GA) , Particle Swarm Algorithm(PSA), and/or the combination of a few of them, are used to cope with the problems occurred. Bao[1] designed a behavior-based architecture using fuzzy logic for mobile robot navigation in unknown environments and implemented the basic behaviors by using fuzzy logic controller.To integrate the basic behaviors, a behavior controller is designed to determine the control action of the mobile robot. Velappa Ganapathy and Soh Chin Yun [4] adopted fuzzy logic and artificial neural network to assist autonomous mobile robot move, learn the environment and reach the desired goal. They expolred the four combinations of training algorithms composed of FL and ANN that avoid acute obstacles in the environment.

To integrate behavior-based control and fuzzy logic control, this paper puts forward a fuzzy behavior-based architecture for mobile robot navigation in dynaminc unknown environments. First, it designs four basic behaviors for mobile robot navigation, goal seeking, obstacle avoidance, wall following, and deadlock disarming. Each behavior is carried out with fuzzy controller to acqure respective navigation task. Then, a behavior controller is designed to integrate basic behaviors to control the mobile robot move. In the cases where mobile robot is trapped in the 'U' or 'V' shaped obstacles, it is very difficult for the robot to come out from these obstacles. Path remembering behavior is employed to assist the mobile robot to come out from such obstacle and virtual wall behavior is used to prevent the mobile robot from reentering the same obstacle in the environment.

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II. System Description

A. Mobile Robot Sensors Arrangement

To achieve autonomous behaviors, one of the most important tasks of mobile robot is acquiring the information of the surrounding environments. In order to control a mobile robot to reach its goal without colliding any obstacle, the robot must equip some sensors to sense the environment and tranfer the circusmance information to the robot control center to interpret the sensed information. The commonly used sensors on mobile robot are ultrasonic sensors, CCD cameras, infrared sensors, laser sensors, global positioning systems and so on. Because the ultrasonic sensor has many characteristics such as cost-effective, simple operation, easy implementation in hardware, little information processing and so on, it has gotten widely used in mobile robot. So here we adopt ultrasonic sensors to detect obstacles' distance and the mobile robot's direction. Three group sensors, each composing of two neighboring sensors, are arranged as explained in Figure 1. The left, front, right obstacle distance, D_L, D_F and D_R are determined as follows:

$$D_L = \min(d_1, d_2) \tag{1}$$

$$D_F = \min(d_3, d_4) \tag{2}$$

$$D_R = \min(d_5, d_6) \tag{3}$$

Where d_i ($i = 1, \cdots, 6$) is the reading data of ith ultrasonic sensor.

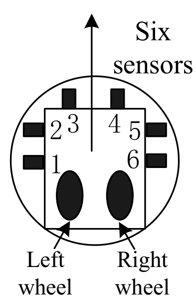


Figure 1. Ultrasonic sensor arrangement scheme

B. Coordinate System and Control Variable

There are two coordinate systems: world coordinate system depicted by XOY and robot local coordinate system depicted by xoy, the relationship between these two coordinate systems and the relationship of control variables are explained in figure 2. Rectangle area depicts the robot, empty circle depicts the goal and the black circle area depicts the obstacle.

The meaning of the control values are described as follows: D – Distance between the robot and the goal; D_L –Distance between the robot and the left obstacle; θ – Robot heading angle; α – Angle of goal in XOY ; ϕ – Robot steering angle.

When the mobile robot moves in the unknown environments, D and ϕ can be computed from the robot current position and goal positions in global coordinate.So the control values are the real turning angle W and linear velocity V .

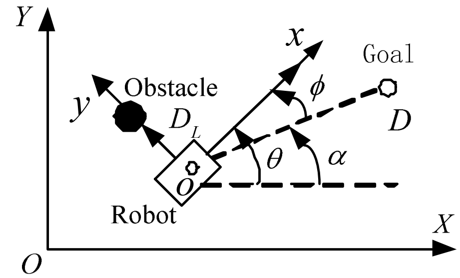


Figure 2. Coordinate systems and control variables scheme

For this mobile robot navigation process geometrical model, we design a behavior-based hierarchical fuzzy controller to realize the mobile robot's navigation in dynamic unknown environments.

III. Design Of The Behavior-Based hierarchical Fuzzy Controller

The behavior-based hierarchical fuzzy controller architecture for mobile robot navigation is depicted in Fig. 3. Behavior controller is designed according to the obstacle distance D_L , D_F and D_R . Then the behavior controller will be used to decide which behavior controller has high priority, and the mobile robot will be controlled by the highest priority behavior during the mobile robot moving towards the goal.

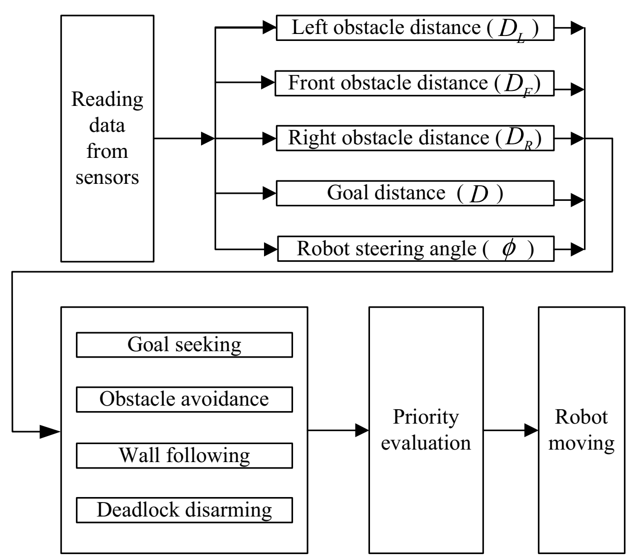


Figure 3. Behavior-based hierarchical fuzzy controller architecture

A. Four basic behaviors design

(1) Goal seeking

When there are no obstacles around the robot, goal seeking behavior makes the robot move along the direction of the goal. For the function, this behavior receives goal distance

(D) and robot steering angle (ϕ) as the input values of the goal seeking fuzzy controller, the output control values are the turning angle W_g and the linear velocity V_g.

The membership function of input values, D and ϕ are depicted in Fig. 4(a) and Fig. 4(b) (NB: Negative Big; NM: Negative Medium; NS: Negative Small; ZE: Zero; PS: Positive Small; PM: Positive Medium; PB: Positive Big; Negative and Positive means that the goal is on the left and right of the robot, respectively.). And the membership function of output values, W_g and V_g are respectively shown in Fig. 4(e)(LB: Left Big; LM: Left Medium; LS: Left Small; ZE: Zero; RS: Right Small; RM: Right Medium; RB: Right Big; Left and Right means that the robot turns to be left and right, respectively.) and Fig. 4(f).

The goal seeking fuzzy rules can be summarized as follows:

a. If the goal is on the left (right), the robot turns left (right); If the goal is on the front, the robot moves forward;

b. If the robot steering angle ϕ in Fig. 2 is big (medium, small), the robot's turning angle W_g is big (medium, small);

c. If the distance between the current position and the goal is near (medium, far), the linear velocity V_g is slow (medium, fast).

(2) Obstacle avoidance

This behavior is activated when there are some obstacles come on the front, right-front, left-front of the robot. So this behavior receives front obstacle distance (D_F) and side obstacle distance (D_S) as the input values of the obstacle avoidance fuzzy controller, the output control values are the turning angle W_O and the linear velocity V_O.

The membership function of input values D_F and D_S are illustrated in Fig. 4(c) and Fig. 4(d) (RL: Right Large; RS: Right Small; ZE: Zero; LS: Left Small; LL: Left Large); when the left (right) obstacle distance is bigger than 1 meters, side obstacle distance $D_S = -D_R$ ($D_S = D_L$). And the membership function of output values W_O and V_O are respectively shown in Fig. 4(e) and Fig. 4(f).

The obstacle avoidance fuzzy rules can be summarized as follows:

a. If an obstacle is on the right-front (left-front), the robot turns left (right); If there is an obstacle directly in front of the robot, the robot turns left;

b. If the front obstacle distance is small (medium, large), the turning angle is big (medium, small) and the linear velocity is slow (medium, fast).

(3) Wall following

This behavior is activated when the robot meets wall obstacles on any one side or both sides. So left obstacle distance (D_L) and right obstacle distance (D_R) are the input values of the following fuzzy controller, the output control values are the turning angle W_T and the linear velocity V_T.

The membership function of input values D_L and D_R are illustrated in Fig. 4(c). And the membership function of output values W_T and V_T are respectively shown in Fig. 4(e) and Fig. 4(f).

The following behavior fuzzy rules can be summarized as follows:

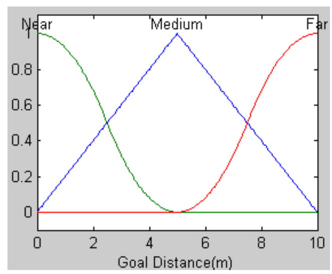
a. If an obstacle is on the left (right) side and the goal is on the left, the robot moves forward (moves towards the goal);

b. If an obstacle is on the left (right) side and the goal is on the right, the robot moves towards the goal (moves forward);

c. If the robot move towards the goal, the linear velocity is fast, otherwise, the linear velocity is medium.

(4) Deadlock disarming

In some cases when the robot goes into U-shaped or V-shaped obstacles, it is very difficult for the robot to come out. In order to make the robot get away from these areas, path remembering behavior is employed to help the robot to come out from such obstacle and virtual wall behavior is used to prevent the mobile robot from re-entering the same obstacle in the environment.



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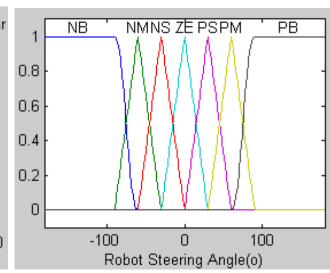

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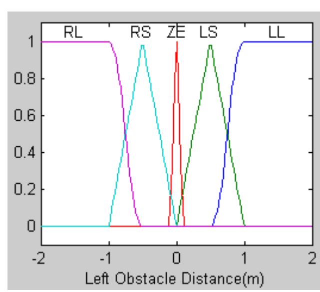

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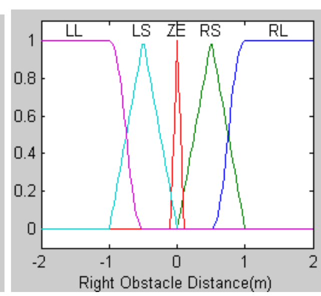

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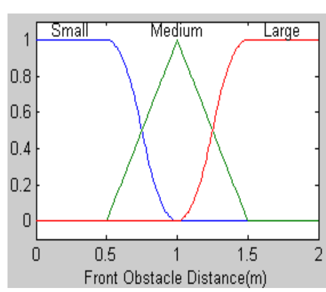

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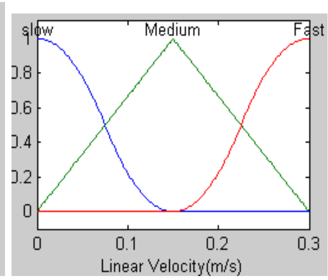

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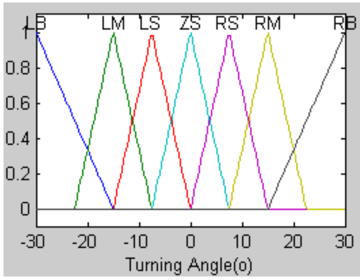


(g)

Figure 4.Membership function of input/output control variables

(i) *Path Remembering*

Wall Following behavior will only be activated when at least 5 sensor readings are on. Due to this constraint, the robot will keep looping inside the acute obstacle until at least 5 sensor readings are on. In order to minimize the number of iterations required by the robot to come out from the obstacle, path remembering behavior[4] is introduced. The flowchart of path remembering behavior is shown in Figure 5.

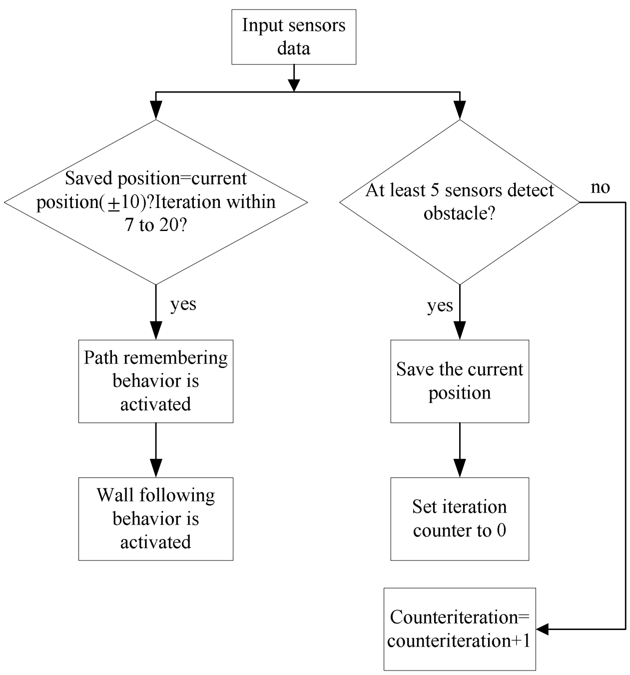


Figure 5. Flowchart of path remembering

(ii) *Creation of Virtual Wall*

By introducing the path remembering behavior, the number of iterations for the robot to escape from the acute obstacle has been reduced. But in some cases, after escaping from the acute obstacle, the robot might move back and get trapped in the same obstacle again. This problem can be solved by introducing the creation of the virtual wall[4]. When the acute obstacle is detected, the robot will construct the virtual wall which indicates that the area around the obstacle is prohibited. The created virtual wall can only be recognized by the robot itself. So, the robot will not enter the prohibited area again.

The virtual wall will be created when the wall following behavior or path remembering behavior is activated. The virtual wall can only be created when the robot moves away from the goal. This is identified by the distance of the robot position towards the goal. The increasing distance means that the robot moves away from the goal. On the other hand, if the distance is decreasing it means that the robot moves towards the goal. The creation of the virtual wall will be deactivated only when the robot crosses the reference point. The reference point is also set when the wall following behavior or path remembering behavior is activated.The flowchart of constructing of the virtual wall is shown in the Figure 6.

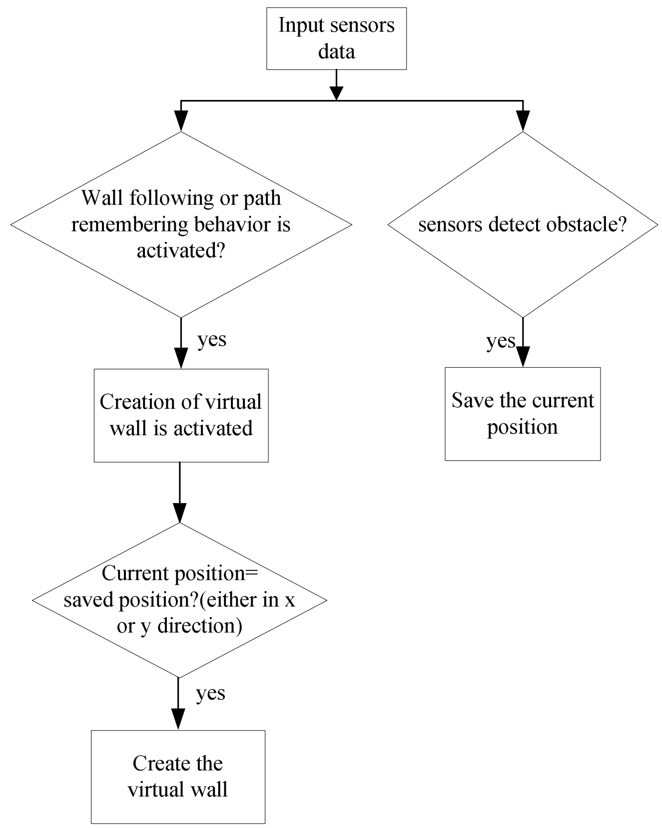


Figure 6. Flowchart of creation of virtual wall

B. Basic behavior integration

To integrate the four basic behaviors, a behavior controller is designed shown in figure 7. The concrete control procedure is explained as follows:

Step1: The behavior controller always begins from goal seeking behavior. If there are no obstacles in direction towards the goal, the robot will move towards the goal directly, otherwise turn to Step2;

Step2: When the robot meets obstacles, the controller stops goal seeking behavior and changes to other behaviors. Which behavior has high priority depends on the distance between the obstacle and robot. Define the threshold of obstacle distance is 1 meters and evaluate the relationship between the threshold and the obstacle distance, then go to

Step3 to decide which behavior has the highest priority to control the robot;

Step3: If the relationship between the threshold and the obstacle distance is: $\left(\left(D_L < 1\right) | \left(D_R < 1\right)\right) \& \left(D_F < 1\right)$ or $\left(D_L > 1\right) \& \left(D_R > 1\right) \& \left(D_F > 1\right)$, obstacle avoidance behavior will have high priority, the robot will avoid obstacles; If the relationship is: $\left(D_L < 1\right) \& \left(D_R < 1\right) \& \left(D_F > 1\right)$ or $\left(\left(D_L < 1\right) | \left(D_R < 1\right)\right) \& \left(D_F > 1\right)$, wall following behavior will have high priority, the robot will move along the wall; If the relationship is: $\left(D_L < 1\right) \& \left(D_R < 1\right) \& \left(D_F < 1\right)$, deadlock disarming behavior will have high priority, the path remembering and virtual wall construction function will be employed to guide the robot going out of these acute obstacles.

Step4: At the same time, obstacles will be detected and the distance between obstacles and robot current position will be updated in real time. If there are no obstacles, the robot will move towards the goal, otherwise, go to Step3 until the robot arrives the goal.

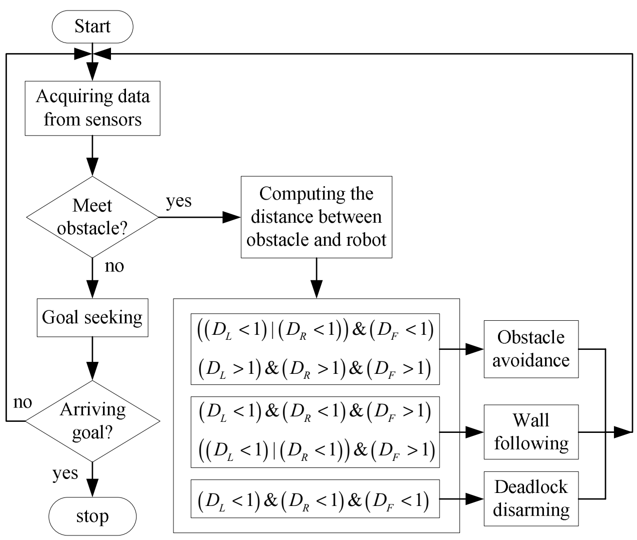


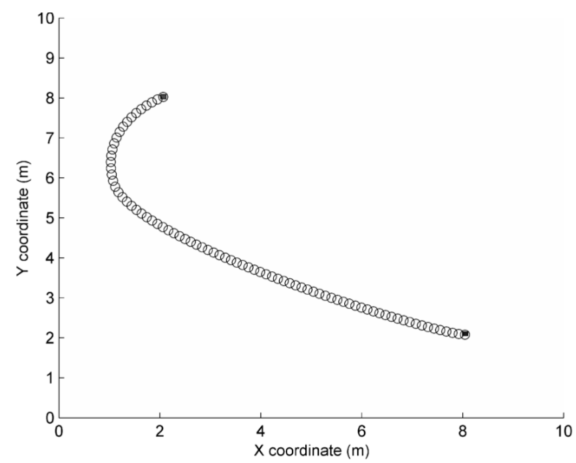
Figure 7. Scheme of behavior controller

IV. SIMULATION

In order to verify the feasibility of the behavior-based hierarchical fuzzy controller proposed in this paper, using Simulink to construct simulation system model in MATLab, simulating the control rules using fuzzy logic toolbox. During the simulation, the starting point and the terminal point can be set arbitrarily, and the obstacles' size, shape and position can also be set arbitrarily. So we can testify the effectiveness of the proposed method in arbitrary circumstance.

The path composed of the red little circles is the path produced by the proposed method in this pape. Four charts in figure 8 depicts four diffferent navigration experimrnts in four different cases. Chart (a) illustrates the goal seeking behavior. Without obstacles in the surrounding environment, the architecture simply generates a path from start point (1, 6) to destination point (9, 1) using the goal seeking fuzzy rules. Chart (b) illustrates the obstacle aviodance behavior. During this process, obstacle avoidance behavior has high priority according to the behavior controller. After moving around the obstacles successfully, the robot move towards the destination point. Chart (c) demonstrates the deadlock disarming behavior. The robot traps in a U-shaped obstacle. Using the path remembering and virtual wall construction, the architecture generates a path to guide the robot going out of the acute obstacle using the deadlock disarming and goal seeking fuzzy rules. Chard (d) shows a successful navigation in complex environments. There are many obstacles generated randomly in the environment. Following the path generated by the control architecture, the robot arrives at the destination without colliding.

In the aforementioned four simulation experiments, the mobile robot can get through the environments without colliding which demonstrate that the method proposed in this paper can deal with the mobile robot navigation seccessfully in dynimic unknown environments.



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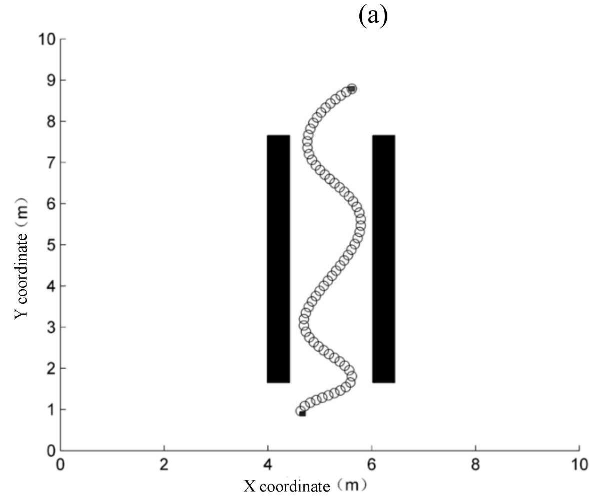

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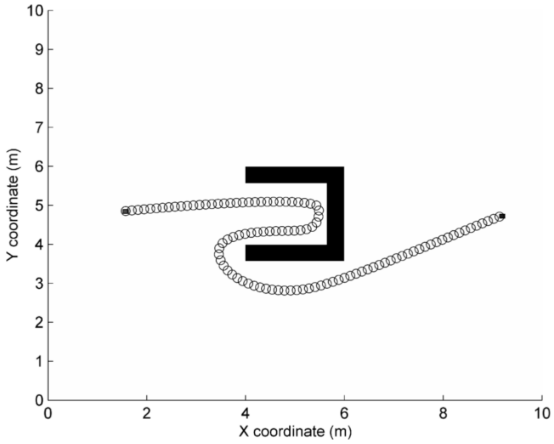

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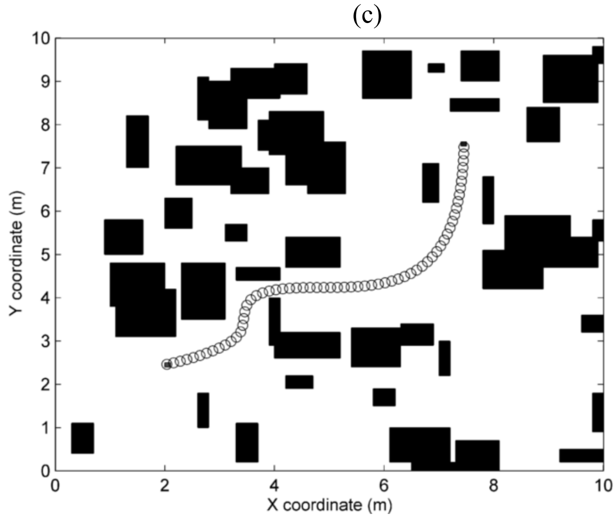

(d)

Figure 8. Simulation results under different obstacle environments

V. CONCLUSION

With the more applications of mobile robot in human daily life and work, its navigation in dynimic unknown circumstance is becoming a more and more important research field. This paper proposes a behavior-based hierarchical fuzzy controller for mobile robot navigation in dynamic unknown environment. Robot behaviors are devided into four categories: goal seeking, obstacle avoidance, wall following and deadlock disarming, and constructing their corresponding fuzzy rules. Each behavior's priorities can be evaluated by setting sensors detecting threshold and computing the obstacle distance. So each behavior has different priority in different cases and the hierarchical fuzzy controller can control robot to adopt corresponding action according to the behavior priority in different cases. For the robot trapped in a acute U-shaped or V-shaped obstacle, path remembering and virtual wall construction functions are employed to help the robot to get out of these obstacles. Simulation results in four different cases show that the behavior-based hierarchical fuzzy controller proposed in this paper can navigrate the mobile robot in dynamic unknown circumstances effectively.

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