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Study on the Path Planning of the Spherical Mobile Robot based on Fuzzy Control

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***Abstract* - To improve the adaptability of the spherical mobile robot in unknown environment, this paper proposed the behavior-based fuzzy control method, and integrated fuzzy obstacle avoidance performance into this method. Firstly, the sensors were arranged according to the motion model of the spherical mobile robot, and which improved the flexibility and autonomy of the spherical mobile robot in unstructured environment. In the process of motion, the spherical mobile robot use multi-sensor, which is used to collect the obstacles and the target position information in the environment, to complete the path planning. Then, the MobotSim simulation platform was used to design the behavior-based control experiments for the spherical mobile robot, including wall-following, through narrow road, obstacle avoidance and trending target experiments .etc. The simulation results verified the validity and reliability of the fuzzy control system. Finally, the path planning experiments in the real environment was completed, which controlled the spherical mobile robot behavior by fuzzy controller and priority decisions, including obstacle avoidance, wall-following, cruising, tending to target and unlocking the deadlock behaviors, and so on, and modified the pose of the robot based on the angle of real-time feedback information to avoid obstacles precisely. The experimental results showed that the spherical mobile robot could complete control method based on behavior, further verified the effectiveness and practicability of the fuzzy control system.**

Index Terms - The spherical mobile robot. Fuzzy control. Multi-sensors. Obstacle avoidance. Path planning.

I. INTRODUCTION

Path planning is to find a safe path from the starting position to the target position in the environment with obstacles. The most basic intelligent behavior of mobile robots is obstacle avoidance, which is the basis of advanced intelligent behavior such as decision-making and motion control of robots [1], and it is also an important guarantee for completing various tasks in complex or unknown environments. Therefore, the research of a behavior-based obstacle avoidance strategy is also the difficulty and hot spot of robot path planning technology.

At present, research in the field of robot path planning is developing rapidly. Various countries are committed to the development of this research, and new achievements are constantly being born. For example, BYQ-3 robot, designed by Beijing University of Posts and Telecommunications, can achieve precise motion by visual navigation system [2]; GroundBot robot, developed by the Swedish Rotundus, can adapt to various complex environments, such as sand, mud and snow, and also can achieve rolling on the water; The amphibious spherical robot, developed by Kagawa University, can achieve both land and underwater motion with high flexibility and low noise [3].

Spherical mobile robots are widely used in amphibious and complex environments due to its special structure and flexible motion [4]. To complete the motion switching based on multiple obstacle avoidance behaviors, therefore, we take the spherical mobile robot as the research object in this paper., which perceives the external environment and makes decisions on the complex environment by sensors [5].

The most basic intelligent behavior of the spherical mobile robots is to avoid obstacles. It is the basis of the high-level intelligent behavior for decision-making and motion control, and it is the guarantee of completing various tasks in an unknown environment [6]. The commonly used obstacle avoidance methods based on multi-sensors include bug algorithm, artificial potential field method and fuzzy control method, and so on. In the bug algorithm, the dynamics of the robot is not considered [7]. The artificial potential field method has a local optimal solution, namely deadlock. When the spherical mobile robot moves, the surrounding environment changes dynamically, which makes it difficult for the robot to establish an accurate mathematical model [8]. Using the fuzzy control method can solve such problems well.

In this paper, the fuzzy control algorithm is applied to the obstacle avoidance of the spherical mobile robot. The fuzzy controller is fused with the priority decision, and the path planning of the spherical mobile robot is controlled in a complex environment, and the effectiveness and reliability of the designed controller is verified by simulations and experiments.

II. SYSTEM STRUCTURE AND KINEMATICS MODEL OF THE SPHERICAL MOBILE ROBOT

A. System Structure

The spherical mobile robot consists of four groups of driving devices [9]. Each group of driving devices consists of two waterproof servo steering gears, a water jet motor and a bracket. By adjusting the deflection angle of the waterproof servo steering gear in each group of driving devices, the four legs can cooperate with each other to form regular movement,

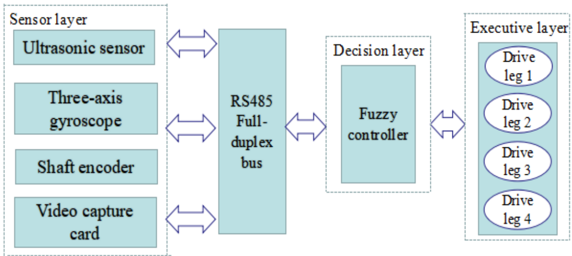
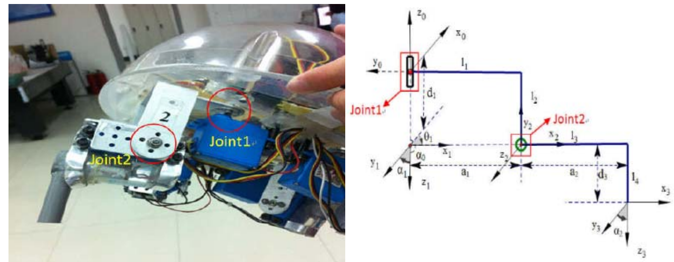


Fig. 1 System structure diagram of the spherical mobile robot.



(a) schematic diagram (b) coordinate system

Fig. 3 Kinematic model of the spherical mobile robot.

and The adjustment of the drive leg is conducive to the control of trajectory and posture. System structure shown in Fig. 1, it has a total of three layers structure, the leftmost sensor layer to collect environment information, including ultrasonic sensors, shaft encoder, gyroscope and video capture card; The middle decision-making control layer can realize the motion control of the spherical mobile robot through the fuzzy control system; The rightmost is the execution layer, which is composed of four driving units and completes the movement of the spherical mobile robot [10].

In order to make the spherical mobile robot to complete its obstacle avoidance tasks in complex environment, four ultrasonic sensors (HC-SR04) are installed on the spherical mobile robot, and the numbers 1 to 4 show that the four ultrasonic sensors on the ontology of the spherical mobile robot numbered from left to right. And the video capture card is fixed directly under the robot acrylic board, as shown in Fig.2. The shaft encoder and gyroscope are fixed inside the spherical mobile robot, which is used to collect the position and direction of the robot's driving leg, so that the spherical mobile robot can recognize the target more accurately.

B. *Kinematic Model of the Spherical Mobile Robot*

The movement of the spherical mobile robot is mainly to adjust four driving legs, so it is very necessary to analyze the operation of the driving leg [11]. Fig. 3(a) is a schematic diagram of a kinematic joint of the spherical mobile robot, and each leg consists of two rotating joints, which complete the rotation of the hip joint and the flexion-extension of the knee joint of the spherical mobile robot, respectively. Among them, Joint 1 represents the hip joint, and Joint 2 represents the knee joint. In this paper, the D-H parameter method was used to construct the kinematics model of the spherical mobile

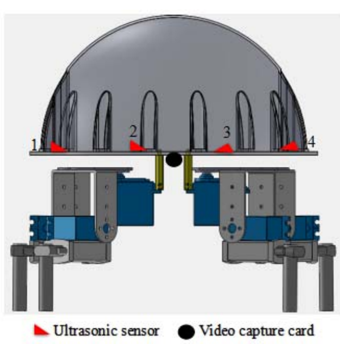


Fig. 2 Layout of the spherical mobile robot sensor.

robot, in which l_1, l_2, l_3, and l_4 represents the lengths of each rods. The coordinate system of the drive leg is established as shown in Fig. 3(b).

Each leg is determined by four independent parameters, namely the length of the rod α_{i-1}, the twist angle of the rod α_{i-1}, the joint distance d_i and the joint rotation θ_i. The pose matrix between adjacent links is derived from the pose matrix joint i-1 to joint i, as shown in equation 1.

$$^{i-1}_{i}T = Trans(a_{i-1},0,0)Rot(x_{i-1},\alpha_{i-1})Trans(0,0,d_i)Rot(z_i,\theta_i) \quad (1)$$

Among them, Trans(α_{i-1},0,0) represents the α_{i-1} flat distance along the x_{i-1}-axis; Rot(x_{i-1}, α_{i-1}) represents the α_{i-1} angle of rotation along the x_{i-1}-axis; Trans(0,0,d_i) represents the d_i flat distance along the z_i-axis; Rot(z_i, θ_i) represents the θ_i angle of rotation along the z_i-axis.

III. DESIGN OF FUZZY CONTROL SYSTEM

The design of a fuzzy control system can be divided into five processes: fuzzification of input variables, fuzzy relational operations, fuzzy synthesis operations, synthesis of different rule results, and defuzzification.

A. *Design of Fuzzy controller*

The core of the fuzzy control system is the fuzzy controller. The rules of the fuzzy controller are implemented by the computer program. The PC acquires the precise value of the controlled variable through sampling. Then the error signal is obtained by comparing this quantity with the given value, and through the feedback error signal as the input of fuzzy controller [12].

The input quantity of fuzzy control selected this time is the distance (D_L, D_R) of the sensors on the left and right sides. The output variables are the rotational angle and the step size scale factor of the robot, as shown in Fig. 4 [13]. The spherical mobile robot acquires obstacle distance information on the left and right sides of the spherical mobile robot through four ultrasonic sensor arrays installed in front of the robot [14].

The ultrasonic sensors are numbered from left to right, denoting 1, 2, 3, and 4 successively. The four ultrasonic sensors are divided into two groups, which (1, 2) is the left group, and (3, 4) is the right group. The distance signals of the two sensors on the left is x1 and x2, and the smallest value is selected as the input on the left, D_L=min{x1, x2}. Similarly, the input distance on the right is D_R= min{x3, x4}. The input

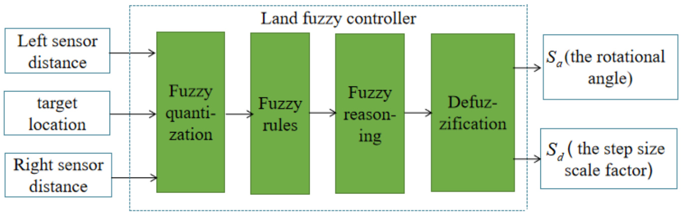


Fig. 4 Fuzzy control scheme of the spherical mobile robot.

distances between the left and right sides is D_L and D_R. Using the linearization method, the fuzzy subset of the input variable is divided into {near, middle, far}, represented by {ND, MD, FD}. According to the actual measurement distance of the ultrasonic sensor, the actual domain is [0.5m , 2m], take the calculation domain as [-5,5]. With linear transformation, as shown in formula (2) :

$$x = k_1 x^* - 10 \tag{2}$$

Where x* is the actual distance value, x is the discrete universe of points, and k_1=10 is the scale factor. The membership function of the fuzzy subset of input variables and output variables is shown in Fig. 5, and (a) represents the fuzzy language membership function of the input distance between the left and right sides; (b) and (c) indicate that the output variable is the step size scale factor and rotation angle of the spherical mobile robot, respectively. From Fig. 5(b), it can be seen that the domain of step size v is [0, 6]. It can be seen that the calculation domain is [-45, 45] in Fig. 5(c).

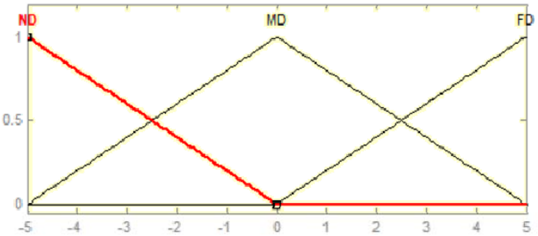
The fuzzy control rule is a set of multiple conditional statements [15]. It can be known from fuzzy set t heory that this causality can be expressed as two fuzzy relational matrices from input variables to output variables. When the robot is far away from obstacles, the behavior of tending to the target plays a major control role; when the robot is closer to the obstacles, the obstacle avoidance behavior of the fuzzy control plays a major role. The robot will make reasonable decisions according to the distribution of obstacles and the target position. The rules for input variables D_L and D_R, and the two output variables v and θ are composed of statement for "if and then". The rules are as follows:

$$\begin{aligned} R_i : If\,(D_{Li} isND \,\&\, D_{Ri} isFD) then (VisVM) and \\ If\,(D_{Li} isND \,\&\, D_{Ri} isFD) then (qisPB) \end{aligned} \tag{3}$$

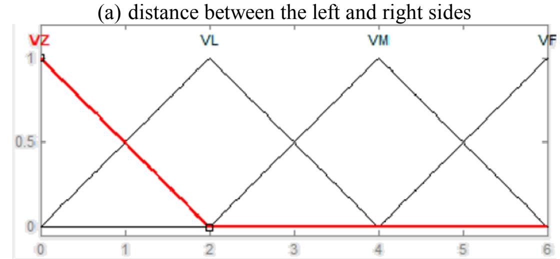
A total of nine fuzzy rule statements are written. The fuzzy controller has two inputs and two outputs, due to v and θ are independent from each other, the fuzzy inference operation of v and θ can be carried out respectively. For example, the fuzzy relation of v can be expressed as:

$$R = \bigcup_{i=1}^{9} [(D_{Ri} \times D_{Li})^T \circ U_i] \tag{4}$$

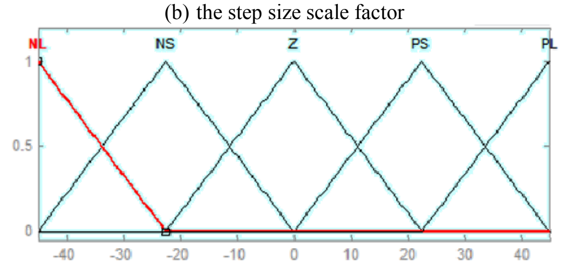
Among them, i is the rule serial number, U_i represents the output result of the i-th system, x represents the direct product of the two sets, and o represents the synthesis of the two sets.



(a) distance between the left and right sides



(b) the step size scale factor



(c) rotation angle

Fig. 5 The membership function of the fuzzy subset of input variables and output variables.

The output is based on the detected right-side distance variable D_R and the left-side distance variable D_L. θ is the same thing as v.

The next step is to defuzzification. Since the above formula calculated the fuzzy quantity, and it needs to be converted into a precise quantity. This paper uses the center of gravity method to defuzzify, and its expression is as follows:

$$u = \frac{\int u_N(x) \bullet x dx}{\int u_N(x) dx} \tag{5}$$

Where u represents the membership function corresponding to the input D_L and D_R, and x represents the center of gravity of the area corresponding to the output v and θ membership functions.

B. *Priority Decision*

In order to improve the flexibility and autonomy of the spherical mobile robot in the unstructured environment, a behavior-based control method is adopted, which can effectively overcome the environmental uncertainty. The fuzzy obstacle avoidance performance is integrated into the behavior-based control method, and the master control right is obtained through the competition. Thus accomplishes the control method based on behavior, and realizes the path planning of the spherical mobile robot [16].

The control structure of spherical mobile robot is divided into "cruising behavior", "trending to the target behavior", "fuzzy obstacle avoidance behavior", "escaping behavior" and "anti-static behavior". The cruising behavior has the lowest priority and no need for the input of sensor signal. Once the spherical mobile robot detects the sensor signal, it will automatically switch to other behaviors. The video acquisition module controls “the anti-static behavior” and “trending to the target behavior”. When there is no change in the scene captured during a period of time, the robot is proved to be in a non-moving state. At this time, the anti-static behavior will be triggered to control the rotation and retreat of the spherical mobile robot; After detecting the target object, the trending target behavior will master the main control and control the spherical mobile robot to move towards the target. The fuzzy obstacle avoidance behavior is controlled by the ultrasonic sensors. When the obstacle is detected, the spherical mobile robot will inhibit the trending to target behavior. The escaping behavior is affected by the values of the gyroscope and the axis encoder, mainly to prevent deadlock problems [17]. The movement of the driving leg of the spherical mobile robot is controlled by various behaviors switches.

When the spherical mobile robot conducts the cruising behavior, in the ideal case, the ultrasonic sensor detects an obstacle and the robot will jump to the fuzzy obstacle avoidance behavior. When the robot collides with an obstacle, the robot jumps to the escape behavior [18]. The design introduces fuzzy obstacle avoidance behavior into behavior-based control method, make each behavior through the competition mechanism for the spherical robot’s mastership, ultimately realizes the path planning of the spherical mobile robot, and also improves the robustness of the spherical mobile robot in an unknown environment.

IV. Simulation of Fuzzy Obstacle Avoidance Algorithm

The spherical mobile robot climbs from starting point to the target point in the process, there are actually two kinds of behaviors: one is the obstacle avoidance behavior, and the other is the trending to the target behavior. These two kinds of behaviors are integrated into the fuzzy controller and output after work together to get the robot's average speed and rotational speed. In order to verify the validity and reliability of the proposed theory, the obstacle avoidance path planning of the spherical robot is simulated in the virtual environment.

The simulation platform is MobotSim. According to the driving principle of the robot designed in this paper, a corresponding number of sensors are set up. And the process of avoiding obstacles and trending to the target of the spherical mobile robot is graphically simulated in an arbitrarily changed two-dimensional complex environment. The language used is Sax Basic language, which uses the specific functions provided by the software to obtain the external environment information of the robot and the position coordinates of the robot, and assigns the robot drive speed so that the robot moves in an unknown environment. The shadedpart in the figure represents the perceptual range of each sensor. The yellow circle represents the target point, and the dark green is various shapes of obstacles.

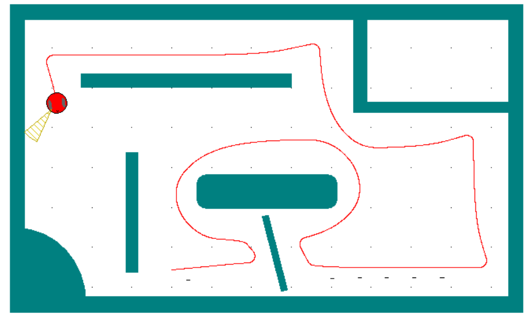


Fig. 6 The result of walking along the wall and crossing the narrow road.

Three experiments were designed in this simulation, including the experiment of walking along the wall and crossing a narrow road, the experiment of avoiding obstacles and trending to the target, and the experiment of avoiding obstacles in complex environment.

A. The Experiment of Walking Along the Wall and Crossing the Narrow Road

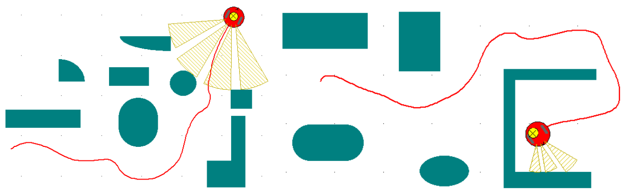
In the simulation experiment, if the robot detected the existence of obstacles on one side, the walking along the wall behavior would acquire the mastership of the robot and control the robot to drive along the obstacles; if the robot detected the existence of obstacles on both the left and right sides, the crossing narrow road behavior would acquire the mastership of the robot. The simulation results were shown in Fig. 6.

B. The Experiment of Avoiding Obstacles and Trending to the Target

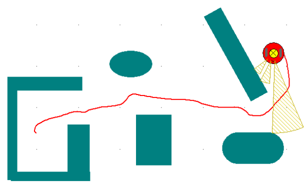
In the simulation experiment, if the target orientation was known, the trending to the target behavior would acquire the mastership of the spherical mobile robot and control the robot to move towards the direction of the target; If there were obstacles in the movement process, the fuzzy obstacle avoidance behavior would inhibit the current trending to the target behavior. Controlling the robot to avoid obstacles, when the obstacle avoidance behavior was over, the tendency toward the target behavior acquired the mastership again, the simulation result was shown in Fig. 7(a). When the target point was inside the concave obstacle, the robot could reach the target smoothly, as shown in Fig. 7(b). When the target point was located directly behind the obstacle, the robot could switch to walking along the wall behavior, effectively completing the deadlock problem, as shown in Fig. 7(c).

C. The Experiment of Avoiding Obstacles in Complex Environment

Finally, the path planning performance of the fuzzy control method in a complex environment was tested, and the results were shown in Fig. 8. The simulation results showed that the robot movement was continuous and stable, could effectively avoid the obstacles in the environment, and the resulting motion path was smooth without excessive circuitous, indicating that the proposed fuzzy control scheme could be well adapted to the complex environment.



(a) obstacle avoidance (b)entering the concave obstacle



(c) leaving the concave obstacle

Fig. 7 The result of avoiding obstacles and trending to the target.

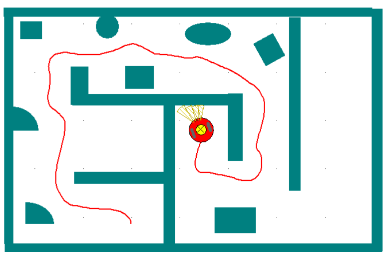


Fig. 8 The result of avoiding obstacles in complex environment.

V. The Path Planning Experiments for Spherical Mobile Robot

Through the simulation results of the fuzzy control algorithm above, we have verified the effectiveness of the control scheme in the virtual environment. In order to further test the path planning effect of the spherical mobile robot in the actual environment, the corresponding code was written using Arduino IDE and debugged.

We have conducted many experiments in the laboratory. The spherical mobile robot uses the installed sensor system to sense the external environment, and the visual image is transmitted to the PC through the wireless video capture card for processing. After the processing is completed, the target object information will be obtained, and transmit to the main control chip by PC. The data information measured by other sensors is processed directly by the main control chip. The spherical mobile robots complete various actions under the control of the main control chip.

A. The Concave Obstacle Experiments of Spherical Mobile Robot

The concave obstacle is an effective experiment to verify that the robot does not have canyon effect. The obstacle avoidance experiment of concave obstacle was tested in real environment, as shown in Fig. 9. In Fig. 9(a), the spherical mobile robot was about to enter the concave obstacle; in Fig. 9(b)-(e), the spherical mobile robot enters the concave obstacle. At this time, according to the fuzzy obstacle avoidance rule, the robot always thinks there are obstacles on one side, so switch to walking along the wall behavior, and finally avoid the concave obstacles successfully. We use the NDI system to complete the tracking of the robot under the concave obstacle. After analyzing and calculating the collected data, the error is about 2%, which satisfies the feasibility and stability of the fuzzy control system.

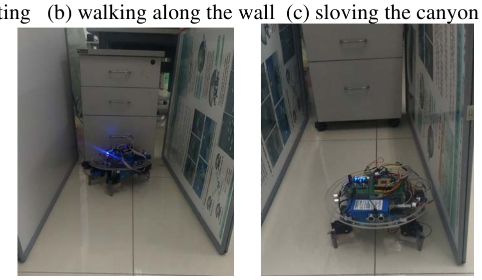
B. The Obstacle Avoidance Experiments of the Spherical Mobile Robot

Because the fuzzy obstacle avoidance behavior also includes obstacle avoidance behavior, walking along the wall behavior, cruising behavior and crossing narrow road behavior, trending to the target behavior and solving the deadlock behavior, thus an experimental environment as shown in Fig. 10(a) was designed to the start point in the laboratory. Various behaviors cooperate with each other. At a suitable moment, a certain behavior acquires the membership of the spherical mobile robot through the competition mechanism, and eventually controls the spherical mobile robot to reach the target position smoothly. In Fig. 10(b) the spherical mobile robot was in the cruising state; In Fig. 10(c), the spherical mobile robot was switched to the obstacle avoidance behavior, avoiding the first obstacle; In Fig. 10(d)-(e), the spherical mobile robot was switched to the walking along the wall behavior and passed through the narrow road smoothly. In Fig. 10(f), the spherical mobile robot was switched to the obstacle avoidance behavior and avoiding two obstacles continuously. In Fig. 10(h)-(i), the spherical mobile robot found the target point and switched to the trending to target behavior that the target point is determined by GPS. Finally, by analyzing and calculating the collected data, the error value is less than 5%, which further verifies the stability of the fuzzy control system.

VI. Conclusions

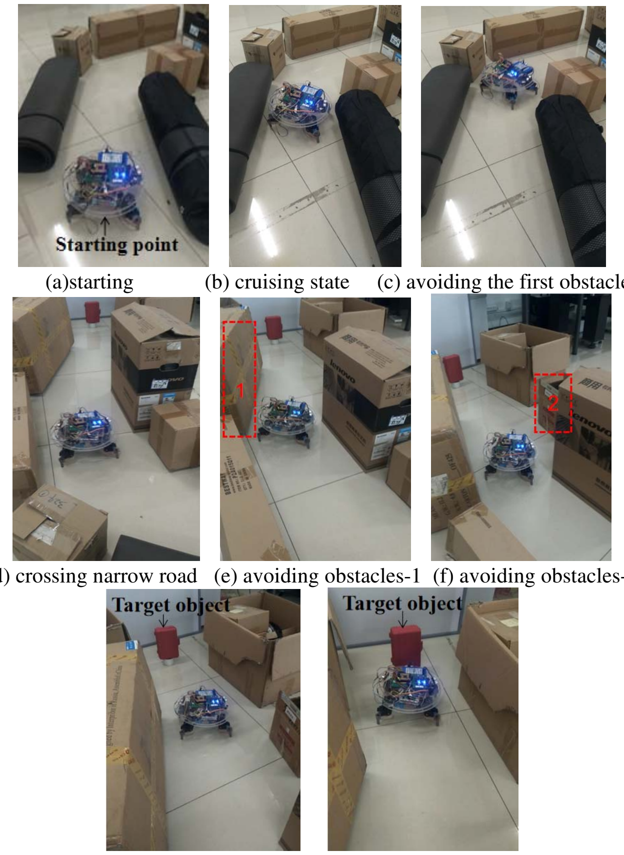
To improve the adaptability of the spherical robot in unknown environment, this paper proposed the behavior-based fuzzy control method. Firstly, the kinematics equation of the

(a)starting (b) walking along the wall (c) sloving the canyon effect-1



(d) sloving the canyon effect-2 (e) leaving the concave obstacles

Fig. 9 The experimental result of spherical mobile robot in concave obstacles.



(a)starting (b) cruising state (c) avoiding the first obstacle

(d) crossing narrow road (e) avoiding obstacles-1 (f) avoiding obstacles-2

(h) trending to the target (i) reaching the target point

Fig. 10 The experimental results of the spherical mobile robot.

driving leg based on the operational model of the spherical mobile robot was established. Next, the fuzzy control system was designed, which combined with the priority decision-making to complete the behavior control method of the spherical mobile robot. The trending to target motion was the leading behavior when there are no obstacles, and the obstacle avoidance was the leading behavior when there are obstacles. The spherical mobile robot completed the path planning by switching various behaviors. To verified the rationality and reliability of the behavior-based fuzzy control method, the MobotSim software platform completed obstacle avoidance experiments, including walking along the wall, simple obstacles avoidance and complex obstacles avoidance. Finally, the path planning experiments of the spherical mobile robot was carried out in the unknown environment. The experimental results showed that the designed fuzzy control system enabled the spherical mobile robot to reach target position successfully, which further verified the effectiveness of the behavior-based fuzzy control method.

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REFERENCES

[1] Abdalla Turki Y, Abed Ali A, Ahmed Alaa A, et al, "Mobile Robot Navigation Using PSO-optimized Fuzzy Artificial Potential Field with Fuzzy Control," *Journal of Intelligent & Fuzzy Systems*, vol. 32, no.6, pp.3893-3908, 2017.

[2] Marwah Issa Salim Al-Rawahi, Ruqaya Said Salim AL-Khayari, Munaf Salim Najim Al-Din, "Reactive Mobile Robot Navigation Using Fuzzy Controller," *National Symposium on Engineering Final Year Projects*, 2017.

[3] Zhang Lin, Liu Rong, Wang Yongxuan, et al, "Mobile Robot Navigation Based on Shared Control of Fuzzy Discrete Event System," *IEEE, IEEE International Conference on Control & Automation*, pp.711-715, 2014.

[4] Vinod Kapse, Bhavana Jharia, Thakur S. S, et al, "Design of Analog Fuzzy Controller for Autonomous Mobile Robot," *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, vol. 25,no.3, pp.477-494, 2017.

[5] Elkari Badr, Ayad Hassan, Kari Abdeljalil El, et al, "A New Approach of Fusion Behavior-Based Fuzzy Control for Mobile Robot Navigation," *International Review of Automatic Control*, vol.10,no.1,pp.13, 2017.

[6] Patle B.K., Pandey Anish, Jagadeesh A., Parhi D.R., "Path Planning in Uncertain Environment by Using Firefly Algorithm," *Defence Technology,* vol. 14, no.06, pp.51-61, 2018.

[7] Zhao Xudong, Shi Peng, Zheng Xiaolong, "Fuzzy Adaptive Control Design and Discretization for a Class of Nonlinear Uncertain Systems," *IEEE Transactions on Cybernetics*, vol. 46, no.6,pp.1476-1483, 2016.

[8] Jiazhen Chen, Ping Ye, Hanxu Sun, et al, "Design and Motion Control of a Spherical Robot with Control Moment Gyroscope," *International Conference on Systems and Informatics IEEE*, 2017.

[9] Yanlin He, Lianqing Zhu, Guangkai Sun, Junfei Qiao, Shuxiang Guo, "Underwater motion characteristics evaluation of multi amphibious spherical robots," *Microsystem Technologies*, vol. 25,no.2, pp.499-508, DOI: org/10.1007/s00542-018-3986-z, 2019.

[10] Yanlin He, Shuxiang Guo, Liwei Shi, Huiming Xing, Zhan Chen, Shuxiang Su, "Motion Characteristic Evaluation of an Amphibious Spherical Robot," *International Journal of Robotics and Automation*, DOI: 10.2316/J.2019.206-5399, 2019.

[11] Xihuan Hou, Shuxiang Guo, Liwei Shi, Huiming Xing, Yu Liu, Huikang Liu,Yao Hu, Debin Xia and Zan Li, "Hydrodynamic Analysis-Based Modeling and Experimental Verification of a NewWater-Jet Thrusterfor an Amphibious Spherical Robot," *Sensors*, vol. 19, no.259, DOI: 10.3390/s19020259, 2019.

[12] Shuoxin Gu, Shuxiang Guo, "Performance Evaluation of a Novel Propulsion System for the Spherical Underwater Robot (SUR III)," *Applied Sciences*, vol. 7, no.11, DOI:10.3390/app7111196, 2017

[13] Shixiong Li, Qiang Yuan, "The Study of Robot Obstacle Avoidance Based on Fuzzy Control," *Applied Mechanics and Materials*, vol. 577, pp.386-389,2014.

[14] Mohamed Boumehraz, Zineb Habba, Rafia Hassani, "Vision Based Tracking and Interception of Moving Target by Mobile Robot Using Fuzzy Control," *Journal of Applied Engineering Science & Technology*, vol. 4, no.2,pp.159-165,2018.

[15] Aissa Bencherif, Fatima Chouireb, "Adaptive Neuro-fuzzy Control for Trajectory Tracking of a Wheeled Mobile Robot," *IEEE, International Conference on Electrical Engineering*, pp.1-4, 2016.

[16] Yen Chihta, Cheng Mingfeng, "A Study of Fuzzy Control with Ant Colony Algorithm Used in Mobile Robot for Shortest Path Planning and Obstacle Avoidance," *Microsystem Technologies*, pp.1-11, 2016.

[17] Jyunyu Jhang, Chengjian Lin, Chinteng Lin, "Navigation Control of Mobile Robots Using an Interval Type-2 Fuzzy Controller Based on Dynamic-group Particle Swarm Optimization," *International Journal of Control, Automation and System*, vol. 16,no.5,pp.2446-2457, 2018.

[18] Abdessemed Foudil, Faisal Mohammed, Emmadeddine Muhammed, "A Hierarchical Fuzzy Control Design for Indoor Mobile Robot," *International Journal of Advanced Robotic Systems*, vol. 11,no.1,pp.415-429, 2014.