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INTELLIGENT OBSTACLE AVOIDANCE WHEELCHAIR BASED ON FUZZY REASONING

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Abstract. *The aged are more likely to make mistakes when operating electric wheelchairs than young people. Especially when driving in a complex environment, it can even cause accidents. In this case, this paper proposes an obstacle avoidance method based on fuzzy reasoning considering the intention of the user simultaneously. In terms of hardware, a variety of sensors mounted on wheelchairs can obtain the distance information of obstacles in the environment, and the collected data can be processed in real time through fuzzy algorithm to obtain the direction of obstacle avoidance. The user controls the joystick to express the expected direction. Finally, the expected direction is weighed to obtain a safe obstacle avoidance path that satisfies the user's intention to the greatest extent. The experimental result demonstrates that the design of intelligent obstacle avoidance wheelchair based on fuzzy reasoning is effective and achieves the desired goal.*
Keywords: Obstacle avoidance, Fuzzy reasoning, Intelligent wheelchair

1. **Introduction.** As the number of elderly and lower extremity disabled patients increases, the demand for walking tools such as electric wheelchairs is increasing. At the same time, electric wheelchairs are increasingly combined with mobile robot technology [1-3], becoming intelligent wheelchairs. Considering that intelligent wheelchairs are for the elderly and patients with lower limb disability. This group has the following main characteristics: poor physical coordination, slow response, cognitive decline, in the operation of electric wheelchairs due to slow response, emotional anxiety caused by misoperation. Coupled with the complexity of the environment, the occurrence of random conditions, it is easy to cause accidents. For the sake of safety, it is important to study the obstacle avoidance strategy.

In the previous research, the obstacle avoidance strategy of the intelligent wheelchair is single, and the driving direction that can safely avoid obstacles is determined only by the position of obstacles in the external environment. At present, the research on the obstacle avoidance strategy of intelligent wheelchair is more diversified, mainly focusing on the control method, machine vision, planning and navigation, information fusion and so on. Sinyukov et al. [4] proposed a hardware and software control framework for a semi-automatic wheelchair. Obstacle avoidance is realized through auxiliary control and semi-autonomous navigation. Khalilullah et al. [5] studied a robot obstacle avoidance method based on machine vision. In the process of obstacle avoidance, the robot uses the estimated parameters of the calibrated camera to measure the distance from the position of the obstacle, so as to realize the obstacle avoidance function. Alshraideh et al. [6] proposed a robot capable of self-direction and speed control, which uses navigation technology to avoid obstacles and safely deliver the elderly or patients to their destinations. Utaminingrum et al. [7] proposed an obstacle distance estimation method, which uses a

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combination of camera and laser line to identify obstacles in the environment at a certain angle according to the laser line. Thus, the distance between the wheelchair and the obstacle can be estimated to avoid obstacles.

According to the above research status of the obstacle avoidance function of intelligent wheelchair, the obstacle avoidance function has been widely used and involved in the intelligent wheelchair, but there are few researches on the obstacle avoidance strategy considering the user's intention in the process of obstacle avoidance. In the specific process of obstacle avoidance, such problems often occur. If the wheelchair adjusts the driving state completely according to the obstacle environment during the obstacle avoidance process, it will ignore or even violate the user's individual will in many cases, which will cause the user to feel frustrated and forced, which will reduce the comfort level. Therefore, this paper aims to propose an obstacle avoidance strategy which can make the intelligent wheelchair consider the user's intention in the process of performing the obstacle avoidance function. Make the intelligent wheelchair in the process of obstacle avoidance on the basis of ensuring safety can take account of the user's intention direction, which is of great significance to improve the safety and comfort of the intelligent wheelchair.

2. **Problem Statement and Preliminaries.** The wheelchair-wheeled mobile robot of the research institute is selected as the experimental platform, as shown in Figure 1.

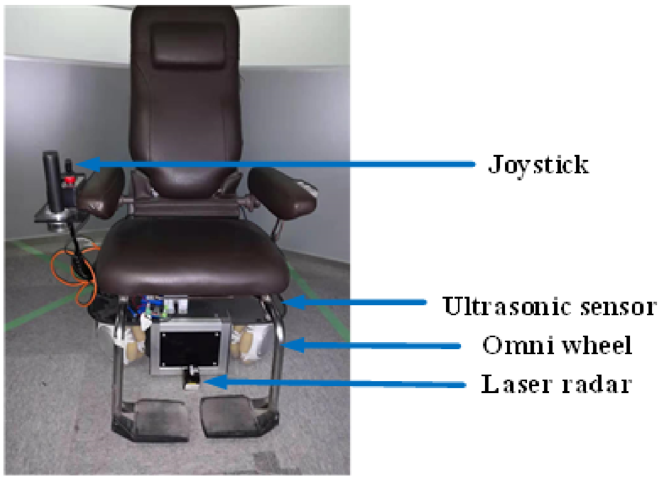

FIGURE 1. Physical picture of wheelchair robot

Electric wheelchairs are equipped with joysticks that allow the user to determine the direction of travel. The obstacle distance information in the environment is obtained by a combination of ultrasonic sensors and lidar. The base part uses the omni-directional wheel as the power system of the wheelchair and reserves the secondary development interface to communicate the data of the upper and lower computers. Schematic diagram of data exchange between upper computer and lower computer is shown in Figure 2. Set to 5 cycles per second, the lower computer reads the data and sends it to the upper computer, which then sends the instructions to the lower computer for execution.

The motorized wheelchair does not have an obstacle avoidance function. To realize the obstacle avoidance function, an appropriate algorithm is needed to establish the control model in the upper computer. In this process, there are many kinds of data to be processed, with complex characteristics and huge amount. It is difficult to establish accurate mathematical model, so the fuzzy reasoning method [8-10] is selected to realize obstacle avoidance function.

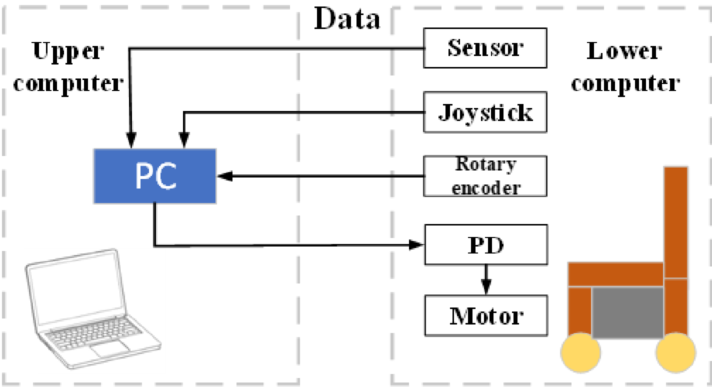

FIGURE 2. Data exchange diagram

3. Methodologies.

3.1. Obstacle avoidance based on fuzzy reasoning. The key point of this paper is that the development of an obstacle avoidance method based on fuzzy reasoning considering the intention of the user simultaneously. Multiple ultrasonic sensors mounted on the wheelchair can obtain the distance information of obstacles in the environment and process the collected data in real time through fuzzy algorithm to obtain the obstacle avoidance direction. The user controls the joystick to express the expected direction. Figure 3 shows the decision flow chart of the system.

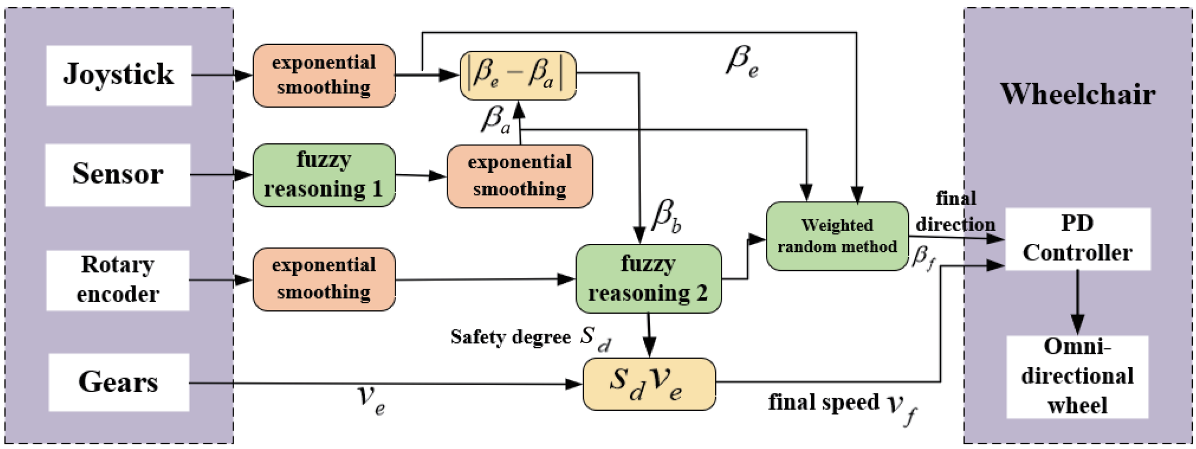

FIGURE 3. The execution flow of fuzzy reasoning and mathematical models

As shown in Figure 3, the distance data are input into fuzzy reasoning 1 to obtain the obstacle avoidance direction β_a. Obstacle avoidance direction is the safe driving direction obtained by fuzzy reasoning 1 based on the position of the obstacle. Sometimes it is not always the direction that user wants to drive. User can reflect the desired direction by controlling the joystick, which is called the expected direction and is represented by the symbol β_e. Based on essential safety, the expected direction is considered, and the concept of safety degree is introduced. Safety degree is determined by fuzzy reasoning 2. The safety degree s_d is the coefficient of random weight method. The final direction of the wheelchair is given by Formula (1):

$$\beta_f = s_d\beta_e + (1 - s_d)\beta_a \tag{1}$$

The expected speed ν_e of the wheelchair is determined by the different positions set by the buttons, such as 0.5 meters per second for high speed and 0.1 meters per second for low speed. The final speed ν_f of the wheelchair is given by Formula (2):

$$\nu_f = s_d \nu_e \tag{2}$$

With the change of safety degree, obstacle avoidance process is also completed. In this process the expected direction is taken into account to varying degrees. It is important to note here that both the ultrasonic data and the joystick data are exponentially smoothing.

3.2. **Data acquisition and processing.** The sensor and joystick data are sampled at a frequency of five times a second in the upper computer, so the discrete data is obtained. The user's orientation intention is expressed by manipulating the wheelchair with a joystick, and sometimes interference data is generated due to misoperation. In order to solve this problem, we need to process the collected data in the exponential smoothing [11].

$$S_t = \alpha\beta_t + (1-\alpha)S_{t-1} \tag{3}$$

Due to the large fluctuation of data, in order to retain the time series information S_{t-1} per second while taking account of the timeliness, the value of smoothing coefficient α should be larger, and the value is 0.7. β_t is the measurement at the present moment. S_t is the value for fuzzy reasoning.

3.3. **Fuzzy reasoning 1.** The intelligent wheelchair to achieve obstacle avoidance function, collecting environmental information is very important, only on the environment of the obstacles have a comprehensive grasp, in order to ensure the completion of subsequent functions. Environmental detection requires the selection of appropriate sensors and installation methods. Here, ultrasonic sensor and lidar are combined. Figure 4 shows a schematic diagram of the placement of ultrasonic sensors and lidar.

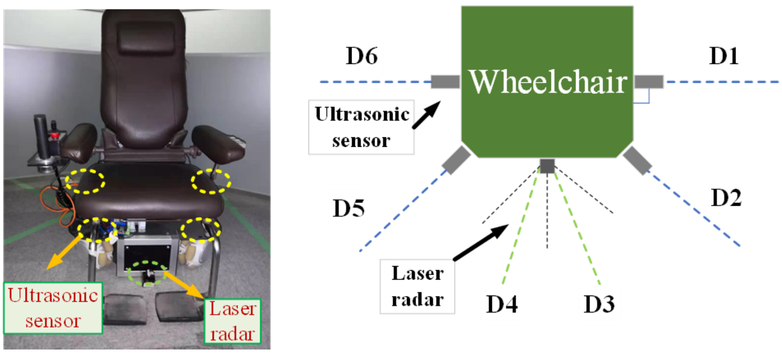

FIGURE 4. Diagram of sensor placement

The symbols in the picture above are D1, D2, D3, D4, D5, D6 which represent the six distances measured by the sensor in the corresponding direction. D1, D2, D5, and D6 are the distances measured by ultrasonic sensors. D3, D4 are the distances measured by the laser radar. The schematic diagram of the lidar is shown in Figure 5. The schematic diagram of the ultrasonic sensor is shown in Figure 6.

The section marked yellow in Figure 5 is the sector of the lidar to be used. The shortest distance detected in sector 1 is D3. The shortest distance detected in sector 2 is D4. The lidar can measure the range between 60 mm and 4096 mm, and the measurement range is 240 degrees. Ultrasonic sensor in Figure 6 has the characteristics of short wavelength, high frequency, small diffraction phenomenon and good directionality, and can become ray and directional propagation. The ultrasonic sensors can detect the range of 50 mm to 3152 mm.

Six precise distances are measured by ultrasonic sensors and lidar (D1, D2, . . .). They are converted into corresponding fuzzy language variables "S" and "L", where S (Short)

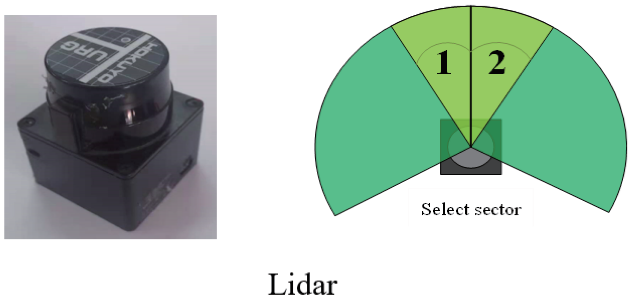

Figure 5. (color online) Diagram of lidar

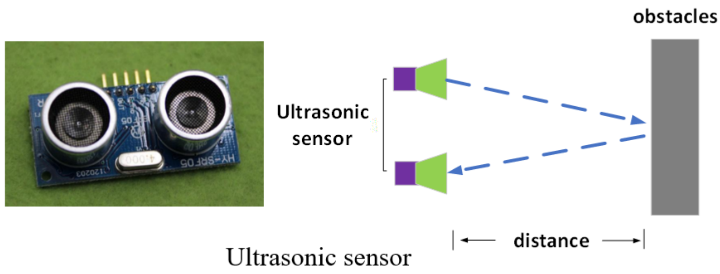

Figure 6. Diagram of ultrasonic sensor

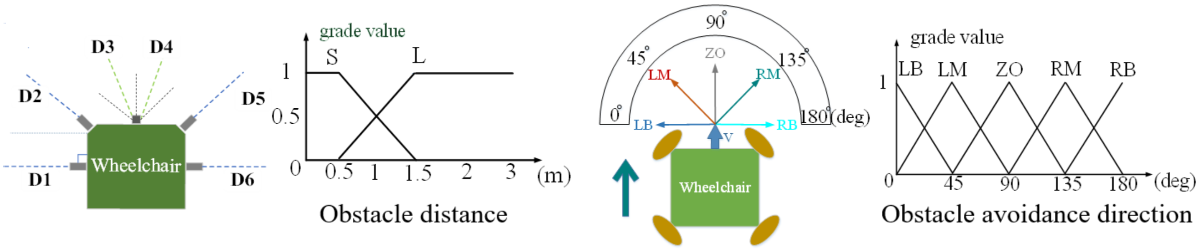

Figure 7. Fuzzy variable of obstacle distance and obstacle avoidance direction

means short distance from the obstacle and L (Long) means long distance from the obstacle. Discourse domain is the range of distance that the sensor can measure. The horizontal left direction of the wheelchair is defined as 0 degrees, and the forward direction is defined as 90 degrees. In the same way, "0" degrees, "45" degrees, "90" degrees, "135" degrees, and "180" degrees represent maximum left, left, straight ahead, right, and maximum right, respectively. Discourse domain range is 0-180 degrees. This way of describing degree is transformed into corresponding fuzzy linguistic variables "LB", "LM", "ZO", "RM" and "RB". As shown in Figure 7 is the membership function about the distance and direction of obstacles.

According to common sense experience, fuzzy rules can be established to avoid obstacles for the robot. The fuzzy rules are shown in Table 1.

Empty parts of a table are not subject to fuzzy rules. The center of gravity method is used for defuzzification.

3.4. **Fuzzy reasoning 2.** User's intention is expressed through the joystick, and the wheelchair needs to take this into account when avoiding obstacles. Therefore, the direction of wheelchair travel is the result of the balance between the direction of obstacle avoidance and the direction of the joystick. When safety is high, the direction of joystick is more followed; otherwise, the direction of obstacle avoidance is more followed.

From the perspective of human experience and common sense, wheelchair safety is related to two aspects: one is the real-time speed of the wheelchair, and the other is

TABLE 1. The fuzzy rule for reasoning 1

Obstacle distance \ Joystick						Expected direction LB	LM	ZO	RM	RB
D1	S	D2	S	D3	S	RB	RB	RB	RB	
					L	ZO	ZO			
			L		S	RB	RB	RB	RB	
					L	RM	RM			
	L		S		S		RB	RB	RB	
					L		ZO			
			L		S		RB	RB	RB	
					L					
D6	S	D5	S	D4	S		LB	LB	LB	LB
					L				ZO	ZO
			L		S		LB	LB	LB	LB
					L				LM	LM
	L		S		S		LB	LB	LB	
					L				ZO	
			L		S		LB	LB	LB	
					L					

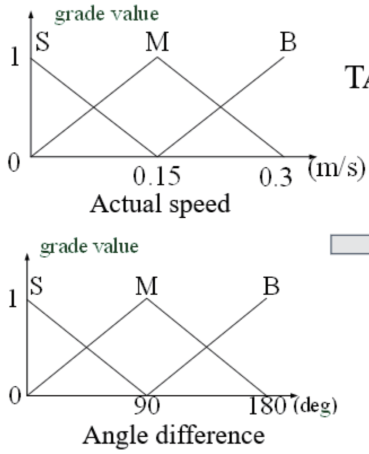

TABLE 2. The fuzzy rule for reasoning 2

v \ β_b	S	M	B
S	B	B	M
M	B	M	S
B	M	S	S

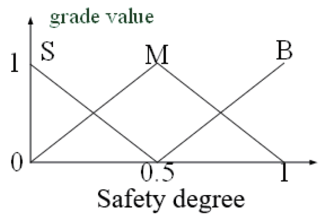

FIGURE 8. Fuzzy rule table and membership function of fuzzy reasoning 2

the difference between the direction of obstacle avoidance and the direction of the joystick. Actual speed of the wheelchair is measured by four rotary encoders. The faster the wheelchair travels, the lower the safety degree is, and the greater the difference between the direction of obstacle avoidance and the direction of the joystick is, the lower the safety degree is. Based on this common sense experience, fuzzy rules about safety degree are established. The membership function image of fuzzy rule 2 and its fuzzy rule table are shown in Figure 8.

The input variables and output variables of fuzzy reasoning 2 adopt the membership function of triangle. The fuzzy variables of input and output membership functions also adopt "B", "M" and "S", used to describe the degree of "big", "middle", and "small". The center of gravity method is used to defuzzify the data, and the center of gravity of the area enclosed by the membership function curve of the output variable and the abscissa is used as the precise output value of fuzzy reasoning.

4. **Main Results.** The obstacle avoidance strategy in this paper is verified in the laboratory electric wheelchair. In order to reflect the influence of user's intention on the obstacle

avoidance process of intelligent wheelchair, two typical cases were selected for the experiment. Test one is that the user puts the joystick in the 90 degree direction in front of the wheelchair during the whole process of avoiding the obstacle, and the user's intention is only to drive vertically. Test two is that in the process of wheelchair obstacle avoidance, the user's joystick direction will be inclined to obstacles, which may be misoperation or the user does not need a large distance to avoid obstacles.

Figure 9 shows a schematic diagram of the trajectory of test one and test two. Figure 10 shows a data image of the expected direction, actual direction and safety degree during

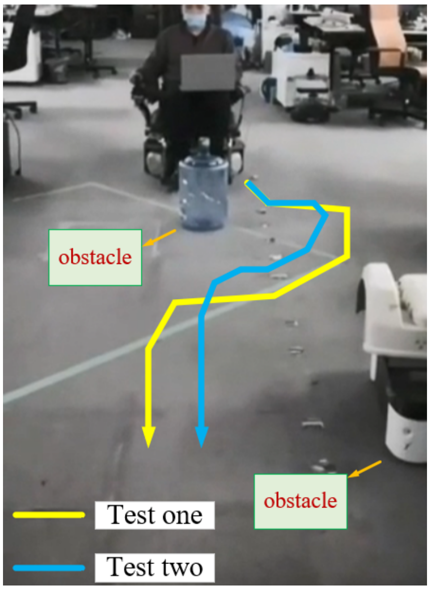

Figure 9. Trajectory diagram

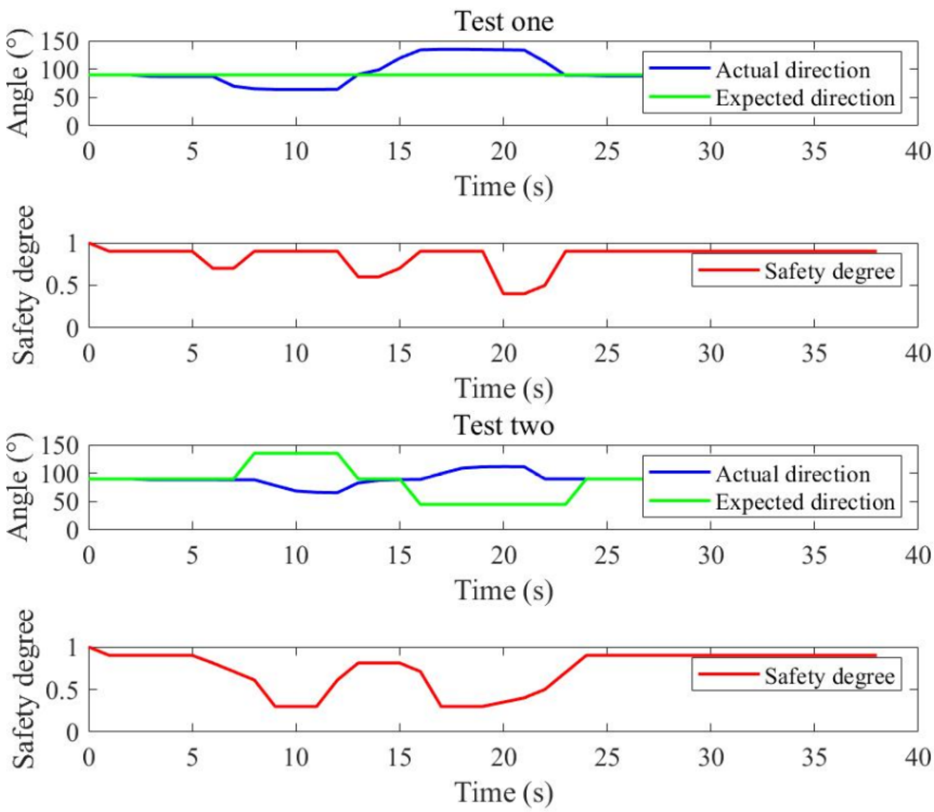

Figure 10. Variation of relevant data

obstacle avoidance. According to the experimental results, wheelchairs can avoid obstacles safely in both cases. In test two, the expected direction and obstacle avoidance direction are opposite. The wheelchair shortens the distance of obstacle avoidance on the basis of safety obstacle avoidance. It can be seen from this result that the wheelchair considers the intention of the operator in the process of obstacle avoidance, reduces the turning direction and shortens the obstacle avoidance distance. This can avoid accidents caused by misoperation.

As expected, the intelligent wheelchair can take the operator's intention into account while safely avoiding obstacles. The direction of travel of the intelligent wheelchair is the result of the tradeoff between the direction of avoiding obstacles and the direction of the joystick.

5. **Conclusions.** In this paper, a design scheme of intelligent wheelchair is proposed aiming at respecting the user's personal wishes when it avoids obstacles, and corresponding experiments are carried out. The experimental result demonstrates that the design of intelligent obstacle avoidance wheelchair based on fuzzy reasoning is effective and achieves the desired goal. There is still a lot to be done, and we are currently working on new ways of perceiving user intent, and how to make the wheelchair more fit the user's individual characteristics, so that the user is more comfortable.

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