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Object Following Fuzzy Controller for a Mobile Robot

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Numerous approaches have been demonstrated to move the mobile robot in an unknown environment. Mostly, sensor-based approaches have been presented for the collision avoidance and implemented on the robots. We propose to implement a tracking system in the mobile robot, which takes the decisions autonomously, with collision avoidance. This paper proposes an approach, which utilizes fuzzy logic controller (FLC) to handle uncertain input data from the sensors, for the object tracking. To this end, FLC selects behavior from the range data at each step and generates output instructions to accelerate the robot wheels. A constant distance is maintained between the robot and the object. The efficiency of the robot is improved by increasing smoothness in motion and by achieving accurate tracking. The simulation and experimental outcomes indicate better adaptability of the robot under various environment conditions. Under the proposed approach, the robot attained the desired turn angle precisely and gained the same speed as that of the followed object.

Keywords: Navigation, Object Tracking, Collision Avoidance, Sensor, Fuzzy Logic Controller.

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1. INTRODUCTION

To move in an uncertain environment, the mobile robot must get information of the surrounding through the sensors, the positioning systems, and the cameras. Numerous behaviors have been designed to extract the environment features from the attained information. Different techniques have been demonstrated for the navigation and implemented on the robots.[1–3] We implemented our proposed system on the wheeled robot because they are easier to control.

The focus of this study is to design an object following mobile robot, which is based on fuzzy logic approach. Fuzzy logic controller (FLC) has a linguistic based architecture. Its processing ability is relatively vigorous for the non-linear systems. FLC is selected due to its capability of controlling the ambiguous data delivered by the sensors in an efficient way, and it handles the data in a very natural way. This system can be established much faster because its parameters can be initialized briskly. FLC has been found a number of applications in the industry and to control the robots. The main disadvantage of the FLC is that the handling process becomes more difficult when the number of inputs and outputs are increased.

Fuzzy logic approach for the robots can deal with various situations without analytical model of environments. Recently, Many fuzzy logic based approaches have been considered for the obstacle avoidance and the path tracking.[4–6] Sensor-based map building technique for the mobile robot has been described using laser range finder.[7] Sonar based obstacle avoidance and navigation approaches has been demonstrated.[8,9] In some cases, simple binary logic controllers were used in the mobile robots.[2] However, they do not give better performance to handle complex data. Therefore, our main purpose is to increase the efficiency of the robot using FLC.

Fuzzy logic system (FLS), which is a non-linear system, maps an input vector into a scalar output.[10] FLC holds four portions: fuzzification, rule base, inference system, and defuzzification. It receives the distance information from the ultrasonic sensors. This information is the crisp input used for the fuzzification to make appropriate membership functions. Rules are established by consulting the input and the output data. The interface system generates the result for each rule, and the crisp output is obtained by the defuzzification. The proposed method can be easily implemented because a small number of rules are employed to decide the action. Control actions are performed to generate commands for the DC (direct current) and servo motors. DC motors are used in many applications due to their simplicity and the control characteristics.

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The proposed FLC navigates the mobile robot behind the object by controlling the distance between them. It guarantees the stability of the robot.

This paper is organized as follows: Section 2 explains the methodology of the object tracking; Section 3 gives a description and actual implementation of the proposed FLC. Simulation and experimental results are discussed in Section 4. Finally, conclusions and directions for the future work are summarized in Section 5.

2. OBJECT TRACKING

To follow the object, the robot must require range measurements in different directions to find position of the object. The robot is equipped with three ultrasonic sensors at the front. The middle sensor gives the range information for the forward and backward movement. Likewise, other two sensors give the range data for the left and right movement. Each sensor has two main parts: transmitter and receiver. In this robot, ultrasonic transmitters are fixed above the receivers to detect horizontal movement. Ultrasonic sensors are preferred because they offer simple operations and high accuracy with low cost.

We assumed distance for near below 30 cm, medium between 30–60 cm, and far between 60–90 cm, as shown in Figure 1. To control the forward and backward movement, two parallel wheels were connected with the DC motor on the back side of the robot. Similarly, front wheels were driven through the servo motor to move the robot in the desired direction. The measured distance from the ultrasonic sensors was divided into three regions: near, constant, and far.

For example, if the sensors detected the object in the constant region, the robot moved to the forward direction. Similarly, if the left sensor detected the object in the near region, middle sensor detected the object in the constant region, and right sensor detected the object in the far region, the robot moved forward in the right direction. If the robot did not detect the object through the sensors, the robot was stopped. The object may be detected at the near, constant, or far position through the each sensor. Therefore, nine different situations were described depending upon the position of the object, as shown in Figure 2.

Overview of the object tracking system using fuzzy logic is shown in Figure 3. Initially, ultrasonic sensors determined the position of the object. The decision was made that whether the object was beyond the distance, or was moving in the measureable distance. This decision was further checked in such a way that the obstacle was at the constant distance, below the constant distance, or above the constant distance. Fuzzy operations were performed on the range data, and the final output was obtained. Finally, Commands were sent to the DC and servo motors.

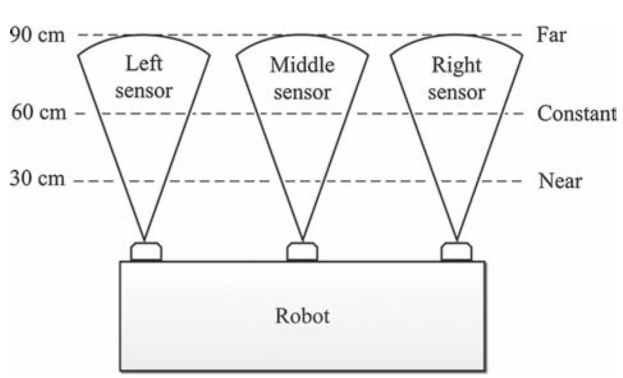

Fig. 1. Robot with the ultrasonic sensors showing different ranges.

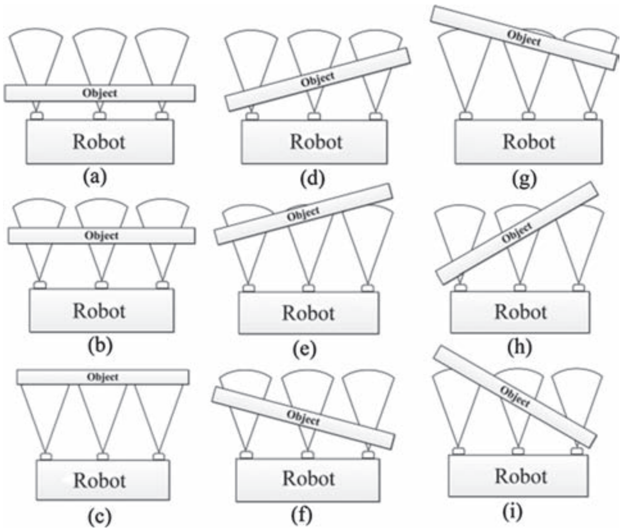

Fig. 2. Robot with different obstacle environments.

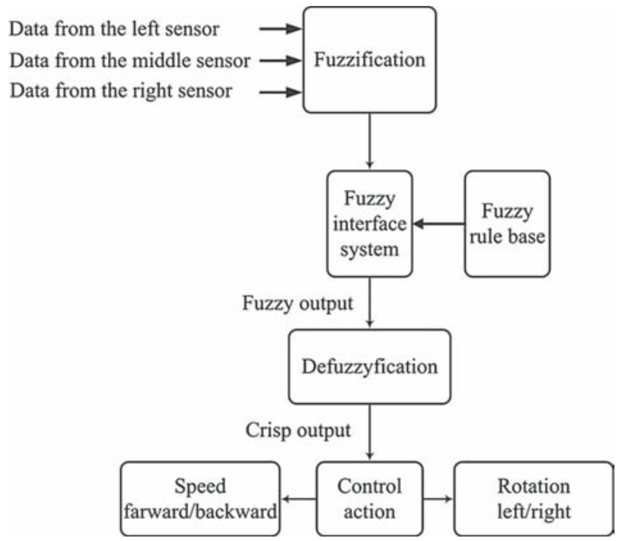

Fig. 3. Overview of the object tracking system.

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3. FUZZY LOGIC CONTROLLER

The proposed FLC had three inputs: left sensor, middle sensor, and right sensor. These inputs were defined by three fuzzy sets: near, constant, and far. In Figure 4, we show membership functions for the linguistic variable, left-sensor, which was decomposed into near, constant and far. The degree of membership is represented on the vertical line, and values are on the horizontal line. The membership functions for the sensors are identical. We might interpret that near to the object close to zero, constant to the object close to 50, and far to the object close to 100. The amount of membership functions is based on the number of inputs and outputs. Better resolution can be achieved by using more membership functions at the price of large computational load. Due to the limited computational resources of the microcontroller, triangular membership function was preferred.

The linguistic variable, servo-motor, was decomposed into three fuzzy sets: leftward, straight, and rightward, as illustrated in Figure 5. The second linguistic variable, DC-motor, for the output of the FLC was demonstrated by three fuzzy sets: back, medium, and fast, as mentioned in Figure 6. The membership functions can be defined by

$$\mu_{\mathrm{S_L,\,NEAR}} = \begin{cases} -2l_S + 100 & 0 \le l_S \le 50 \\ 0 & l_S \ge 50 \end{cases} \tag{1}$$

$$\mu_{\mathrm{S_L,\,CONS}} = \begin{cases} 2l_S & 0 \le l_S \le 50 \\ -2l_S + 100 & 50 \le l_S \le 100 \end{cases} \tag{2}$$

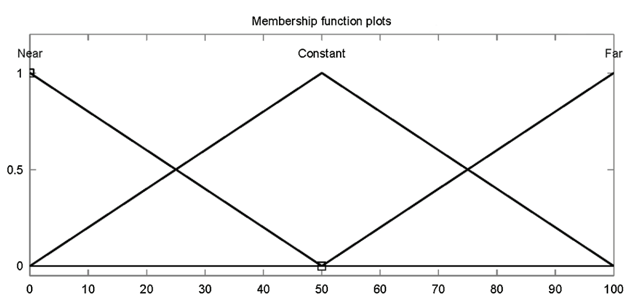

Fig. 4. Input membership functions for the left sensor.

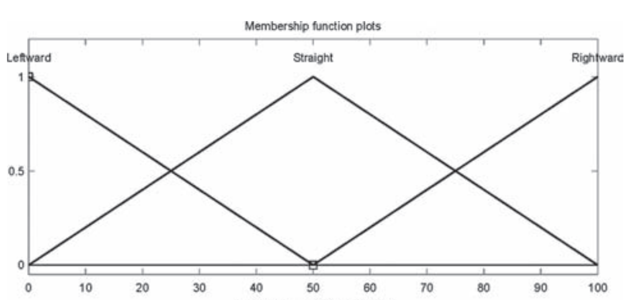

Fig. 5. Output membership functions for the servo motor.

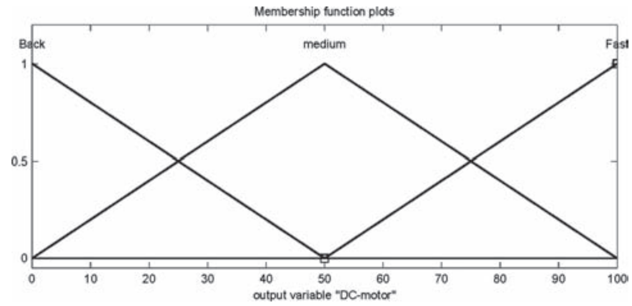

Fig. 6. Output membership functions for the DC motor.

$$\mu_{\mathrm{S_L,\,FAR}} = \begin{cases} 2l_S - 100 & 50 \le l_S \le 100 \\ 0 & l_S \ge 100 \end{cases} \tag{3}$$

The range of the linguistic variables in the universe of discourse is ranging between 0–100. To calculate the consequent part of the each rule, Mamdani's fuzzy reasoning method was preferred, which comprises simple min-operation and max-operation. To obtain better result, fuzzy rules were conducted through different experiments and improved by a number of tests. Fuzzy rules were accumulated containing OR operator and collection of IF-THEN statements. Rule base for the servo motor containing the left and right sensors as input is described in Table I. In Table II, rule base for the DC motor containing middle sensor as an input is illustrated. Center of gravity (COG) method has been confirmed to give accurate and efficient results.[11] In the proposed FLC, COG method was followed for the defuzzification. It can be expressed by[12]

$$Z_{\mathrm{a}} = \frac{\int \mu_C(Z) \cdot Z d_Z}{\int \mu_C(Z) d_Z} \tag{4}$$

where Z_a is the defuzzified output, $\mu_c(Z)$ is the degree of membership, and Z is the output variable.

4. EXPERIMENTS AND RESULTS

Simulation was performed using MATLAB™ Fuzzy Logic Toolbox. The Input (left sensor, middle sensor, and right

Table I. Rule base for the servo motor.

	Left sensor		
Right sensor	Near	Constant	Far
Near	Straight	Leftward	Leftward
Constant	Rightward	Straight	Leftward
Far	Rightward	Rightward	Straight

Table II. Rule base for the DC motor.

	Middle sensor	
Near	Constant	Far
Back	Medium	Fast

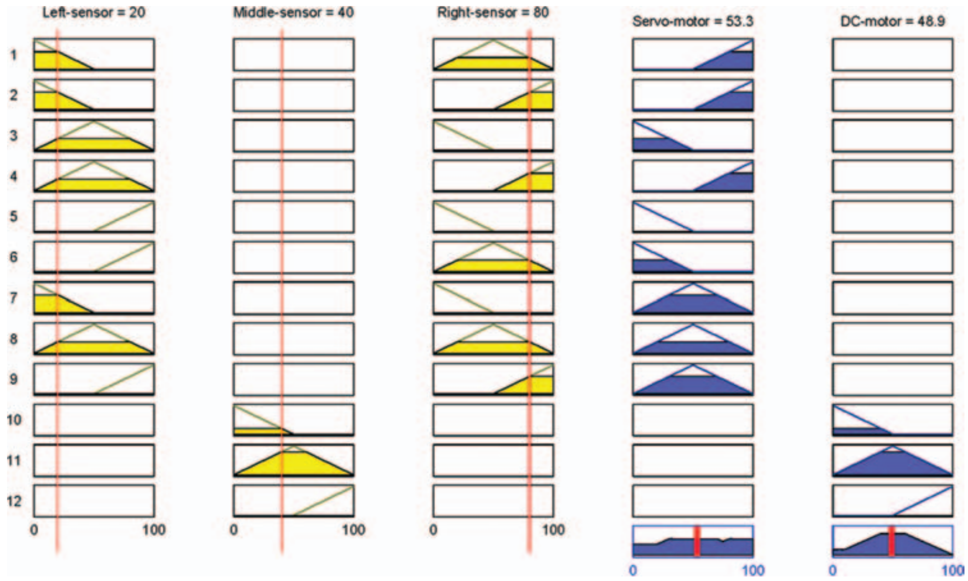

Fig. 7. Implication and defuzzification process.

sensor) and output (DC motor and servo motor) membership functions were defined to achieve the defuzzified output value, where the left sensor determines the near, the middle sensor determines the constant, and the right sensor determines the far. As a result, the robot started to move in the right direction to follow the object with the medium speed. Implication and defuzzification process are shown in Figure 7. A control surface is drawn to see the dependency of the output on the inputs, as illustrated in Figure 8.

Configuration of the mobile robot and the working environment is shown in Figure 9. To test the robot, a vehicle was moved in front of the robot. The robot followed the vehicle by maintaining a constant distance from it. We varied the speed of the followed vehicle, and the robot accurately tracked the vehicle. The robot was monitored by changing the movement of the followed vehicle

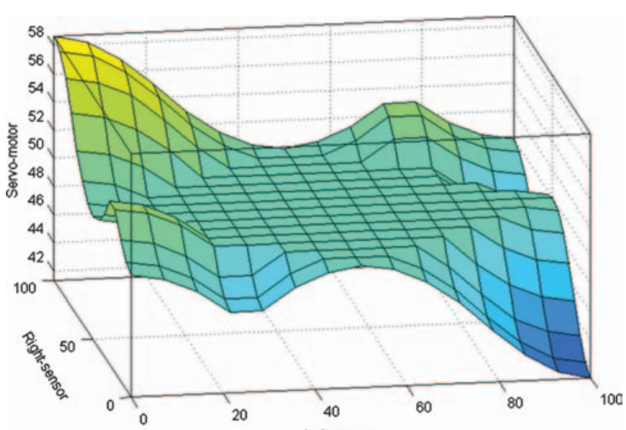

Fig. 8. Output surface map representing the dependency of the output (servo motor) on the inputs (left sensor and right sensor).

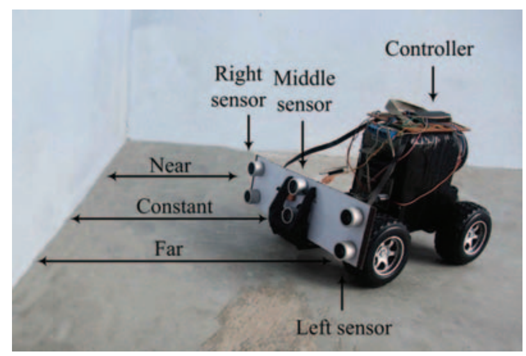

Fig. 9. Configuration of the object following mobile robot.

in the forward and backward directions. The robot was also tested by different experiments with different obstacle environments (Fig. 2). The robot followed the object by achieving the desired turning angle properly and attained the speed (forward and backward) very smoothly. Overall, the robot was able to perform tracking and security actions in an efficient way. The experimental results have demonstrated that the FLC can handle well the uncertain data, and can make decision in a very natural way.

5. CONCLUSIONS

In this study, the design and implementation of the object following wheeled mobile robot has been presented. The conventional binary logic controller does not show appropriate performance to drive the DC and servo motors from the uncertain data. To this end, we have developed FLC, which handles the data in a very natural way. The proposed method enables the mobile robot to track the object without collision. It has been verified from the experiments that it maintains the predefined constant distance from the object. Finally, simulation and experimental outcomes have displayed the authenticity of the proposed FLC.

In the future, we will enhance the performance of the controller by introducing more sensors and a separate control unit to identify the followed object.

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