Real-time Object Following Fuzzy Controller for a Mobile Robot

Irfan Ullah[1], Furqan Ullah[2], Qurban Ullah[3]
[1]Department of Electrical Engineering, COMSATS Institute of Information Technology, Lahore, Pakistan
[2]Department of Mechanical Engineering, Myongji University, Yongin, South Korea
[3]Department of Computer Science and Information Technology, Virtual University of Pakistan
[1]irfan752@live.com, [2]furkan@mju.ac.kr, [3]qurbanullah@hotmail.com

***Abstract*— This paper presents an object following wheeled mobile robot in which fuzzy logic controller is utilized to handle uncertain input data from three ultrasonic sensors. A maintenance system selects behaviour from the range data at each step so that the mobile robot can move behind the object by keeping the distance constant. The proposed model is attested in an environment containing moving objects. The experimental and simulation outcomes indicate better adaptability, attain the desired turn angle precisely, and adopt the same speed as that of the followed object.**

***Keywords*— Navigation, Object following robot, Fuzzy logic controller, Motion control, Ultrasonic sensors**

I. INTRODUCTION

To move in an uncertain environment, the mobile robot must get information of surrounding by using sensors, positioning systems, and cameras. Numerous behaviors have been designed to extract the environment features from attained information. Different techniques have been presented for navigation and implemented on the robots. 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 based on fuzzy logic controller (FLC); FLC has a linguistic based architecture and its processing ability is relatively vigorous for non-linear systems. FLC has been chosen because of its capability to control the ambiguous data; delivered by the sensors and handle it 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. A main disadvantage of FLC is that the handling process becomes more difficult when the number of inputs and outputs are increased. Fuzzy logic system (FLS) maps an input vector into a scalar output; it is a nonlinear system [1]. FLC holds four portions: fuzzification, rule base, inference system, and defuzzification. FLC receives distance information from three ultrasonic sensors which is crisp input used for fuzzification to make the appropriate membership functions; rules are established by consulting input and output data. The interface system generates the result for every rule and crisp output is obtained by defuzzification; afterward, control actions are performed to generate commands for the DC and servo motors. DC motors have been mounted in many applications due to their simplicity and control characteristics. The proposed FLC navigates the mobile robot behind the object by controlling the distance between them and guarantees the stability of the system.

Many fuzzy logic based methods have been considered for obstacle avoidance and path tracking. Sensor based map building technique for a mobile robot is described by using laser range finder in [2]; sonar based obstacle avoidance and navigation approach are presented in [3]. A number of fuzzy approaches have been introduced with mobile robots [4], [5]; the mobile robot navigation approach was also described using fuzzy logic controller in [6], [7]. The remaining paper is prepared as follows: Section II explains the methodology of the object following mobile robot; Section III gives a description and actual implementation of the proposed fuzzy controller. Simulation results, experiments, and comparing the performance of the newly proposed fuzzy controller with simple binary controller are presented in Section IV. Finally the conclusions and directions for future work are mentioned in Section IV.

II. IMPLEMENTATION OF OBJECT FOLLOWING ROBOT

This work presents a study of a Fuzzy Logic based object following mobile robot. In order to follow the object, the robot must require range measurements in different directions to find position of the object; thus, the robot is equipped with three ultrasonic sensors at the front. The middle sensor gives the range information for forward and backward movement; likewise, other two sensors give the range data for the left and right movement. Every sensor has two main parts: transmitter and receiver; ultrasonic transmitters are fixed above the receivers. Due to this arrangement, the following robot is able to determine the object size. Ultrasonic sensors are preferred as those offered simple operation, more accuracy, and low cost. We assumed distance for near below 30-cm, medium from 30-cm to 60-cm, and far between 60-cm to 90-cm. To control forward and backward movement, two parallel wheels are connected with DC motor on back side of the robot; similarly, front wheels are driven by servo motor to rotate the robot in desired direction. The measured distance from ultrasonic sensors is divided into three regions: near, constant, and far. For example, if all sensors detect the object in constant region then robot will go forward; in the same way, if left sensor detects the object in near region, middle sensor detects the object in constant region, and right sensor detects the object in far region then robot will

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go forward in right direction. If no object is detected by the sensors then the robot will remain stationary. The object may be detected at near, constant, or far position by each sensor; therefore, nine different situations are described depending upon the position of the object in Fig. 1.

Initially, ultrasonic sensors would determine the position of the object; the decision would be made whether the object is beyond distance or is moving in the measureable distance. Moreover, this decision would further be checked whether that the obstacle is at the constant distance, below the constant distance, or above the constant distance. Fuzzy operations are performed on the range data and final output will be obtained. Finally, Commands are sent towards DC and servo motors. Overview of the system architecture is shown in Fig. 2.

III. FUZZY CONTROLLER DESIGN

MATLAB Fuzzy Logic Toolbox is used to design the object following fuzzy logic controller. FLC has three inputs: left sensor, middle sensor, and right sensor; these inputs are defined by three fuzzy sets near, constant, and far. Fig. 3 depicts membership functions for linguistic variable "left-sensor" (which is decomposed into near, constant and far); the degree of membership is represented on vertical line and values on the horizontal line. The membership functions for three sensors are identical; we might interpret 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 larger computational complication. Due to the limited computational resources of the microcontroller, triangular membership function is utilized. The linguistic variable "servo-motor" can be decomposed into three fuzzy sets leftward, straight, and rightward as illustrated in fig. 4. The second linguistic variable "DC-motor" for the output of the FLC is demonstrated by three fuzzy sets; they are back, medium, and fast as mentioned in Fig. 5. The membership functions can be defined by expressions:

$$\mu_{LEFT\text{-}SENSOR,\,NEAR} = \begin{cases} -2l_s + 100 & 0 \le l_s \le 50 \\ 0 & l_s \ge 50 \end{cases} \tag{1}$$

$$\mu_{LEFT\text{-}SENSOR,\,CONS} = \begin{cases} 2l_s & 0 \le l_s \le 50 \\ -2l_s + 100 & 50 \le l_s \le 100 \end{cases} \tag{2}$$

$$\mu_{LEFT\text{-}SENSOR,\,FAR} = \begin{cases} 2l_s - 100 & 50 \le l_s \le 100 \\ 0 & l_s \ge 100 \end{cases} \tag{3}$$

The range of linguistic variables in the universe of discourse is ranging between zero to hundred. To calculate consequent part of every rule, Mamdani's fuzzy reasoning method is 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 are accumulated containing OR operator and a collection of IF-THEN statements. The rule base for servo motor containing left and right sensors as input is described in Table 1; in Table 2 rule base for DC motor containing middle sensor as an input is shown. Center of gravity (COG) method has confirmed to give accurate and efficient results [8]. In our proposed controller COG method is followed for defuzzification. It can be expressed as:

$$Z_a = \frac{\int \mu_c(Z) \cdot Z \, dz}{\int \mu_c(Z) \, dz} \tag{4}$$

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

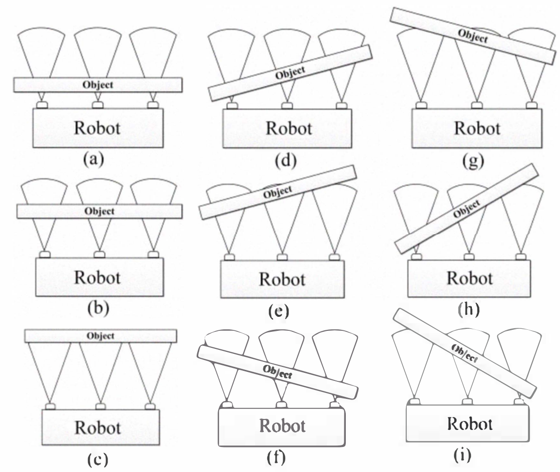

Fig. 1 Experiments under different obstacle environments

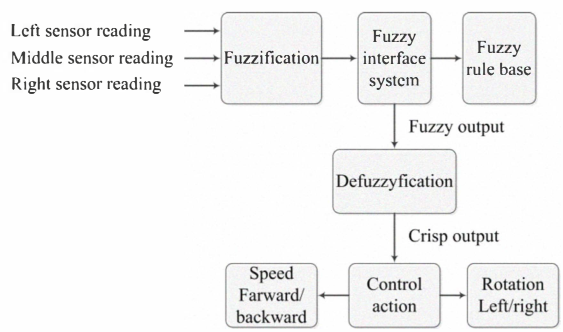

Fig. 2. Overview of the object following system

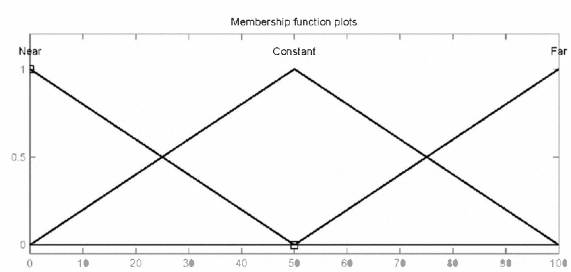

Fig. 3 Input membership functions for left sensor

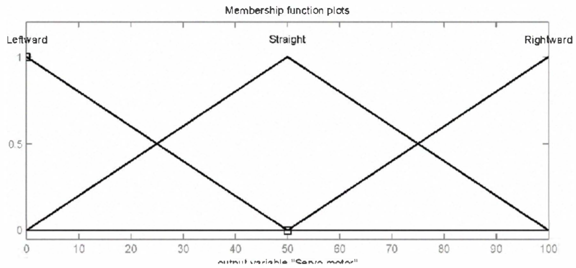

Fig. 3 Output membership functions for servo motor

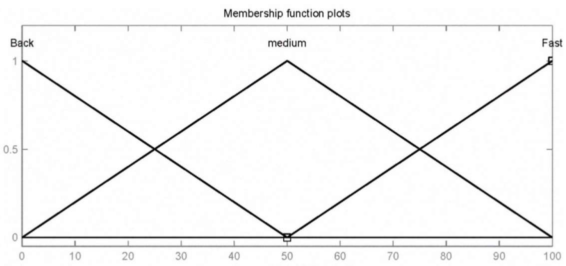

Fig. 4 Output membership functions for DC motor

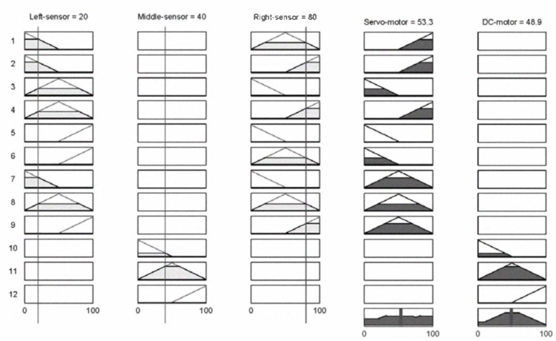

Fig. 5 Implication and defuzzification process

TABLE I
RULE BASE FOR SERVO MOTOR

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

TABLE II
RULE BASE FOR DC MOTOR

Middle sensor		
Near	**Constant**	**Far**
Back	Medium	Fast

IV. SIMULATION AND RESULTS

The simulation was performed using MATLAB fuzzy logic toolbox. Implication and defuzzification process are expressed in Fig. 6; input (left sensor, middle sensor, and right sensor) and output (DC motor and servo motor) membership functions are defined to achieve defuzzified output value, where left sensor determines near, middle sensor determines constant, and right sensor determines far. As a result, the robot will start moving towards right to follow the object with the medium speed. A control surface is drawn to see the dependency of output on inputs which is illustrated in Fig. 8. Configuration of the mobile robot and its working environment can be seen in Fig. 7. To test the robot, a remotely controlled toy vehicle is moved in front of it; the robot is then followed by the vehicle by maintaining the distance from it. The robot was in different experiments as illustrated in Fig. 1. In [9] conventional binary logic based mobile robot is presented; we compared our results and distance accuracy with it. The experimental results demonstrate that the FLC can handle well the uncertain data. This fuzzy logic based robot can follow the object by achieving desired turning angle properly and attains speed (forward and backward) very smoothly.

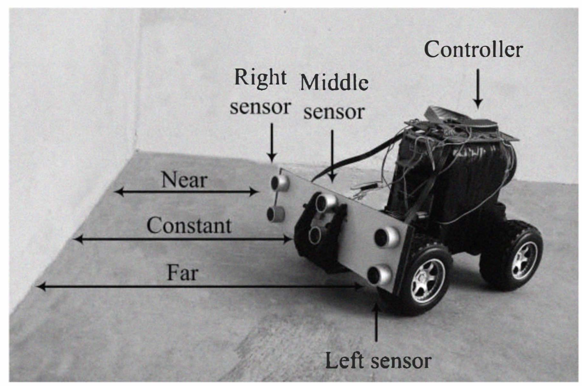

Fig. 6 Configuration of the robot

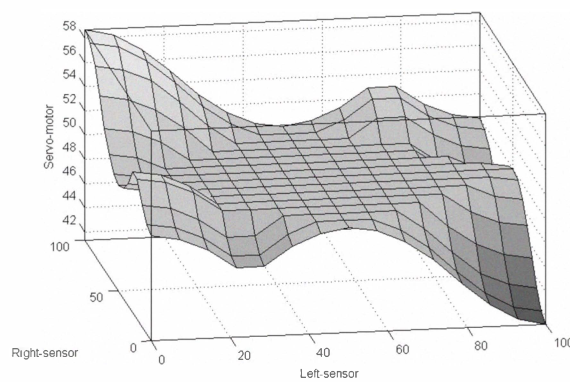

Fig. 7 Output surface map representing the dependency of output (servo motor) on inputs (left sensor and right sensor)

V. CONCLUSION

In this study, design and implementation of the object following robot has been described. The conventional binary logic controller cannot have the appropriate performance to drive DC and servo motors from the uncertain data. To further obtain the acceptable outcomes and smoothness in tracking the object, a fuzzy logic controller was developed. It demonstrates precise results in object following without collision that show it has progressive performance. Finally, experimental and simulation outcomes have displayed the authenticity of the system. In the future, this controller can be enhanced by introducing more sensors and a separate controller to identify a specific object.

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