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by Rina Mardiati

Fuzzy Logic Control for Semi-Autonomous Navigation Robot Using Integrated Remote Control

Farhan Wildani
Department of Electrical Engineering
UIN Sunan Gunung Djati Bandung
Bandung, Indonesia
farhan.wildani18@gmail.com

Rina Mardiati
Department of Electrical Engineering
UIN Sunan Gunung Djati Bandung
Bandung, Indonesia
r_mardiati@uinsgd.ac.id

Edi Mulyana
Department of Electrical Engineering
UIN Sunan Gunung Djati Bandung
Bandung, Indonesia
edim@uinsgd.ac.id

Aan Eko Setiawan
Department of Electrical Engineering
Telkom University
Bandung, Indonesia
aaneko@student.telkomuniversity.ac.id

Rin Rin Nurmalasari
Department of Electrical Engineering
UIN Sunan Gunung Djati Bandung
Bandung, Indonesia
rinrinnm@uinsgd.ac.id

Nike Sartika
Department of Electrical Engineering
UIN Sunan Gunung Djati Bandung
Bandung, Indonesia
nikesartika@uinsgd.ac.id

***Abstract*— Along with the times, technology in the field of mobile robots continues to progress very rapidly. In the development of autonomous robots, navigation is one part that has an important role. Therefore, mobile robots must be able to adapt to their environment. So we need a control method that can help the robot in the process of adjusting the dynamics of the surrounding environment. In this study, the semi-automatic navigation robot adopts artificial intelligence Fuzzy logic as an output processor that will be generated by the robot. Fuzzy logic on this robot is used to control the speed of the motor based on the distance of the obstacle that is read by the sensor and the input provided by the remote control. In this research, one ultrasonic sensor HC-SR04 is used which is mounted on the front of the robot, and remote control to give commands to the robot and Arduino MEGA 2560 as the microcontroller. To make the robot's movement more stable when avoiding obstacles, a fuzzy logic algorithm is applied to control the right and left motor PWM. Fuzzy robot system testing is carried out with a robot scenario detecting obstacles at a distance of 4cm and the remote providing an input value of 1870Hz. The results shown on the Arduino IDE application serial monitor are 62.5 PWM for the right motor and 103.53 PWM for the left motor, while the simulation results in the Matlab application show that the right motor PWM is 62.5 PWM and the left motor is 104 PWM. By comparing the output of the semi-automatic navigation robot based on Fuzzy with the output of the simulation results, it is found that fuzzy logic has been successfully implemented on the robot with a success rate of 100% for the right motor and 99.995% for the left motor.**

Keywords—navigation robot, fuzzy logic, remote control, ultrasonic sensor

I. INTRODUCTION

Obstacle avoidance is one of the main requirements of mobile robots, including autonomous navigation robots. The obstacle avoidance robots are designed to be able to navigate in unknown environments avoiding collisions. Sensors play an important role in the designed distance measurement system. Sensors used for distance measurement include ultrasonic sensors, infrared sensors, and lasers. Ultrasonic sensors are widely used in the design of distance measurement systems because they are not affected by the color of the reflective object, the smoothness of the reflective object, and are not affected by interference or other wave noise. By using ultrasonic sensors, the robot can detect obstacles around its path and then provide information to avoid objects immediately. However, digital control systems only work with logics 0 and 1, go or stop. It is also a robot mobility issue that suddenly stops when the obstacle you are facing is out of the robot's path [1] [2].

Since fuzzy logic does not require a mathematical model of the process, it is one of the newest controllers that can work well in nonlinear systems by providing convenience to program design [3]. Fuzzy-based controllers are control methods that belong to the class of artificial intelligence. Unlike Proportional Integral Derivative (PID) control, which uses only mathematical calculations, fuzzy controllers combine mathematical calculations with algorithms to control the robot's behavior with respect to environmental dynamics [4][5].

Of course, there have been some studies of obstacle avoidance robot warning systems using fuzzy logic or similar methods. Several previous studies have shown mobile robots being engineered to perform disaster rescue operations that occurred in static and dynamic environments [4][5][8]. In a study jointly conducted by Hee-Joo Yeo and Mun_Hyung Sung, a mobile robot controlled by a fuzzy control system avoids obstacles and tracks the path to avoid obstacles in the path, and the application of fuzzy control [5].

In 2020, research on mobile robots using the fuzzy logic method was conducted by Abdul Mutholib and others such as Alwan Abdul Zaki for industrial wall monitoring [9] and line sensor-based product transportation robots [2]. Research on robots controlled by remote control was also conducted by Mohamad Adhipramana and Aan Eko Setiawan in 2020 [10]. Monitor several factors that affect the water quality of the area [11].

This autopilot robot works automatically, but in this case the user and remote control assume a system that commands the robot [12]. The problem that sometimes occurs is that the input provided to the robot is excessively disconnected, resulting in false detections of the system and incomplete robot startup [5][6]. Due to these problems, a warning system is required so that the robot operates when an input error occurs in the system that controls the robot.

In this study, a matt logic control system is provided to control the speed of the DC motor caused by negligence to

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give the robot a command. Basically, this study is applied to the control with the vision of the computer [12][13]. However, the role of the computer vision is replaced by the users who provide commands using the remote control.

II. Design and Implementation

A. Design of System

The design is carried out to determine the process of implementing the tools that have been designed. The design stage of this system includes hardware and software design, where the hardware design section explains the schematic design of the robot's electronic components and the configuration of the Arduino MEGA 2560 device. Meanwhile, in software design, we will discuss the program design on the Arduino IDE and the Fuzzy Logic simulation process in the application. MatLab.

In the design of this robot, there are 3 stages of the system, namely input, process and output. In the input process, an ultrasonic sensor HC-SR04 is used which is mounted on the front of the robot and a 2.4 GHz receiver gets input from the remote control. The readings from the remote control and ultrasonic sensors will be processed by the Arduino MEGA 2560 which is based on a Fuzzy Logic control system and will affect the output results of the two DC motors mounted on the robot. In Fig. 1 you can see a block diagram of the hardware design of this robot.

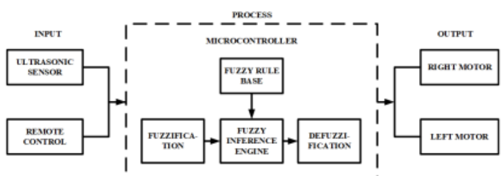

Fig. 1. Robot control system diagram.

The obstacle avoidance robot's working method is based on fuzzy logic control, including input, processing and output. In general, all these parts are related to each other, so that a usable robot can be created.

1) The input part is a remote control and a distance sensor. The components used are three HC-SR04 ultrasonic sensors, which are used to measure and provide the distance information between the robot and the obstacle in front. The remote control provides input for the DC motor. So that the robot can move forward.

2) The processing part is the main part of this tool, because this tool processes the distance from the sensor to the obstacle and processes the input given by the remote control. In this section, the Arduino MEGA 2560 microcontroller is used to control the fuzzy logic control, and the sensor and remote control inputs are used to process the distance measurement results.

3) This output part is the final result of data processing after the Arduino MEGA 2560 receives the input of the HCSR04 ultrasonic sensor and the remote control. The output uses two DC motors, namely the right motor and the left motor.

B. Hardware Design

In this study, a component consisting of an Arduino MEGA 2560, motor driver shield L293D, ultrasonic sensor, DC motor, 11V Lipo battery, and a 2.4GHz receiver as the receiver of the input signal received from the remote control was used. The schematic of the robot circuit for this research can be seen in Figure 2.

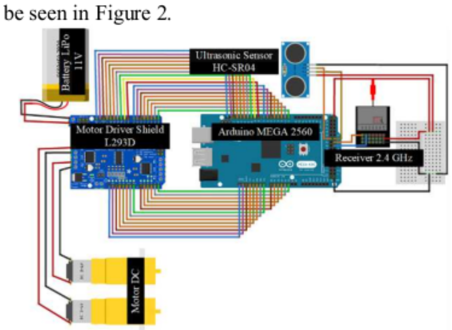

Fig. 2. Robot circuit schematic

C. Design of Fuzzy Logic Control System

This study uses Arduino IDE software to program the Arduino MEGA 2560 microcontroller. Before the program is made on the Arduino IDE, first make a fuzzy logic design using the Matlab application. Fig. 3 shows the fuzzy logic design for the input and output and TABLE I shows the rule base for this semi-autonomous navigation robot.

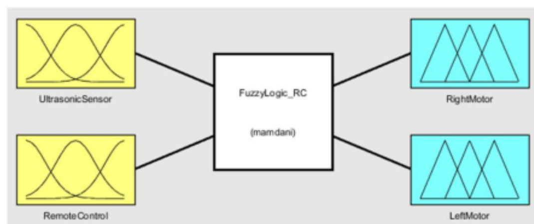

Fig. 3. Design of fuzzy logic

TABLE I. Fuzzy Rule Base

Rule	Input		Output	
	Sensor	**Remote**	**Right Motor**	**Left Motor**
R1	Close	Shallow	Normal	Fast
R2	Close	Medium	Normal	Fast
R3	Close	Deep	Normal	Fast
R4	Middle	Shallow	Slow	Slow
R5	Middle	Medium	Normal	Nomal
R6	Middle	Deep	Normal	Nomal
R7	Far	Shallow	Normal	Nomal
R8	Far	Medium	Normal	Nomal
R9	Far	Deep	Fast	Fast

D. Software Design

After the hardware design is done, then the software design is carried out. The software used in this research is Arduino IDE which is used to create programs and send the results of the compilation of the program to Arduino Mega 2560, the application for simulation is MATLAB and Fritzing software which is used to design the circuit schematic of the robot. Figure 4 shows flowchart program for this robot.

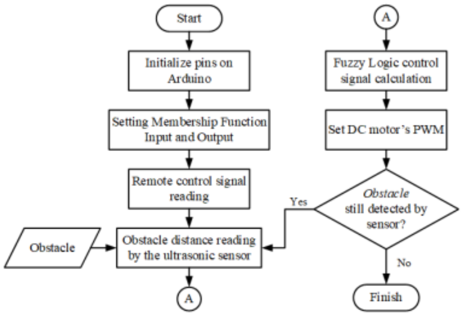

Fig. 4. Flowchart program

E. Implementation

After designing the system of the semi-autonomous navigation robot, the implementation or realization of the design is carried out. Fig. 5 is the implementation of the upper robot circuit while Fig. 6 is the implementation of the front robot.

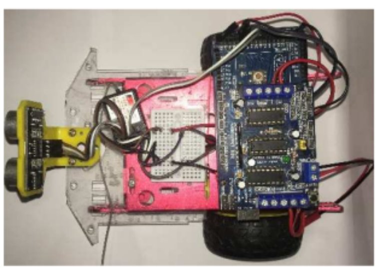

Fig. 5. Top view

Fig. 6. Front view

III. Test and Result

In this test, a case is taken with the condition of the ultrasonic sensor getting an input distance of 4cm from the obstacle and the remote control providing an input of 1870. Using the Fuzzy control system, the left motor (PWM) and right motor (PWM) output values will be searched for the robot. Testing the Fuzzy model that was built was done by doing 3 comparisons of the results of the calculations, namely: The results of manual Fuzzy calculations, simulation results, and the results of the system calculations on the robot that has been built.

A. Testing Fuzzy Calculations Manually

1) Fuzzy Set of Ultrasonic

$$\mu_{Close}(4) = 1 \tag{1}$$

2) Fuzzy Set of Remote Control

$$\mu_{Medium}(1870) = \frac{1900-1870}{50} = 0.6 \tag{2}$$

$$\mu_{Deep}(1870) = \frac{1870-1850}{50} = 0.4 \tag{3}$$

3) Application Function Implication

Based on the rule base that has been made, in this case, it shows that there are 2 rules that give a value (fulfilling) namely [R2] and [R3].

$$\begin{aligned}[R2] \rightarrow \quad & \lambda_{[R2]} = \mu_{Close} \cap \mu_{Medium} \\ & \lambda_{[R2]} = \min\{1, 0.6\} \\ & \lambda_{[R2]} = 0.6\end{aligned} \tag{4}$$

$$\begin{aligned}[R3] \rightarrow \quad & \lambda_{[R3]} = \mu_{Close} \cap \mu_{Deep} \\ & \lambda_{[R3]} = \min\{1, 0.4\} \\ & \lambda_{[R3]} = 0.4\end{aligned} \tag{5}$$

4) Composition of Rules

The composition of the rules is the overall conclusion by taking the maximum membership degree from each consequence of the application of the implication function by combining all the conclusions from each rule, so that the fuzzy solution area is obtained as follows:

$$\begin{aligned}[R2] \rightarrow \quad Right\ Motor: \quad & \frac{\alpha_{21} - 25}{25} = 0.6 \\ & \alpha_{21} = 35\end{aligned} \tag{6}$$

$$\begin{aligned}Left\ Motor: \quad & \alpha_{22} = (0.6 \times 25)100 \\ & \alpha_{22} = 85\end{aligned} \tag{7}$$

$$\begin{aligned}[R3] \rightarrow \quad Right\ Motor: \quad & \alpha_{31} = (0.4 \times 25) + 25 \\ & \alpha_{31} = 35\end{aligned} \tag{8}$$

$$\begin{aligned}Left\ Motor: \quad & \alpha_{32} = (0.4 \times 25) - 100 \\ & \alpha_{32} = 65\end{aligned} \tag{9}$$

5) Defuzzification

$$Right\ Motor \rightarrow \quad Z^{*} = \frac{M}{L} = \frac{2250}{36} = 62.5\ PWM \tag{10}$$

$$Left\ Motor \rightarrow \quad Z^* = \frac{M}{L} = \frac{2640}{25.5} = 103.53\ PWM \quad (11)$$

After manually calculating the PWM value generated by the case study of the ultrasonic sensor 4 cm away and the remote control giving commands worth 1870, the results obtained are the PWM speed of the right motor 62.5 PWM and the left motor 103.53 PWM.

B. Fuzzy Test Using Simulation Aplication

Fuzzy testing using a simulation application is carried out with the exact case study where the ultrasonic sensor detects an obstacle 4 cm away and the remote control gives a command worth 1870. From this test, the right motor PWM output is 62.5 and the left motor PWM is 104 as seen in Fig. 7.

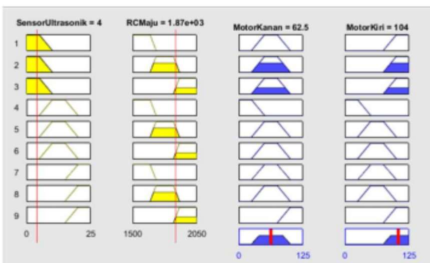

Fig. 7. Fuzzy calculation results in simulation applications.

C. Fuzzy Testing on Robotic Systems

In testing the Fuzzy model on this semi-automatic navigation robot system, the results are displayed from the Arduino IDE application serial monitor with a case study on an ultrasonic sensor of 4cm and 1870 input from a remote control as shown in Fig. 8.

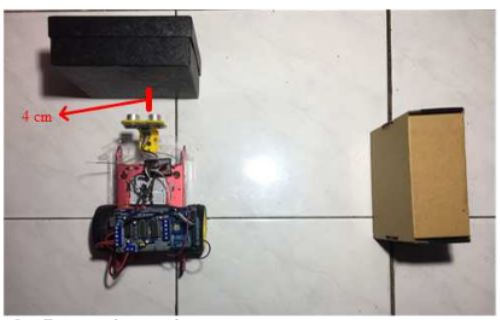

Fig. 8. Fuzzy testing on robot systems.

Based on Fuzzy testing on this robotic system, the output on the right motor PWM is 62.5 and on the left PWM motor, the resulting PWM is 103.53. Figure 9 shows the Fuzzy output on the Arduino IDE application serial monitor.

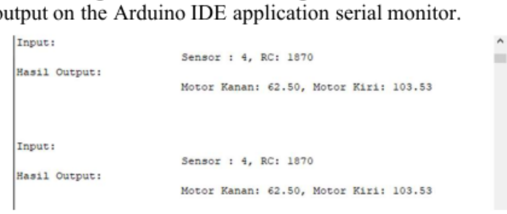

Fig. 9. Fuzzy test results on the robot system

D. Comparison of Error Difference

There is a difference in the PWM output value between the simulation software and the system being built. The differences shown in TABLE II are not very significant and are still in accordance with the predetermined fuzzy rules. The difference in the output results can be caused by several factors, one of which is an error in rounding numbers. TABLE II shows the results of calculations on manual testing, through simulation applications and on the system built.

TABLE II. FUZZY CALCULATION RESULTS

Output	**Manual Calculation**	**Simulation Results**	**System built**
Right motor PWM	62.5	62.5	62.5
Left motor PWM	103.53	104	103.53

There is a difference in the PWM output of the right motor and the left motor on the obstacle avoidance robot system with the results of the simulation software. Therefore, it is necessary to find the error value in the system built as follows:

Right Motor Error Value :

$$\%error = \left|\frac{62.5-62.5}{62.5}\right| \times 100\% = 0\%$$

Left Motor Error Value :

$$\%error = \left|\frac{103.53-104}{104}\right| \times 100\% = 0.005\%$$

Based on the results of the comparison test of the robot system with the results of fuzzy modeling in the simulation application, an error of 0.005% is obtained on the left motor and 0% on the right motor. With the results of the error value, the Fuzzy logic control method was successfully implemented on this robot with a success percentage of 100% for the right motor and 99.995% for the left motor.

IV. ANALYSIS

Fuzzy robot model testing has been compared with three test results from case studies that have been determined previously, namely an ultrasonic sensor that detects obstacles at a distance of 4cm and remote control that gives command of 1870. In this section three tests are carried out, namely manual calculations obtained the result of the output value in the form of the right motor PWM is 62.5 PWM and the left motor is 103.53 PWM. From the test on the simulation application, the PWM output value on the right motor is 62.5 PWM and the left motor is 104 PWM. In testing the system that has been built, the output results are 62.5 PWM for the right motor and 103.53 PWM for the left motor. Testing the Fuzzy logic control method can be declared successful based on the tests carried out running well, because an error value of 0.005% is obtained for the left motor and 0% for the error value on the right motor.

V. CONCLUSION

Based on the explanation above and the results of the design of a semi-automatic navigation robot using a remote control and ultrasonic sensor based on fuzzy logic control, the conclusions obtained are:

1. This research has succeeded in designing a semi-automatic navigation robot based on fuzzy logic control according to the desired specifications.
2. In this study, a semi-automatic navigation robot system based on Fuzzy Logic Control has been tested so that the results of the analysis are as follows:
   a) In the process of applying fuzzy logic control algorithms for semi-automatic navigation robots, a comparison of the results of fuzzy calculations on the system built with the results of calculations in simulation applications and manual calculations is carried out. Based on this comparison, the application of the fuzzy method on the semi-automatic navigation robot can be said to be successful, because the error value on the right motor is 0% and the error value on the left motor is 0.005%.
   b) In the robot test, it was found that the semi-automatic navigation robot based on Fuzzy Logic Control moves stably and can avoid obstacles in front of it.

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