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Modeling Wall Tracer Robot Motion Based on Fuzzy Logic Control

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***Abstract*—In this modern times, robot technology is rapidly having a great progress day by day, especially in robot wall tracer. Robot wall tracer was very useful to lighten human jobs in industry, manufacturing, and infrastructure. Some problems that arises in building the wall tracer robot is how to make a navigation system on the robot so that it always remains in the set point position. Previous study has been done to solve this problem using various methods and approaches such as implemented some intelligence program that used to navigate the robot wall tracer. In this study, we try to design and build a robot wall tracer using an Arduino MEGA microcontroller as the brain for control robot and the HC-SR04 ultrasonic sensor based on fuzzy logic to control the position and DC motor speed. In this study, testing was carried out in terms of hardware and software, as well as overall system testing. Based on hardware testing obtained PWM left motor 110 and PWM right motor 107. Meanwhile, for software testing, it is found that the fuzzy logic has been successfully implemented in the robot. The results of the calculation of fuzzy logic on the robot are compared with the calculation of simulation results and manual calculations. In addition, a performance comparison test of the robot system was conducted, and it was found that robots equipped with fuzzy logic were 2.3 seconds faster than robots without fuzzy logic.**

Keywords—wall tracer robot, fuzzy logic, ultrasonic sensor, motion control

I. INTRODUCTION

The field of technology and industrial automation is currently become rapid progress, especially in the field of robotics since semiconductor devices founded. Many sectors have used robots specifically in the fields of industry, manufacturing, infrastructure and others to help the human's work [1]. One of them is wall tracer robot. A wall tracer robot is designed to move along a wall without hitting it. It has obstacle detection sensors mounted on the body which detects wall and drive DC motors attached to the wheels such that the robot keeps moving along the wall. Some problems that arises in building the wall tracer robot is how to make a navigation system on the robot so that it always remains in the set point position that has been determined. Previous literature has been done to model the motion or navigate the wall tracer robot using various of methods and approaches, such as mathematical model [2], Rule Based Model [3], Cellular Automata [4][5][6], or Social Force Model [7][8][9], Markov Chain [10], etc.

One method that can be used to solve these problems is to trace the contours of the wall with an algorithm to provide robot orientation by navigating through walls [11]. These advantages is it does not need a guideline or a special mark as a robot direction when navigating. Wheeled robots are mechanical devices capable of moving in an environment with a certain degree of autonomy. Autonomous navigation is associated to the availability of external sensors that get information of the environment through visual images or distance or proximity measurements [12].

This paper try to represents the design of wall tracer robot motion using fuzzy logic controller. The robot is design as a robot with two wheel (right and left). And we add two ultrasonic sensor that positioned on front side and rear side. The sensor plays an important role in navigating the wall trajectory in the distance measuring system. Ultrasonic sensors are widely used in the design of distance measuring systems since they not affected by the color of the reflecting object, softening the reflecting object and are safe from noise interference of other waves [14].

The motion will be design using fuzzy logic method, which input are the distances obtained from ultrasonic sensor. While the output are the speed of left and right motor. Fuzzy logic is an approach using mathematical forms to see how obscurity is then expressed in human language [13]. The basis of Fuzzy logic is Fuzzy set theory. In Fuzzy logic there is a membership function of input and output system [15]. Decisive value mapping become a degree of membership then be fuzified and decision making with the fuzzy inference method a system consisting of a number of rules can make Non-LTI systems can be controlled [16].

The paper is organized as follows. Section 1 gives a general introduction, while Section 2 describes the modeling speed of AGV using Fuzzy Logic. In Section 3 describes the calculation of fuzzy logic control using a case study with a mathematical approach. Finally, Section 4 presents the conclusion and future works.

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II. Design and Implementation

A. Block Diagram System

The problem proposed in this research is how to design a speed of robot wall tracer motion so that they always at a set point that has been determined before using Fuzzy logic control. The initial stage of tool design requires an initial description of how the system works from the tool. The control system uses a close loop with the application of fuzzy controller. The block diagram of this research can be seen in Figure 1.

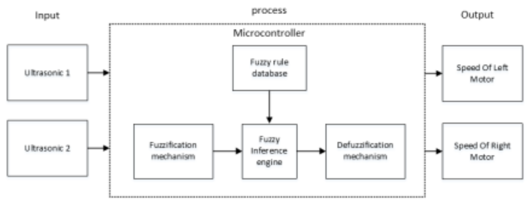

Fig. 1. The block diagram of this control system.

B. Hardware Design

Robot hardware design using smart 2WD aluminum car chassis with a size of 17 cm x 9 cm, with Robot height 5 cm. In figure 2. Shows the robot design on the left side. Figure 3. Shows the robot design on the right side and Figure 4. Shows the sensor model mounted on the robot. The template is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin in this template measures proportionately more than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current designations.

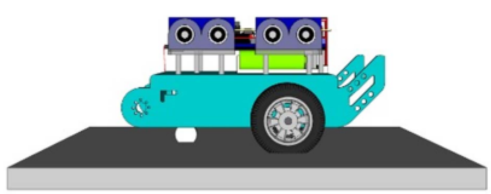

Fig 2. Left side view of the robot with it's sensor.

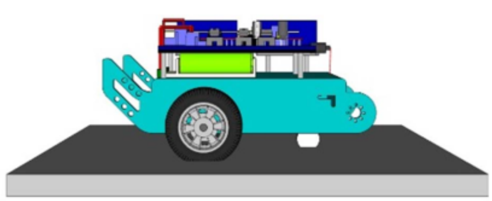

Fig 3. Right view of the robot.

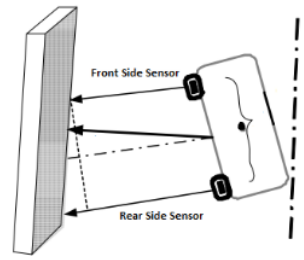

Fig 4. Sensor model illustration.

C. Software Design

In this study, there are 2 input variables and 2 output variables. Variable the input consists of the distance from the front side sensor and the rear side sensor and the output variable consists of PWM right motor and PWM left motor. In Table I the term input variable is used to facilitate Fuzzy control system on the wall tracking robot that was built.

TABLE I. LINGUISTIC TERM OF INPUT

Distance (centimeter)	**Linguistic Term**	
	Front side sensor	***Rear side sensor***
[0 0 15 25]	Near (de)	Near (DE)
[15 25 35 45]	Middle (te)	Middle (TE)
[35 45 100 100]	Far (ja)	Far (JA)

Table II is the term used for the output variable to facilitate the fuzzy control system on the wall tracking robot that is built.

TABLE II. LINGUISTIC TERM OF OUTPUT

Motor Speed	**Linguistic Term**	
	Left wheel	***Right wheel***
[0 0 40 85]	Slow (la)	Slow (LA)
[40 85 135 175]	Normal (no)	Normal (NO)
[135 175 225 225]	Fast (ce)	Fast (CE)

The front side sensor variable is formed into three sets, namely near, middle, and far can be seen in Figure 5. For the set it uses a trapezoidal curve shape.

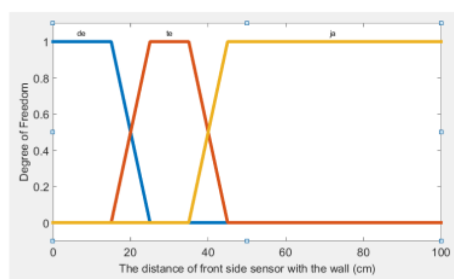

Fig. 5. MF of input front side sensor

The rear side sensor variable is formed into three sets, namely near, middle, and far are shown in Figure 6. For the set it uses a trapezoidal curve shape.

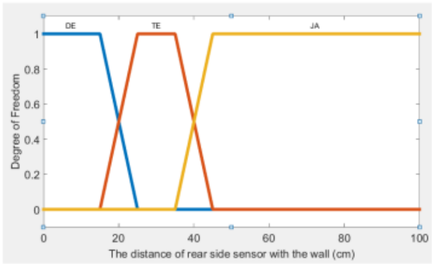

Fig. 6. Membership function of rear side sensor.

TABLE III. EQUATION TERM OF MF INPUT.

µ of Front side sensor	µ of Rear side sensor
$\mu_{de} = \begin{cases} 1, & x \leq 15 \\ \frac{25-x}{10}, & 15 \leq x \leq 25 \\ 0, & x \geq 25 \end{cases}$	$\mu_{DE} = \begin{cases} 1, & x \leq 15 \\ \frac{25-x}{10}, & 15 \leq x \leq 25 \\ 0, & x \geq 25 \end{cases}$
$\mu_{te} = \begin{cases} \frac{x-15}{10}, & 15 \leq x \leq 25 \\ 1, & 25 \leq x \leq 35 \\ \frac{45-x}{10}, & 35 \leq x \leq 45 \end{cases}$	$\mu_{TE} = \begin{cases} \frac{x-15}{10}, & 15 \leq x \leq 25 \\ 1, & 25 \leq x \leq 35 \\ \frac{45-x}{10}, & 35 \leq x \leq 45 \end{cases}$
$\mu_{ja} = \begin{cases} \frac{x-35}{10}, & 35 \leq x \leq 45 \\ 1, & x \geq 45 \\ 0, & x \leq 100 \end{cases}$	$\mu_{JA} = \begin{cases} \frac{x-35}{10}, & 35 \leq x \leq 45 \\ 1, & x \geq 45 \\ 0, & x \leq 100 \end{cases}$

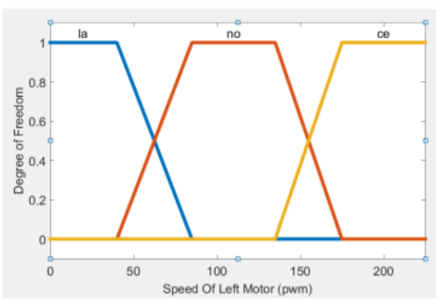

Fig. 7. MF output of left motor speed

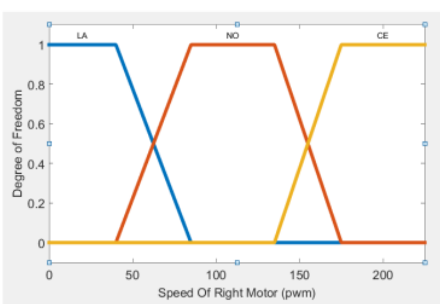

Fig. 8. MF output of right motor speed

TABLE IV. EQUATION TERM OF MF OUTPUT.

µ of left motor speed	µ of right motor speed
$\mu_{la} = \begin{cases} 1, & x \leq 40 \\ \frac{85-x}{45}, & 40 \leq x \leq 85 \\ 0, & x \geq 85 \end{cases}$	$\mu_{LA} = \begin{cases} 1, & x \leq 40 \\ \frac{85-x}{45}, & 40 \leq x \leq 85 \\ 0, & x \geq 85 \end{cases}$
$\mu_{no} = \begin{cases} \frac{x-40}{45}, & 40 \leq x \leq 855 \\ 1, & 85 \leq x \leq 135 \\ \frac{175-x}{40}, & 135 \leq x \leq 175 \end{cases}$	$\mu_{NO} = \begin{cases} \frac{x-40}{45}, & 40 \leq x \leq 855 \\ 1, & 85 \leq x \leq 135 \\ \frac{175-x}{40}, & 135 \leq x \leq 175 \end{cases}$
$\mu_{ce} = \begin{cases} \frac{x-135}{40}, & 135 \leq x \leq 175 \\ 1, & x \geq 175 \\ 0, & x \leq 225 \end{cases}$	$\mu_{CE} = \begin{cases} \frac{x-135}{40}, & 135 \leq x \leq 175 \\ 1, & x \geq 175 \\ 0, & x \leq 225 \end{cases}$

TABLE V. RULE FUZZY LOGIC.

Rules	**Input**		**Output**	
	Distances of front side	***Distances of rear side***	***Motor Speed Left-Wheel***	***Motor Speed Right-Wheel***
R1	de	DE	no	no
R2	de	TE	no	la
R3	de	JA	no	ce
R4	te	DE	la	no
R5	te	TE	no	no
R6	te	JA	ce	la
R7	ja	DE	la	ce
R8	ja	TE	la	no
R9	ja	JA	no	no

D. Implementation

At the top of the Robot implementation namely implementation The L293D motor driver shield is connected to the right DC motor and motor Left DC. The L293D motor driver circuit can be used for control DC motor with maximum current if there is additional power from the battery. This testing process is carried out to ensure the system is designed can go as planned. Figure 9. Shows the top series of robots.

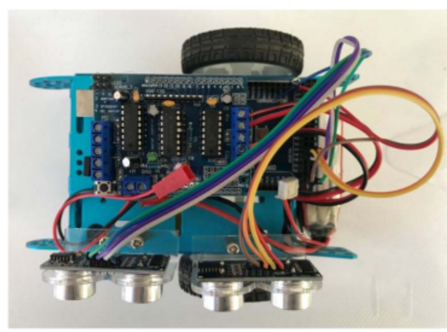

Fig. 9. Top robot circuit.

While the left side is used for robot design install the HC-SR04 ultrasonic sensor component which is connected to the arduino MEGA microcontroller as an object detector, consisting of two sensors with front side sensor and rear side sensor. Figure 10. Shows the left robot.

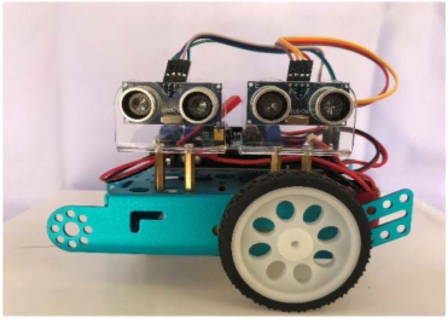

Fig 10. The left side vies of robot.

III. Result and Analysis

A. Hardware Testing

Voltage regulator testing is done by measuring the results The input voltage and output voltage results are shown in the Table VI is as follows.

TABLE VI. HARDWARE TESTING

Device	Ideal Voltage (Volt)	Test Result Voltage (Volt)
Arduino MEGA	7-12 VDC	12.2 VDC
Ulrasonic HC-SR04	5 VDC	5 VDC
Driver Motor L293D	4.5-36 VDC	8V VDC

The results of the stress test can be seen in Table 1, namely the load obtained an average of 12.2 V because the voltage provided by the battery is 12.2 V.

B. Ultrasonic sensor testing

TABLE VII. ULTRASONIC SENSOR LOGIC

Measurement (cm)		Difference error (cm)	Difference error (%)
Ruler	***HC-SR04***		
24	24	0	0,0
28	29	1	3,4

Ultrasonic sensor testing uses a comparison between the sensor and a ruler. The test used 2 sample cases with a distance of 24 cm and 28 cm, at a distance of 28 cm there is a 1cm difference between the sensor and the ruler.

C. Testing Software

In testing this software, it aims to check whether the control model is fuzzy that has been implemented in the robot wall tracer is appropriate or not yet. The results obtained from the fuzzy control system on the robot wall tracer are built, compared with the results of manual calculations and calculation results using Matlab simulation software. To test this, a case is taken with the condition of the front side sensor is 24 cm and the rear side sensor 28 cm away. Using the fuzzy control system, the output value will be searched left and right motor speed on the robot so that it can be stable moving along Wall. In manual calculation of fuzzy control system with case examples 50 above, there are several steps that need to be done which will be discussed in detail next.

Step 1. Determine the fuzzy set

Front Side Sensor Freedom Degrees

In determining the fuzzy set, we must first find the degrees membership of the represented membership function. With input conditions front side sensor distance of 24 cm can be seen at Figure 2, then the value of 24 cm is entered into the NEAR fuzzy set and MIDDLE so based on equations Table 3 obtained:

$$\mu_{de}[24] = \frac{25-24}{10} = 0.1 \quad (1)$$

$$\mu_{de}[24] = \frac{24-15}{10} = 0.9 \quad (2)$$

This shows that on the front side sensor with a distance of 24 cm in the NEAR fuzzy set has a membership degree of 0.1 and MIDDLE has a membership degree of 0.9.

Rear Side Sensor Freedom Degrees

With the input condition the rear side sensor distance of 28 cm can be seen In Figure 3, the value of 28 cm belongs to the fuzzy set MIDDLE so that based on equation Table 4 obtained:

$$\mu_{TE}[28] = 1 \quad (3)$$

This shows that on the rear side sensor with distance 28 cm in the middle fuzzy set has a degree of membership of 1.

Step 2. Application ImplicationThe implication

The implication function used in this process is the MIN function because the fuzzy rule base that is built is an AND function. With the MIN function, the minimum membership degree from input variable as its output. Based on the rule base shown In Table 5 the conditions in this case show only 2 rules provide value, namely [R2] and [R4].

[R2]: If Front Side Sensor Near and Rear Side Sensor Middle then Right Motor Is Slow, Left Motor Is Normal.

$$\alpha_2 = \min(\mu_{de} ; \mu_{te})$$

$$\alpha_2 = \min(0{,}1 ; 0{,}9)$$

$$\alpha_2 = 0{,}1$$

R4]: If the Side Sensor Front Middle and Rear Side Sensor Middle then Motor Right Normal Motor Left Normal.

$$\alpha_4 = \min(\mu_{TE} ; \mu_{TE})$$

$$\alpha_4 = \min(1 ; 1)$$

$$\alpha_4 = 1$$

Step 3. Defuzzification

Defuzzification is interpreting the membership degrees of the fuzzy sets into a specific decision or real value. A common and useful defuzzification technique is *center of gravity*. In the most common technique, all of these trapezoids form are then superimposed one upon another, forming a single geometric shape. Then, the centroid of this shape, called the *fuzzy centroid*, is calculated. Figure 11. Shows the simulation results of the software.

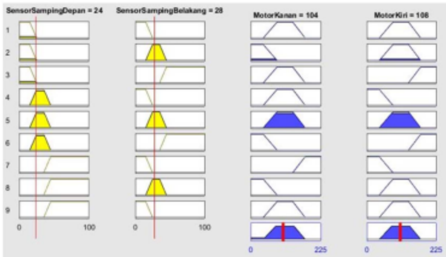

Fig. 11. Simulation results of the software.

The x coordinate of the centroid is the defuzzified value, called Z^*. So, the output of this fuzzy logic:

$$Z^* = \frac{\int_0^{80.5} 0.1\, z\, dz + \int_{80.5}^{135.5} 1\, z\, dz}{(80.5)(0.1\, dz) + (50)(1\, dz)}$$

$$Z^* = \frac{6196.3875}{58.05} = 106.74 \quad (4)$$

and

$$Z^* = \frac{\int_{44.5}^{85} 0.1 z\, dz + \int_{85}^{135} 1 z\, dz + \int_{85}^{135} 0.1 z\, dz + \int_{135}^{171} 0.1 z\, dz}{(40.5)(0.1\, dz) + (50)(1\, dz) + (50)(0.1\, dz) + (36)(0.1\, dz)}$$

$$Z^* = \frac{6863.075}{62.65} = 109.54 \quad (5)$$

D. Fuzzy Model Results on the System Being Built

Fuzzy model in a system built on a wall tracer robot using ultrasonic sensor HC-SR04 based on fuzzy logic control is obtained The results are displayed from the Arduino IDE monitor serial with studies the case on the front side sensor 24 cm and the rear side sensor 28 then the PWM output of the left motor is 110 and the PWM of the right motor is 107. Figure 12 Shows the results of the serial monitor.

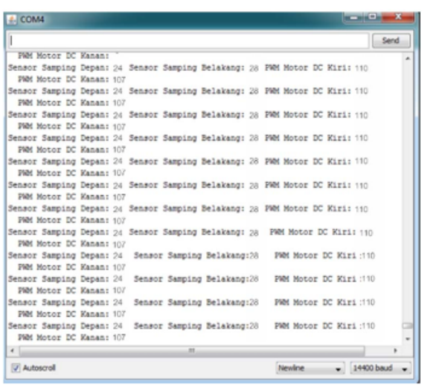

Fig. 12. Defuzzification output from serial monitor.

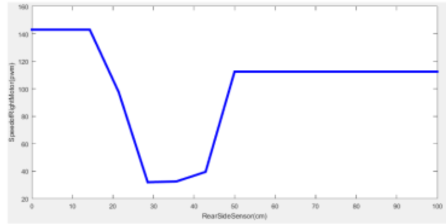

Fig. 13. Rear side sensor graph against speed of right motor.

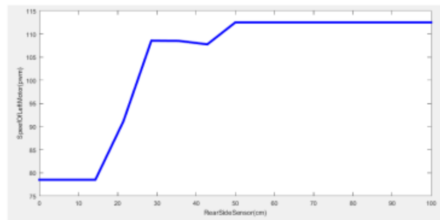

Fig 14. Rear side sensor graph against speed of left motor.

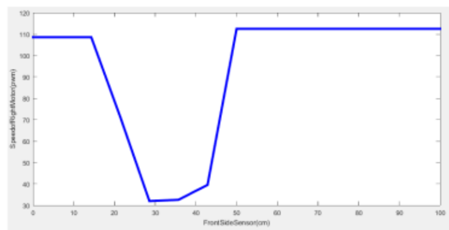

Fig 15. Front side sensor graph against speed of right motor.

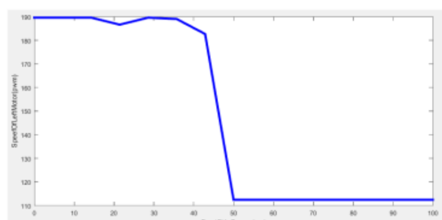

Fig 16. Front side sensor graph against speed of left motor.

E. Robot Comparison Testing

This test is performed by looking at the robot's response when crossing a box-shaped object, then calculated using a stopwatch how long the robot will take work from the start point to the end point completing the trace on the object. Table VIII. Shows Robot Comparison Testing.

Based on Table VIII can be seen the second robot succeeds in tracking the object and the robot using fuzzy logic 2.3 seconds faster than robots without using fuzzy logic things This is because robots that use fuzzy logic can immediately do it maneuver and stabilize the PWM DC Motor.

TABLE VIII. ROBOT COMPARISON TESTING

No	Robot Using Fuzzy Logic		Robots Without Using fuzzy logic	
	Time to Reach the Finish (second)	***successfully traced the object (YES/NO)***	***Time to Reach the Finish (second)***	***successfull y traced the object (YES/NO)***
1	11.53	YES	13.47	YES
2	11.82	YES	14.79	YES
3	11.41	YES	14.40	YES
4	11.87	YES	13.08	YES
5	11.33	YES	13.74	YES
	11.59	YES	13.89	YES

IV. CONCLUSION

From the case example, it is known how to implement Mamdani Fuzzy logic to regulate the PWM motor speed by going through 4 steps by determining the Fuzzy set, application of implication functions, composition of rules, and defuzzification. So that the results obtained from the case of distance of 24 cm and 28 cm with manual calculations obtained PWM of left motor 109.54 and PWM of right motor 106.74. The program development begins with the formation of a Fuzzy Inference System using the Fuzzy logic toolbox in the Matlab software. After the PWM speed detection program is created, the monograph data is inputted. Furthermore, the system testing is carried out by doing defuzzification so that the detection results are displayed in the PWM speed monitor serial of the right motor 107 and the left motor 110. Based on the results of the robot comparison test, it is found that the robot equipped with fuzzy logic 2.3 seconds faster to navigate through objects.

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