The Application of Fuzzy Logic to Identify the Room on Navigation Map of Fire Extinguisher Robot

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Abstract. The Indonesian Fire Extinguisher Robot Contest is a competition for a legged-type robot that puts out the fire in a room. The robot has to identify four rooms then recognize and extinguish the fire. In this research, the mapping route method was used for room identification simulated with MATLAB to obtain the outcome in the form of crisp with Sugeno's Fuzzy Logic approach. The robot's presence was identified in the take-out position, the hallway, and the room. As a result, the robot could distinguish its position if it consistently moved in a straight line and the rules' variations were increasing. The robot went to the room for eight minutes from the start position. Further research can add a fuzzy method to end-effector robots to minimize the moving slope.

Keywords: sugeno, fuzzy logic, fire extinguisher robot, legged robot

1 Introduction

The Indonesian Fire Extinguisher Robot Contest (KRPAI) contests a legged-type robot that extinguishes fire in a room. The robot moves using its legs and ultrasonic sensors to detect the distance in a room. There are four rooms in the KRPAI arena, in which each session of the robot navigation sequences is different[1]. Many methods or algorithms can be used to complete this task, including Dead Reckoning, Follow Line, Follow Wall, Maze Mapping, Neural Networks Algorithm, Shortest Path, and Fuzzy Logic [2] [3].

Fuzzy Logic is the development of the results obtained from Boolean logic. Boolean logic solely recognizes the true value or not, so the obtained truth is not necessarily the true truth. Examples of values in Boolean are 0 and 1, or it can be up and down, or black and white, or other examples that have a yes or no value [4]. Fuzzy logic converts the truth value of a Boolean into a truth level. If we have never known how fuzzy logic is, maybe we are going to imagine the complexity and unpleasant things in fuzzy logic [5]. However, it is important to know that fuzzy logic exists in each of us [1].

Principally, a fuzzy set is an extension of a crisp set, a set that divides a group of individuals into two categories, specifically members and non-members. In a crisp set, the membership value of item x in a set A is often written as A[x]. The Fuzzy Takagi-Sugeno method is a fuzzy inference method for rules that are represented in the form of IF–THEN in which the output

IConVET 2021, November 27, Singaraja, Indonesia

DOI 10.4108/eai.27-11-2021.2315634

(consequent) of the system is not a fuzzy set but a constant or linear equation [6], [7]. The general form of *Fuzzy Model* First Order Sugeno is as follow:

IF (X1 is A1). ………….. (XN is AN) (1)

THEN z = p1* x1 + …+ pN* XN + q . (2)

Trapezoid curve representation formula:

$$f(x) = \begin{cases} 0, x \leq a, x \geq b \\ \frac{x-a}{b-a}, a < x \leq b \\ 1, b \leq x \leq c \\ \frac{d-x}{d-c}, c < x \leq d \text{ .} \end{cases} \quad (3)$$

x: The input value that is going to be converted into a number.
a: The smallest domain value that has zero membership degree.
b: The smallest domain value that has a degree of membership of one.
c: The value of the largest domain that has a membership degree of zero.
d: The value of the largest domain that has a degree of membership of one [8]

The *fuzzy* system has a weighted average value (Weighted Average Values) in the IF-THEN fuzzy rule section in this alteration. Sugeno's fuzzy system also has weaknesses, especially in the THEN section, in the form of the existence of mathematic calculations in which it cannot provide a natural framework to represent human knowledge in truth. The second issue is related to the limitation of using different principles in fuzzy logic, so the uncertainty of the fuzzy system cannot be represented properly [9]. Fuzzy logic with various rules has been applied in previous studies related to fire extinguishment. One of them is the study of Barera et al. [4]. This study used fuzzy logic in robots to find fire extinguishing routes. However, only 18 rules were used, so it is necessary to add more rules to increase accuracy.

During the robot competition, several problems were experienced by participants with their robots, such as the robot only rotated around one or two rooms, and they could not determine the presence of fire. These problems occurred because the robot only used a simple navigation system, i.e., the *wall follower's* method [10].

From the issues mentioned, one helpful solution is by identifying each room, so the robot can find out its existence. Hence, the robot will be able to discover the location of the room. Therefore, the robot can decide which direction to move after finding a certain room. The method that can help identify rooms in the map of the Indonesian Fire Extinguisher Robot Contest is to utilize fuzzy logic.

2 Method and material

The research steps included data collection and data identification in determining variables and the universe of conversation needed in carrying out calculations and problem analysis. The data processing included the process of fuzzification, the formation of basic rules, the composition of rules, defuzzification, and testing. The Sugeno-FIS type used a weighted average to calculate output, so Sugeno's output membership function was either linear or constant [11]. The robot was controlled by using Fuzzy Logic. Fuzzy Logic was used to translate a quantity expressed in linguistics. Fuzzy logic control was a system that could be applied specifically in the field of control [12], [13]. Fuzzy logic control could be used to adjust the speed of the servo motor in the robot. The robot's speed depended on the distance of the object that was read by the proximity sensor.

This research was conducted to facilitate the robot in determining the optimal path in the arena. Fuzzy Sugeno was chosen to identify the room on the navigation map in this research. In previous research, Fuzzy Sugeno obtained high truth level in the decision supporting model. [14] Thus, Fuzzy Sugeno is expected to provide optimal output in choosing the best path to the next route in the arena. This research was going to be implemented in an application designed in MATLAB programming.

The legs and the head of the robot were combined using a spacer that connected the top base of the legs with the middle base, which was used as a support for the mainboard and slave circuit. The overall design of the robot is shown in **Figure 1**.

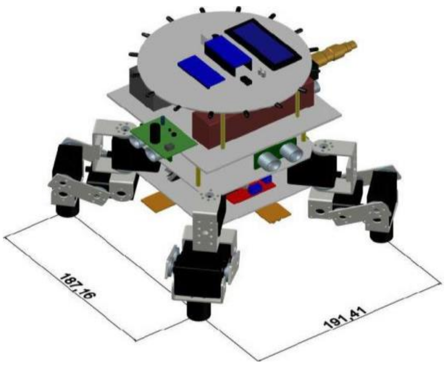

Fig. 1. Mechanical design of robot.

The robot was tested in an arena designed to resemble a maze with four rooms of various sizes and shapes. The arena design is shown in **Figure 2**.

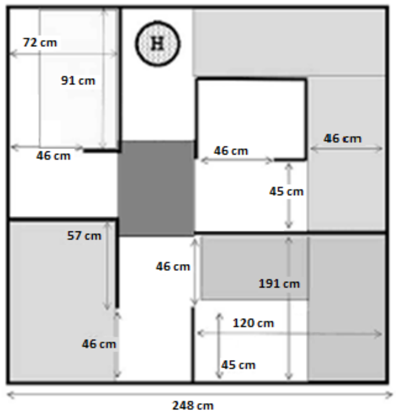

Fig. 2. Robot arena.

Figure 3 shows three main processes in the system, i.e., Arduino nano, Arduino Uno, and STM32 processes. Arduino nano processed data from input in the form of a TPA81 thermal sensor with I2C communication to retrieve the data. There were 16 flame sensors to detect where the hotspots were because the output from the sensor was analog and Arduino nano only had 8-analog pins, so it used a 16-multiplexer channel for the data retrieval process from the flame sensors. The data was taken from the TPA81 thermal sensor, and the flame sensor was sent to STM32 via Arduino and STM32 pin communication. In other words, Arduino nano acted as a slave, which sent data to STM32 as a master.

STM32 as a master, besides receiving data from Arduino Nano and Uno, processed data from other inputs in the form of UVTron sensors connected to the Hamamatsu driver to detect UV light emitted by candles and two pushbuttons to start and reset the robot. In addition, STM32 also controlled all robotic actuators, starting from the servo motor as a robot foot driver, a motor driver connected to a DC pump to spray water, and 2 LEDs and an i2c 16x2 LCD as a robot indicator.

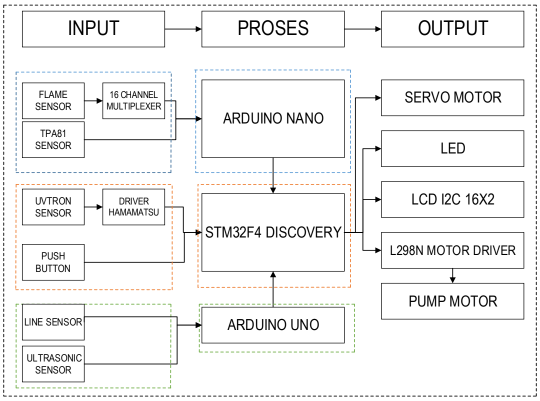

Fig. 3. Block diagram system.

Figure 4 described the flow of the robot program, in which after the robot was turned on, it initialized the program and remained silent before the robot got a command from the pushbutton to start reading. When the robot started, the distance data processing process continued in real-time to present data, which was later executed by a microcontroller to detect obstacles and trace the room. The distance data was processed to give orders to the robot to move, and fuzzy logic equations functioned for selection. The flow of this robot program was when the robot got a command from the pushbutton start. It moved through the room in the arena. If the robot recognized the presence of the room using a line sensor, the robot would detect the presence of fire using the UVtron sensor. If the presence of fire is detected, the robot would enter the room and find the source of fire using the *Flame* sensor. If the source of the fire were in front of the robot, it would detect heat using the TPA81 thermal sensor to see the proximity of the fire to the robot. If the heat exceeded the setpoint, which indicated the robot was close to the fire, the robot would turn on the pump motor to spray water in front of the fire, so it went out. However, if the presence of fire were not found, the robot would walk out of the room and look for another room until it found the room where the fire was detected and extinguished.

The robots were made using the following components:

1. The RDS3115MG Servo Motor was capable of working in both directions (CW and CCW) in which the direction and angle of the rotor movement could be controlled only by setting the PWM signal duty cycle setting on the control pin. This motor was used to move the robot's legs.
2. Ultrasonic sensors were used to detect walls in the robot arena.
3. The line sensor used a photodiode to detect the presence of a room in the arena.
4. Tron's UV sensor detected the source of fire at a range of 3 cm – 300 cm, and the UVTron sensor angle range was around 1800 without using a UVTron. Flame Sensor protection Hamamatsu used a UVTron tube produced by Hamamatsu, which had a simple working method.
5. Ultimate Battery Eliminator Circuit (UBEC) was useful for lowering a large DC voltage to a smaller DC voltage. UBEC was usually limited to lowering the voltage at a four-cell voltage and only emitted the output between 5-6V, but UBEC provided a large current output.

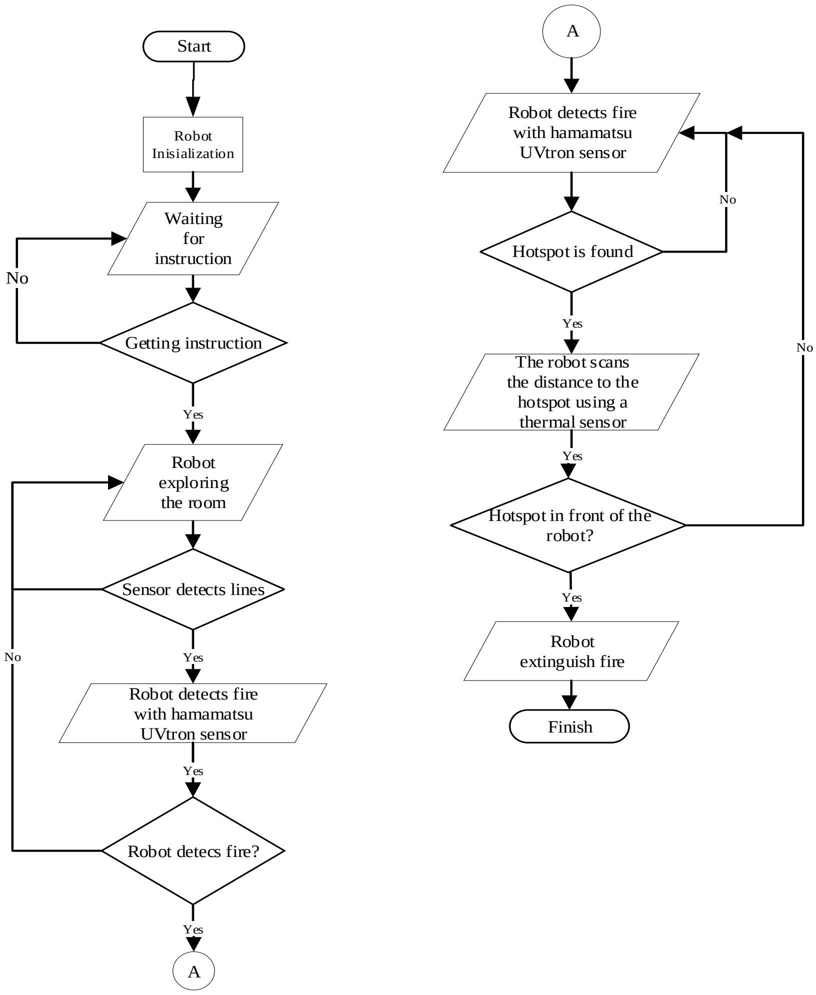

Fig. 4. Flowchart system.

Fuzzy logic served to detect the room in the available rooms with the input was in the form of an ultrasonic sensor. The expected output was in the form of results that could distinguish the rooms, the hallway, and the room and take the route Fuzzification of each output was if, in the hallway, the robot would walk following the route selected. The robot would scan the fire if the output were taking the route.

The robot moved to explore the room after obtaining distance data on the five sides of the robot, the path of the robot's motion in exploring the room was as shown in **Figure 5**.

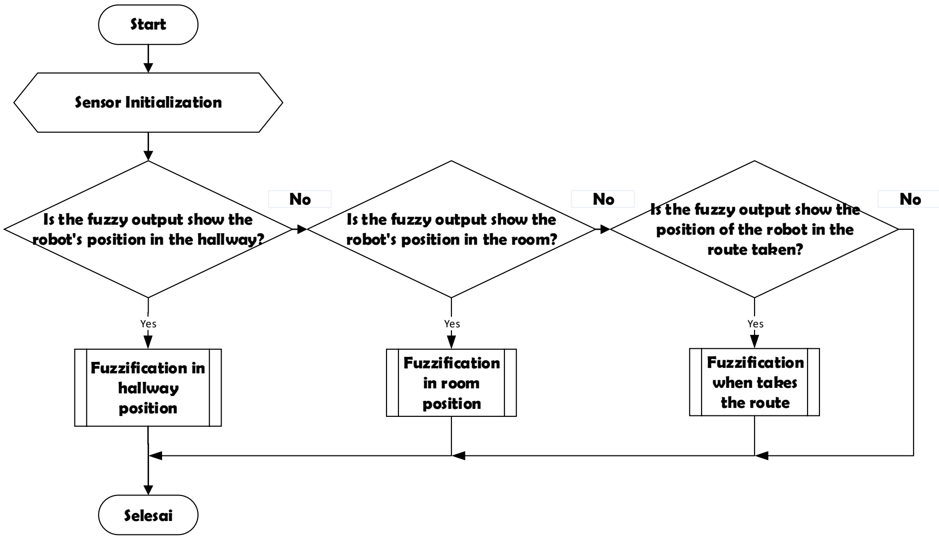

Fig. 5. Fuzzy system flowchart.

After knowing the position of the robot, its distance, and its route, the next step was identifying the room based on predetermined variables. In this first stage, the room was identified only by using the right and left distances when the robot was successfully out of a room (**Figure 6** to **Figure 11**).

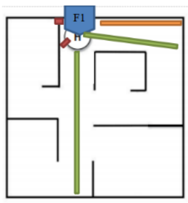

Fig. 6. Identifying F1 position using distance.

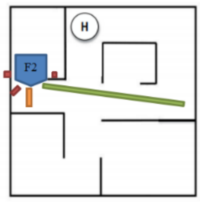

Fig. 7. Identifying F2 position using distance.

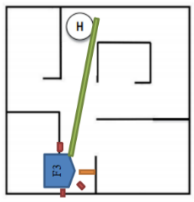

Fig. 8. Identifying F3 position using distance.

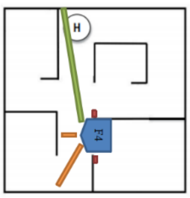

Fig. 9. Identifying F4 position using distance.

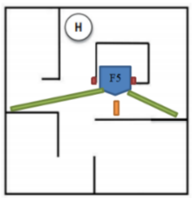

Fig. 10. Identifying F5 position using distance.

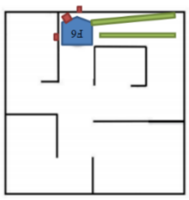

Fig. 11. Identifying F11 position using distance.

Red = J1 (short distance)
Orange = J2 (medium distance)
Green = J3 (long distance)

After identifying the room using distance, the next step was identifying the room using the route. This stage was carried out because at the identification stage using distance. There were still four rooms that could not be identified. For more details, it can be seen in **Figures 12** to **Figure 15**.

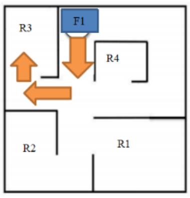

Fig. 12. Route from home to room 3.

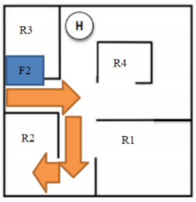

Fig. 13. Route from room 3 to room 2.

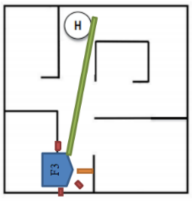

Fig. 14. Route from room 2 to room 1.

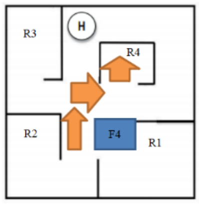

Fig. 15. Route from room 1 to room 4.

Furthermore, the calculation of the fuzzy membership function using MATLAB can be seen in **Figure 16**. In the close membership function, the trapmf type was in the form of a trapezoid in which the input consisted of four parameters in MATLAB, [0 0 10 50].

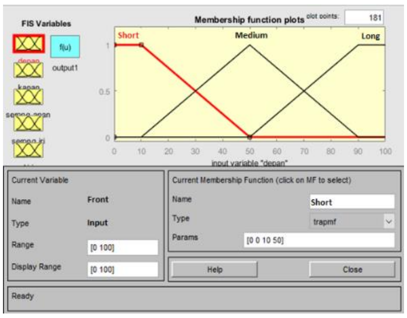

Fig. 16. Close distance membership graph.

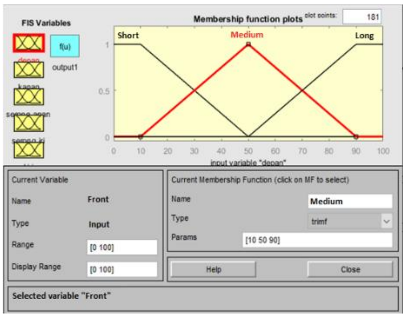

Fig. 17. Medium distance membership graph.

Figure 16 shows the result of the close distance membership that had been calculated. The result of each input whose values were >=1 to <= 0, starting from x <= 1, was the same in condition 1 and would decrease to condition 0 when the value of x >= 10 to x<=50. **Figure 17** shows the result of the medium distance membership that had been calculated. The result of each input whose value was 0 to 1 increased from x >=10 to x <= 50, then would decrease from x>=50 to x<=90. The medium membership function used a triangular-shaped trim type whose input consisted of 3 parameters in MATLAB, [10 50 90].

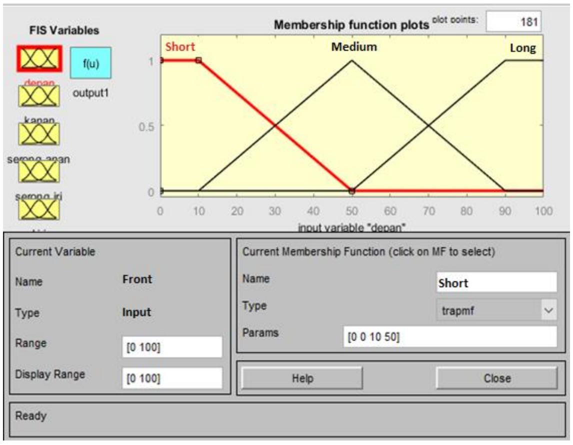

Fig. 18. Long-distance membership graph.

Figure 18 shows the results of the long-distance membership that had been calculated. The result of each fuzzification input that values were 0 to >=1, starting from x >= 50, were the same in condition 1 when x>= 90. In the close membership function, a trapezoid-shaped type trapmf was used in which the input consisted of 4 parameters in MATLAB, [50 90 100 100].
Result and Discussion

3.1 Ultrasonic sensor testing

The difference among home position on the sensor, right distance (kn distance), and right oblique distance (skn distance) resulted in 0 cm, while for front distance (kd distance), left distance (kr distance), and left oblique distance (cur distance), the difference reached 7% of the actual distance. The difference at a distance of more than 100 cm was quite large. The results of ultrasonic data collection were used to determine the suitability of the distance measured by the sensor with the actual distance, fuzzy logic input, and identification of the robot arena. The ultrasonic sensor used was the SRF-05 ultrasonic sensor. Some samples from tests were carried out by facing the sensor on the board.

3.2 Hamamatsu UVtron sensor testing

The Hamamatsu UVtron sensor detected UV rays emitted by a fire at an angle of 90° to -90°. Testing was done by placing candles in front, back, right, and left of the sensor at varying distances.

3.3 TPA81 sensor testing

The TPA81 sensor was used to detect the heat generated by the fire to be extinguished by the robot. Testing was done by placing a candle in front of the sensor at varying distances. The result of the test showed that the TPA81 sensor still detected heat at a distance of 40 cm. The TPA81 sensor was placed on the front of the robot by forming an angle of 75 degrees to 105 degrees in front of the sensor so that the new robot would extinguish the fire directly from a distance of 40 cm from the sensor to the point of fire.

3.4 Flame sensor testing

Sensor flame was used to detect the light emitted by a candle. Testing was done by placing candles in front, behind, right, left of the robot alternately with varying distances. The test showed that the flame sensor could still detect the presence of fire with a distance of 210 cm well, even though the fire points were placed in front, behind, right, left/ Considering the flame sensor was installed round, the flame sensor was still able to detect up to a distance of 210 cm well.

3.5 Line sensor test

Line sensor was a sensor to detect the presence of a room in the arena. The test was done by comparing the black, grey, or white floor. Each floor colour had a different ADC to distinguish which one the room is (marked by a white line) and which one is not a room. The result showed that the sensor could distinguish between the room and the hallway.

3.6 Fuzzy test

The mapping data of the KRPAI room was influenced by the distance from how many parts of the sensor, i.e., the distance from the front, right side, right side, and left side. Then it looked for the degree of membership of the value of each variable from the data, and the next step was looking for -predicate for each fuzzy combination rule. Using the robot's average (weight average), the result of -predicate that was not zero was used to find the average value, which was also a defuzzification. Testing was done by comparing the manual calculations, MATLAB, and the microcontroller results. From this comparison, it could be concluded that manual calculations could not be used as a reference because the difference between rule 1 and the others was almost the same.

In the microcontroller STM32 program, the calculation reference was based on MATLAB, and experiments using Ms. Excel. The program produced by STM32 could be classified to distinguish its output. The MATLAB results in **Figure 19** contained 30 lines which indicated 30 rules, and six columns consisting of five fuzzy inputs and one fuzzy output from each created rule.

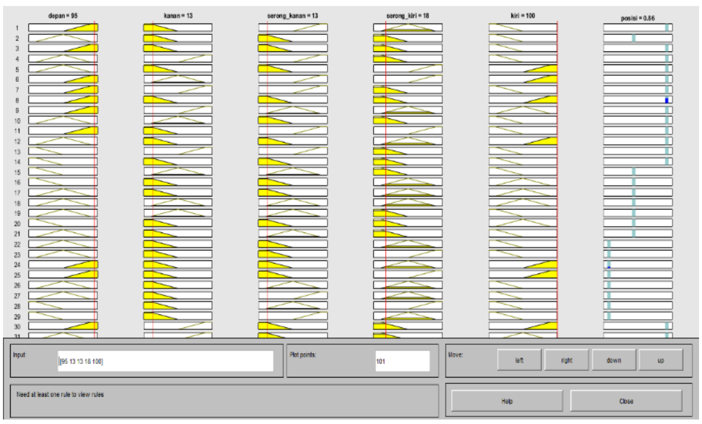

Fig. 19. The rule and defuzzification results in MATLAB.

In the input column, there was a red line showing the value of the input rule, and there was the oldest color among the outputs. It is the appropriate rule from the input determined in the input column below. The sign on each rule output showed the members of the resulting output. The MATLAB results in **Figure 19** contained 30 lines which indicate 30 rules and 6 columns consisting of five fuzzy inputs and one fuzzy output from each rule made.

Table 1. Room identification test results based on distance.

Front	Right	Left	Oblique Left	Oblique Right	Position
115	14	15	15	14	Hallway
93	84	64	46	68	Hallway
115	14	98	100	15	Take Route
67	13	138	50	15	Hallway
35	17	11	41	111	Take Route
33	15	13	80	18	Take Route
50	16	12	13	43	In room

After getting the test results from all components and the Fuzzy Sugeno method used, it was implemented on the designed robot. Table 1 presents the grouping of each fuzzy output membership, which will be used as a fuzzy rule to compare outputs and designs that had previously been simulated with MATLAB. The values in the table are the results in ADC.

Table 2. room identification test results based on distance.

From-To	Route Used	Traveling Time (min)
Home to R3	Route U	8
R3 to R2	Route U	6
R2 to R1	Route L1	6
R1 to R4	Route Z1	8
R4 to *Home*	Route L1	8

4 Conclusion

In the moving robots, the application of fuzzy was regarded optimal, even though it was not in full agreement. It is due to the inverse kinematics mechanism in the robots was still being applied, which had changed the servo arrangement thus, there were different coordinates and making a change in a route that caused the robot to walk tilted and fuzzy, which has been designed to be able to adapt to the changes made. The results of the findings revealed that the robot could go to room three for eight minutes from the start position because of the delay between Arduino and STM32 serial communication and multitasking with medium priority, so it was not real-time. The Ultrasonic SRF-05 sensor could provide distance data with a difference of 7% for distances above 100 cm and 0% for distances between 3-100 cm.

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