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Design of Mobile Robot Transporter Prototype Using Sensor Vision and Fuzzy Logic Method

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Abstract

The industrial field has experienced significant developments in the automation process, especially robots play an important role in the world of automation. One type of robot used in industry is a transporter robot. This research designs and develops a prototype mobile robot transporter that uses Pixy camera as a visual sensor and Mamdani fuzzy logic control method to control the speed of DC motor. This robot is able to move objects based on color using Arduino UNO as a microcontroller, motor driver shield L298N, two DC motors, and gripper module as actuators. The distance and speed of the robot are determined to ensure the ability to approach and move objects based on color appropriately. Testing of the robot system is done with X position value and area as parameters. Simulation of the experiment was carried out with a case study of the X position value of 73 and an area of 1012. Robot testing is done using simulation software and Arduino IDE which is then calculated manually for comparison. The results obtained in testing with simulation software are 88.70 PWM for the right DC motor and 76.10 PWM for the left DC motor. Based on the data obtained from simulation software, testing with Arduino IDE, and manual calculations, an error value of 0.158% for the right DC motor and 0.092% for the left DC motor was found. Additional tests were carried out with variations in the distance of the object being moved as well as the transfer of the object to the destination. These results show that Mamdani fuzzy logic control is effective in controlling the transporter robot, allowing accurate maneuvering and adaptive to environmental changes.

Keywords: Automated Guided Vehicle, Pixy camera, fuzzy logic control, Arduino, Motor DC

1. Introduction

The industrial field has become common in the automation process, especially robots are now one of the important elements in the world of automation. Robots have the role of helping humans in various situations, especially in activities that require a high level of accuracy and are potentially dangerous to the human body (Arijaya, 2019).

One type of robot that is applied in the industrial field is a transporter robot. Transporter robots are vehicles that transport and move goods that can move according to a predetermined path. Generally, proximity sensors, lasers, or magnetic fields are often used to determine the path of movement (Irsyadi, 2021).

The use of transporter robots in industry can be utilized as a means of transporting goods that use a navigation system by following the path on the floor or utilizing laser reflections to move according to predetermined directions. Transporter robots can also be adapted to various types of work and arranged to carry out various tasks such as material transfer, implementation of production processes, or even providing services (Setiawan, 2021). However, the use of transporter robots has disadvantages such as object recognition based on color which allows miscalculation of the distance in front of it which can interfere with navigation and reduce the efficiency and accuracy of carrying out the task of picking and moving objects by the robot (Pratama, 2018).

The industrial sector can use a type of robot equipped with a camera sensor that acts as a visualization tool or imaging of certain objects. One application of image processing is computer vision which functions to process image acquisition, then the next stage is image processing (Nasution, 2022). To overcome this, it is necessary to have a camera sensor and method on the transporter robot system, the camera sensor that can be used is a Pixy camera because of its superior ability to detect, recognize, and process visual information quickly and this camera is placed at the front of the robot to make it possible to collect data directly from the surroundings. This allows the robot to better adjust its movements and respond efficiently to environmental changes. Methods that can be used are Mamdani fuzzy control to ensure that the robot can move with optimal capabilities, detection for the accuracy of object detection with camera sensors (Setiawan, 2022). Fuzzy logic control is a method that allows setting several variables so that the output produced is in accordance with the desired needs (Setiawan, 2020). By utilizing this method, the robot can adapt to various complex situations, improve performance and efficiency of movement, and present a more precise response in carrying out its tasks.

2. Block Diagram System

The block diagram of the mobile robot transporter explains the working principle of the transporter robot in tracking and approaching objects based on object recognition that has been done before. When the robot moves, the Pixy camera will identify the object in front of it based on the x position value. The robot microcontroller will then receive the data from the Pixy camera reading and use the fuzzy logic control method to smoothen the robot's movement and control it (Zaki, 2020). The dc motor will not move if the Pixy camera cannot detect the object correctly because the Arduino Uno cannot process the input it receives and complete the fuzzification process. The input, process, and output phases of a system are separated into three categories in the system design,as shown in Figure 1.

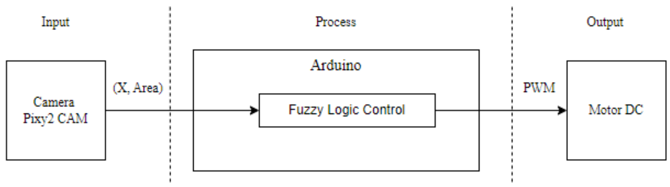

Figure 1: Block diagram of proposed system.

The fuzzy logic control Mamdani approach serves as the foundation for the navigation system, which operates by first employing the vision sensor to identify certain objects.

a. Vision sensor (Pixy camera) and a coloured object (green) are employed in the input part. In order to make sure the sensor can identify and move in the direction of the target object, object identification is performed on the visual sensor that is being used. The set point is the object (green) in this section.
b. Fuzzy logic control is the approach and Arduino UNO is the microcontroller utilised in the process section. The goal of using fuzzy logic control is to improve the smoothness of robot motions.
c. The output portion is what was left over from the previous circuit, in which the Arduino UNO controlled the two DC motors by sending commands to them based on information it received from the Pixy camera. In this context, "feedback" refers to the output that results in input again. The Pixy camera's Input X and Area represent the object movement's output.

Maintaining the Integrity of the Specifications

In designing a prototype of a robot movement navigation system using a pixy camera, several supporting components are needed, such as sensors, microcontrollers, and voltage sources. Some of these components can be seen in Table 1.

Table 1: Component

NO	Component Name	Lots
1	2 WD Smart Car Chassis for Arduino	1
2	Arduino UNO	1
3	Pixy Camera	1
4	Driver Shield Motor L298N	1
5	Motor DC	2
6	Baterai Lipo 12 Volt	1
7	Cable	15
8	Gripper	1

Before designing, a schematic is made from the different parts that are used. As shown in Figure 2, this circuit powers the robot by using a battery (Lipo) and links the Arduino UNO to additional supporting components.

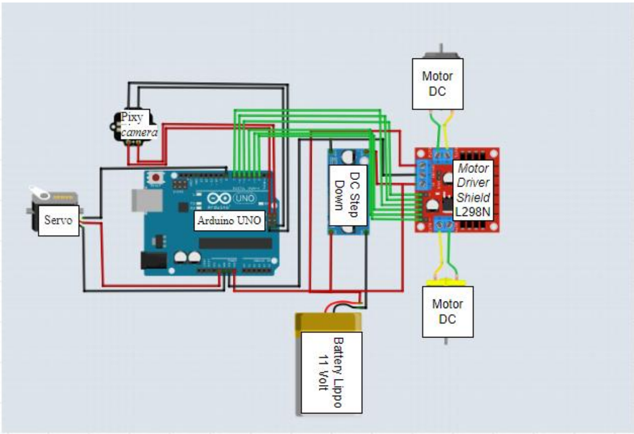

Figure 2: Schematic system.

Software Design

The software design process is tailored to the needs required to support the methodology stages. There are 3 software used for this design, namely Arduino IDE, PixyMon, related software, and Fritzing. Fritzing. The programming language used is C language on the Arduino platform. Arduino IDE plays a role in making programs from input to output on the transporter robot, while PixyMon is used to process the color of objects detected by the Pixy camera. Pixy camera. Simulation software is used to determine the rules of the Fuzzy Logic Controller and is also used as a comparison with the Arduino IDE application. Arduino IDE, and Fritzing applications are used to describe the circuit scheme on the robot transporter. Arduino IDE software is used to create a program on Arduino Uno using a fuzzy logic base. fuzzy logic base. The flow implemented in the program can be seen in Figure 3.

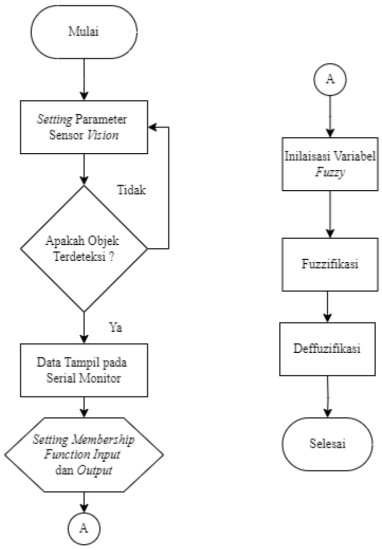

Figure 3: Flow chart of fuzzy logic control system.

Modeling Fuzzy Logic Control on Object Detection System

In this study Figure 4, the fuzzy logic control system uses the Mamdani Method. There are two inputs and two outputs in the modeling used by the software. X Position and Area values, X Position (which indicates the location of the targeted object) and Area (which indicates the area of the item read by the sensor or the distance between the object and the robot) are the variables used in the inputs. The Pixy camera, which is mounted on the front of the robot, provides both inputs. The two variables that make up the output section are the right dc motor and the left dc motor, which control how fast the DC motor moves.

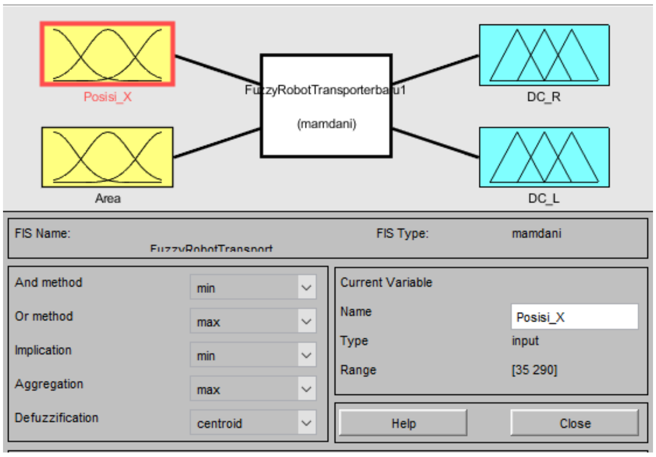

Figure 4: Fuzzy logic design.

Membership Function Input

The input used in this robot is a vision sensor or Pixy camera that is able to detect two variables. which is able to detect two variables to determine membership function used. The membership function used is in the form of an x value as a determinant of the position on the x axis (right or left) of the detected object, then the Area value as a determinant of the determinant of the area of the object seen by the Pixy camera. To distinguish between the two, two linguistic terms used to facilitate the design of this control system. This control system. Table II shows the linguistic terms in the membership function membership function used for the value of X.

Table 2: Membership Function Input Variable X

Linguistic Term of Value X Position(*Coordinate*)	Linguistic Term
[35 35 70 95]	Left
[70 95 150 200]	Center
[150 200 290 290]	Right

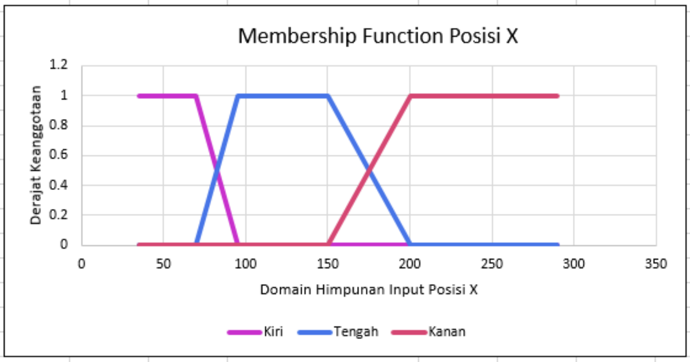

Figure 5: Membership of Value X.

$$\mu_{Left} = \begin{cases} 1, & x \leq x \leq 70 \\ \frac{95-x}{25}, & 70 \leq x \leq 95 \\ 0, & x \geq 95 \end{cases} \quad (1)$$

$$\mu_{Center} = \begin{cases} \frac{x-70}{25}, & 70 \leq x \leq 95 \\ 1, & 95 \leq x \leq 150 \\ \frac{200-x}{25}, & 150 \leq x \leq 200 \end{cases} \quad (2)$$

$$\mu_{Right} = \begin{cases} \frac{x-150}{25}, & 150 \leq x \leq 200 \\ 1, & x \geq 290 \\ 0, & lainnya \end{cases} \quad (3)$$

The following Table III shows the terms used in the membership function for input Area.

Table 3: Membership Function Input Variable Area

Linguistic Term of Area **Area (*Pixel*)**	**Linguistic Term**
[600 600 4500 6500]	Far
[4500 6500 9500 12000]	Intermediate
[9500 12000 14000 14000]	Near

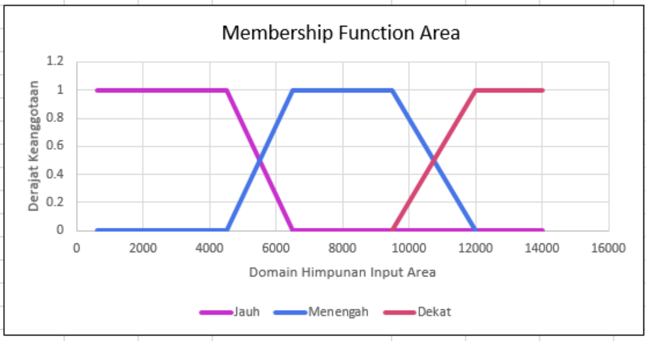

Figure 4: Membership of Area.

$$\mu_{Far} = \begin{cases} 1, & x \le 4500 \\ \frac{6500-x}{2000}, & 4000 \le x \le 6500 \\ 0, & x \ge 6500 \end{cases} \quad (4)$$

$$\mu_{Intermediate} = \begin{cases} \frac{x-4500}{2000}, & 4500 \le x \le 6500 \\ 1, & 6500 \le x \le 9500 \\ \frac{12000-x}{2500}, & 9500 \le x \le 12000 \end{cases} \quad (5)$$

$$\mu_{Near} = \begin{cases} \frac{x-9500}{2500}, & 9500 \le x \le 12000 \\ 1, & x \ge 14000 \\ 0, & lainnya \end{cases} \quad (6)$$

Membership Function Output

This Transporter Robot uses two DC motors as the driving force of the robot. of the robot and a servo gripper as a driver to pick up objects. However, the output used is only from the robot drive system, namely the dc motor which will be entered into fuzzy logic, so the membership function is made for two servos, namely the elbow and base. dc motors, namely the right and left dc motors. Where the speed range. The value entered for the domain of the set of two dc motors is from 0 to 125 speed. Some existing variables use linguistic variables to facilitate the control system made in this study. in this research. The linguistic terms used for each servo are shown below. Table IV shows the linguistic terms used in the membership functions for the variables in the output base. As for following Table IV shows the terms used in the membership membership function for the DC Motor Output.

Table 4: Membership Function Output Variable Motor DC

Linguistic Term of Motor DC **Motor Speed (PWM)**	**PWM Left**	**PWM Right**
[60 60 65 70]	Slow	Slow
[65 70 75 80]	Currently	Currently
[75 80 100 100]	Fast	Fast

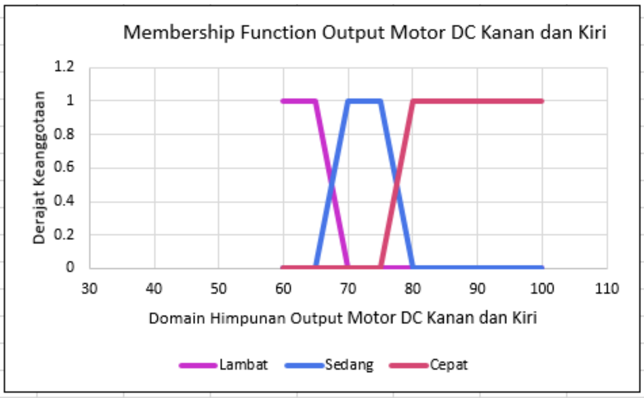

Figure 5: Membership of Motor DC Right and Left.

$$\mu_{Slow} = \begin{cases} 1, & x \leq 65 \\ \frac{70-x}{5}, & 65 \leq x \leq 50 \\ 0, & x \geq 70 \end{cases} \tag{7}$$

$$\mu_{Currently} = \begin{cases} \frac{x-65}{5}, & 65 \leq x \leq 70 \\ 1, & 70 \leq x \leq 75 \\ \frac{80-x}{25}, & 75 \leq x \leq 80 \end{cases} \tag{8}$$

$$\mu_{Fast} = \begin{cases} \frac{x-75}{5}, & 75 \leq x \leq 100 \\ 1, & x \geq 100 \\ 0, & other \end{cases} \tag{9}$$

Fuzzy Rule Based

After defining the membership function for fuzzy modeling of the Pixy camera vision sensor by setting the variables X and Area as input and dc motor as output,Fuzzy is then defined as the probability of this sensor and the dc motor to be parameterized as the process that determines the output value. Several probabilities that can be used in this program are defined, the rules used can be seen in the following Table V:

Table 5: Membership Function Output Variable Motor DC

Rule	Input		Output	
	X	Area	Vr Motor	Vl Motor
R1	Left	Near	Slow	Slow
R2	Left	Intermediate	Fast	Slow
R3	Left	Long	Fast	Currently
R4	Middle	Near	Slow	Slow
R5	Middle	Intermediate	Currently	Currently
R6	Middle	Long	Fast	Fast
R7	Right	Near	Currently	Currently
R8	Right	Intermediate	Currently	Fast
R9	Right	Long	Slow	Fast

Implementation

Implementation is an important stage in the development process, where the results of the careful design in the previous chapter are put into practice. is put into practice. For hardware implementation, the first step is to juxtapose the pre-planned tools. In this case, the components used include the Arduino Uno, Pixy2 camera, and servo motor, which are all integrated and juxtaposed with the DC motor which are all integrated and juxtaposed with the part of the robot transporter kit. Thus, the visual implementation of the hardware can be seen directly through Figure 5, which shows how the entire system functions in the appropriate context.

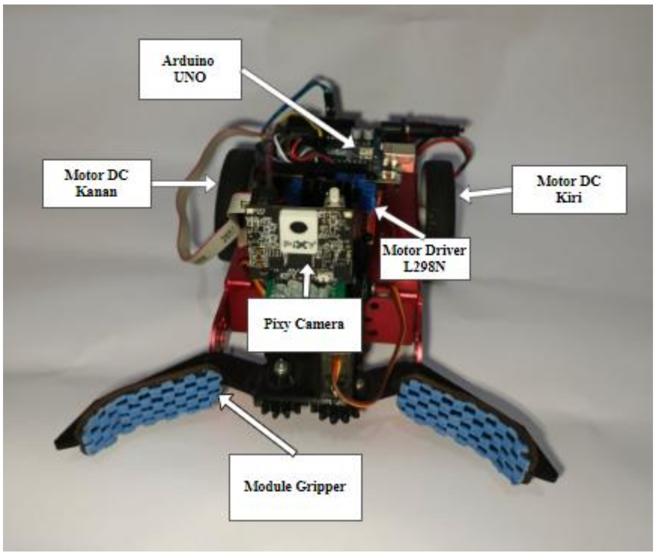

Figure 8: Prototype robot transporter.

3. Result and Analysis

Pixy Camera Test

This research used a Pixy2 CMUCam5 camera as the visual sensor. This camera sensor was then tested. In testing the effect of distance, the steps taken were to change the distance between the object and the camera by 3 cm. The pixy camera sensor testing process can be seen in Fig.9.

Figure 9: Pixy camera test.

Color Test

The first test in Table VI, performed on each color that has been tried before and the result produced will be selected with the best result as the selected object. using the best result as the selected object. Testing is done with Objects with multiple colors are tried with before finally determining one object with satisfactory results that can be used. Objects with multiple colors are tried with before finally determining one object with satisfactory results that can be used. Testing Tests were conducted with a distance of 20 cm-70 cm with room.

Table 6: Membership Function Output Variable Motor DC

No	Distance	Red	Yellow	Green
1	70 cm	detected, blurred	detected, blurred	detected, blurred
2	60 cm	detected, blurred	detected, blurred	detected, clear
3	50 cm	detected, blurred	detected, blurred	detected, clear
4	40 cm	detected, clear	detected, clear	detected, clear
5	30 cm	detected, clear	detected, clear	detected, clear
6	20 cm	detected, clear	detected, clear	detected, clear

Fuzzy Logic

In order to test the use of the fuzzy control system technique, simulations were run using a variety of supporting tools (including the Arduino IDE and simulation software), and comparisons with manual calculations were conducted. Testing the fuzzy model used in this robot navigation system uses a case study with input from the Pixy camera, the X position input value used is 73 and the Area input value is 1012.

1. Determine the Fuzzy Set

Determining the degree of freedom on the visual sensor, the fuzzy set must first find the degree of membership of the membership function to be used. Conditions such as the input value of the X position in Figure 10, then the value belongs to the Left and Center fuzzy sets. The input condition of the Area value as in the case study used, can be seen in Figure 10, then the value belongs to the Far fuzzy set for the left and center positions. The formula can be found at:Input X and area:

Input X and Area:

$$\mu_{Left}[73] = \frac{95-73}{25} = 0{,}88 \tag{10}$$

$$\mu_{Middle} = [1012]\frac{73-70}{25} = 0{,}12 \tag{11}$$

Based on equation 4, the same result is obtained as 1 for the Far fuzzy set [1012].

$$\mu_{Long}[1] = 1 \tag{12}$$

2. The Function Implication

The application of the implication function with the function used in this process is MIN because the fuzzy rule base built is a function of AND. The MIN function is used, then the minimum membership degree of the input variable as the output. Based on the rule base shown in Table 4, the existing conditions in this case show two rules by giving a value (fulfill), namely [R3] and [R6]

[R3]: IF input X Left and area is long then right motor is VFast and left motor is Currently.

$\alpha_{R3} = \mu_{Left} \cap \mu_{Long}$

$\alpha_{R3} = \min(\mu_{Left}, \mu_{Long})$

$\alpha_{R3} = \min(0{,}88, 1) = 0.88$

[R6]: IF Input X middle and area is long then right motor is VFast and left motor is Fast.

$\alpha_{R2} = \mu_{Middle} \cap \mu_{Long}$

$\alpha_{R2} = \min(\mu_{Middle}, \mu_{Long})$

$\alpha_{R2} = \min(0{,}12, 1) = 0.12$

3. Defuzzification

The process of converting a fuzzy set's degree of membership into a clear decision form or one with a real value is known as defuzzification. In this study, the center of gravity methodology is a thorough and practical defuzzification method. The most popular and often applied technique is to create a single geometry by piling all of the trapezoids on top of one another. Next, perform the following computations on the fuzzy centroid or center.

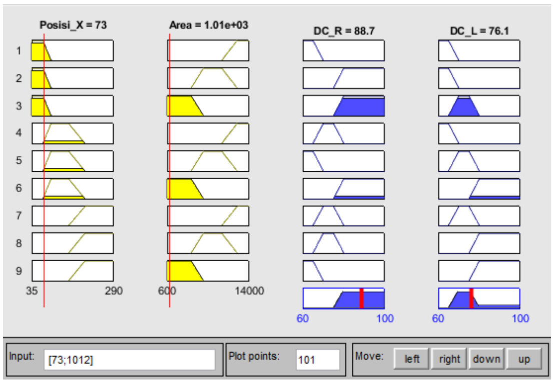

Figure 10: Sofware simulation.

Figure 11: Arduino IDE serial monitor.

The calculation results of the toolbox software are shown in Figure. 10, where the values for the right and left DC motors, respectively, are 88.7 and 76.1, when the input X is 73 and Area 1012. Furthermore, the output from the Arduino IDE with identical X and Area values is shown in Figure. 11. For the right DC motor, the result is 88.56, while that for the left DC motor is 76.17.

$$Z*= \frac{\int_{75}^{79,4}\left(\frac{z-75}{5}\right) z + \int_{35}^{85} 0.88\, z\, dz}{\frac{(100-75)+(100-79,4)(0,88)}{2}} \tag{13}$$

$$Z* = \frac{1776.96053}{20.064} = 88.56 \tag{14}$$

And

$$Z*= \frac{\int_{65}^{69.4}\left(\frac{z-65}{5}\right) z + \int_{69.4}^{75.6} 0.88\, z\, dz + \int_{75.6}^{79.4}\left(\frac{80-z}{5}\right) z + \int_{79.4}^{100} 0.zdz}{\frac{(75.6-69.4+(75.6+65)0.88)}{2} + \frac{((80+75.6)0.88)}{2} + \frac{((100-80)+(100-79.4)0.12)}{2}} \tag{15}$$

$$Z* = \frac{895.15279}{11.764} = 76.09 \tag{16}$$

Software testing of the toolbox and Arduino IDE produced results in accordance with the design. After receiving an X input of 73 and an area of 1012, the robot will move to the left; the manual calculation results are 88.56 for the right DC motor and 76.09 for the left DC motor after comparing with the software output for the same amount of input. Due to the real-time processing required by the Arduino software, there is a slight difference between the manual values and the simulated values. The values generated by Arduino simulation and manual calculation do not differ significantly from each other in the simulation results of the corresponding software.

Error Rate

Table 6: Error Rate

Calculation Type	**Linguistic Term of Motor DC**	
	VRight (PWM)	**VLeft (PWM)**
Arduino IDE	88.56	76.17
Manual Calculation	88.56	76.09
Simulation Software	88.70	76.10

Right Motor

$$\%error = \frac{88.70 - 88.56}{88.70} x100\%$$

$$\%error = 0.158\%$$

Left Motor

$$\%error = \frac{76.10 - 76.17}{76.10} x100\%$$

$$\%error = 0.092\%$$

Based on the test results in Table VII, the comparison of the robot system with the results of fuzzy modeling using simulation support applications, an error of 0.158% for the right motor and 0.92% for the left motor is obtained. By obtaining these error results, the fuzzy logic control method is successfully implemented in this transporter robot system with a success percentage of 99.84% for the right motor and 99.08% for the left motor.

Testing Robot

Testing the robot navigation system is done by placing an object that has been introduced to the sensor, then testing the movement of the robot to follow this stationary and moving object with the results as in Table 5.9. This test is carried out to determine the travel time and the ability of the robot to follow objects with a predetermined distance.

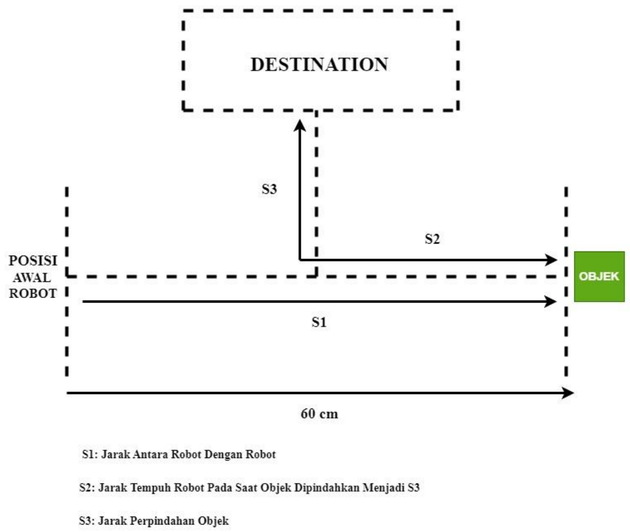

Table 7: Result of robot transporter

No	S1(cm)	S2(cm)	S3(cm)	Waktu (d)
1	60	27	26	13.57
2	40	26	33	11.85
3	25	28	34	9.20

Testing stationary objects is done with a distance of S1, which is the distance between the robot and the object when the test begins. Testing of moving objects is done by combining S3 and S2, S3 is the distance the object moves when the object has traveled half the value of S1, this is called S2. Testing on this moving object is done with the value of S3 against S2 because the robot continues to move even though the object is moved, so the object displacement must be done straight or parallel to the previous object position so as not to change the X Position value too far and only use the Area (distance) value in this test.

Based on the tests in Table 8, the robot can move towards a stationary object and can follow a moving object with a specified distance and move the object according to a predetermined place. The transporter test described here consists of several stages involving horizontal and vertical movement of the robot and placement of objects at the final destination. In the initial stage, the robot starts from the initial position to the left of the S1 path. The first step is horizontal movement along the 60 cm path S1 to reach the object located at the right end of the path. After reaching the object, the robot then switches to path S2, moving vertically upwards. In the next stage, the robot continues its vertical movement through path S3 until it reaches the final destination marked as Destination.

4. Conclusion

Research that has been done on transporter robots by studying objects using a camera sensor (pixy camera). After the object is read, the sensor provides an input value to be processed on the microcontroller (Arduino UNO) which then gives commands to the output, namely the DC motor and gripper to move towards the object that has been recognized at a predetermined speed. in this study using a pixy camera because the object reading is very good and continued by using the fuzzy mamdani method which aims to make the movement of the robot smoother. In this study using a pixy camera because the object reading is very good and continued by using the fuzzy mamdani method which aims to make the robot movement smoother. in this study experiments were carried out using simulation software to calculate the value of the method used. The process of applying the fuzzy logic control algorithm to the robot tranporter, a comparison is made for the results of fuzzy calculations on the system with simulation software, with the results of fuzzy calculations on the system carried out manually. Based on the results of these tests and calculations, the results obtained were 88.56 for the right motor and 76.17 for the left motor in fuzzy calculations with Arduino IDE. The results obtained were 88.70 for the right motor and 76.10 for the left motor with simulation software. Manual calculations were carried out with the results of 88.56 for the right motor and 76.09 for the left motor. Based on hardware testing, it is found that the accuracy of the system built has an average error of 0.158% for the right motor and 0.092% for the left motor. The value obtained in the error, it is known that the robot navigation system test can work well with a value difference that is not too far away. Based on the error value, the success with the system created is 99.84% for the right motor and 99.08% for the left motor.

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