Implementation of Fuzzy Logic Control Algorithm in Mobile Robot Avoider by Using Omnidirectional Vision

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Abstract: Mobile Robot avoider is one of the mobile robot that has capability for moving or maneuvering to avoid obstacles. To do this, mobile robot used many sensors to identify surrounding environment. One of the sensors that can be used in mobile robot avoider is a camera. However, the camera sensor still has a limited viewing angle, to reduce this limitation, we develop a System omnidirectional vision which is a system that capable of providing 360° angle information with just one image so that it can reach the surrounding circumstances. The speed and movement of the robot avoider set automatically by adopting the method of fuzzy logic. In this research, the testing phase is done 2 times on the track corridor of the swivel. The test results show that the mobile robot is maneuvering very well.

Keywords: Fuzzy logic, Mobile robot avoider, Omnidirectional vision

1. INTRODUCTION

Current robot technology always involves in human role. Most of the field work slowly being replaced by robots. Robot avoider is one example of the development of robot technology which can be programmed to avoid obstacles [1]. To be able avoid obstacles, robot avoider requires a sense of vision in the form of sensor.

The camera sensor basically has similar characteristics to the human visual perception. Like the human eye, the angles can be captured by the camera is similar to the human eye point of view that is the direction in which the camera is facing. To find out the circumstances surrounding the camera, The Omnidirectional Vision system is used. This system can provide an angle of 360° with a single image. The system can also be made by pointing the camera towards a convex mirror which can provide information such as distance, angle, object type and speed [2]. Setting the pace and movement of the robot requires a method to regulate the movement of the robot properly. In this paper, Sugeno Fuzzy Logic methods has been used

2. THEORY

A. Robot Avoider

In general robot avoider designed using 3 distance sensors. But to design robot avoider that uses an omnidirectional vision system only requires one camera as a sensor.

B. Digital Image

The digital image is image data in a number representing the level of gray (image in black and white) or color coordinates (color image). In general, digital image has a certain length and width expressed in pixels, so that the image size is always rounded. Computers store only numerical data that show great intensity of each pixel. Digital image obtained through the sampling process three-dimensional object by an image capture system which then formed a matrix in which the elements value of the intensity of light [4].

C. Fuzzy Logic

Based on the theory of fuzzy logic could be worth a value of true and false simultaneously. The amount of truth and error values in fuzzy depending on the weight of its membership. Fuzzy logic has an advantage that had reasoning similar to human reasoning. This is because the fuzzy system has the ability to respond according to qualitative information, inaccurate and ambiguous [5]. A fuzzy rule-based system consists of three main components: Fuzzyfication, Inference and Defuzzyfication. The block diagram of the fuzzy rule-based system is shown in Fig 1.

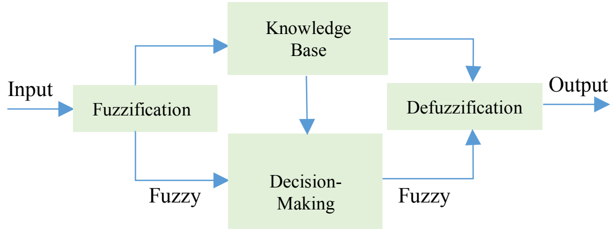

Fig.1 Block Diagram of Rule Based Fuzzy System

3. METHODS

In this study, the design of the system is divided into two main parts: hardware design and software design. Both parts are then integrated to produce a system that is interconnected.

A. Hardware Design

Hardware design phase is done in 2 stages: design robot avoider and camera placement and design of glass omnidirectional vision. There are several devices that are used in the design robot avoider using omnidirectional vision, namely wireless cameras, PC / Laptop, microcontroller and DC motors. Fig 2 shows the Block Design Robot avoider using omnidirectional vision.

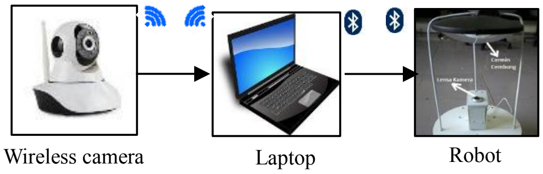

Fig. 2 Block Design Robot avoider using omnidirectional vision

Wireless camera which is used as a sensor used to capture the image around and used as input. Images are captured are sent and processed directly on the computer. Computers are used to perform image processing to produce a pixel value. The pixel values are then sent to the microcontroller on the robot avoider to be forwarded to the motor.

The design of the camera position and the glass omnidirectional vision must be done accurately. This is done to get a proper perspective and spacious. The position of the camera facing up and placed on the side of the ring-shaped robot. While the convex mirror mounted just above the camera. The design of the camera position and the mirror can be seen in Fig 3.

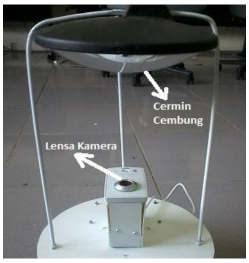

Fig.3. The design of the camera position and mirrors

In a normal camera viewpoint is still not widely produced and still does not meet the data needs to capture the entire image environment, then the omnidirectional vision system is able to provide a field of view (FOV) is greater for the camera.

B. Software Design

Software design in this study consists of two parts, the design of the program for image processing and design of algorithm's fuzzy logic. The block diagram for software design is shown in Fig 4.

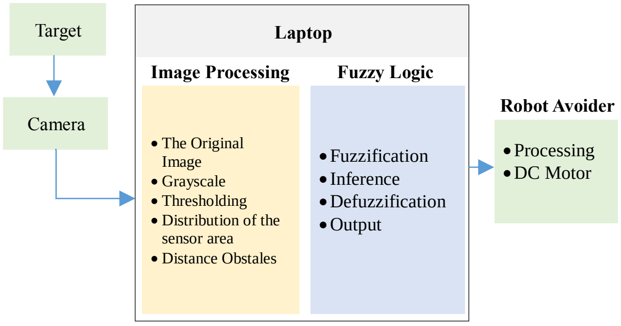

Fig. 4. Block Diagram of Software Design

- Image Processing

Stage image processing consists of several parts, among others, to get digital images (original), changing the original image into grayscale, change the image grayscale into a binary image by threshold method, the zoning and get the distance obstacle sensor. Stages of image processing stages can be seen in Fig 5.

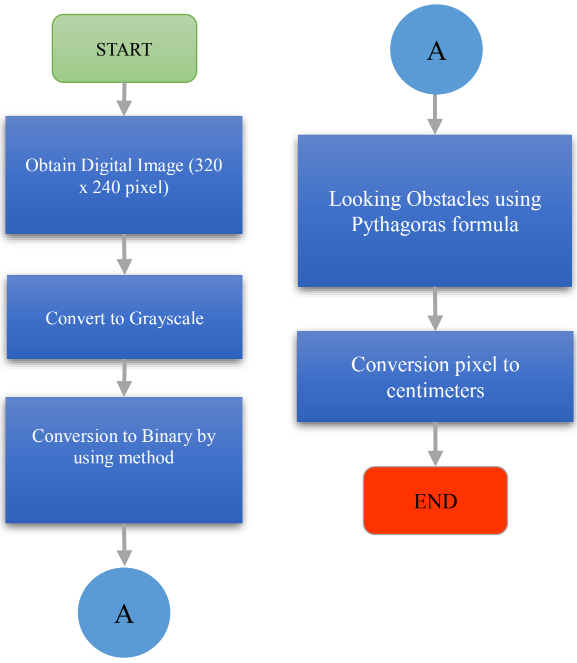
START
Obtain Digital Image (320 x 240 pixel)
Convert to Grayscale
Conversion to Binary by using method
A
A
Looking Obstacles using Pythagoras formula
Conversion pixel to centimeters
END

Fig. 5. The stages of image processing

- Sensor Regional Distribution

At this stage robot standpoint of 180° is divided into 3 parts. Each section is divided into six laser angle to within 10° angle. Pictures of districts every 10^0 to the front can be seen in Fig 6.

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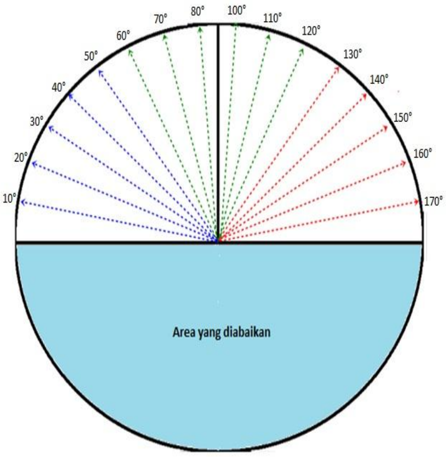


Fig. 6 Distribution region Each 10 Degrees Forward

Fig 6 shows that there is a laser at a different angle laser blue, green and red. Blue laser sensors to indicate the left, a green laser for middle and red laser sensor to sensor right.

- Getting the distance obstacle

After the distribution area and distance sensor carried obstacle has been obtained, the next step is to convert the values *pixel* to the centimeter to get the distance obstacle. To change the value of the pixel into centimeters on the sensor calibration process is required. Table 1 shows the results of test readings on the camera pixel value.

TABLE 1. RESULTS OF TESTING READING VALUE PIXEL CAMERA

Obstacle distance (Cm)	Pixel Values
16	50
20	59
25	70
30	80
35	88
40	95
45	101
50	106
55	111
60	115
65	118
68	120

The calibration process is done by reading the values pixel of each range used from a distance of 16 cm to 68 cm. This is done to generate a sensor output value in the form of the actual distance. A sensor calibration graph can be seen in Fig 7.

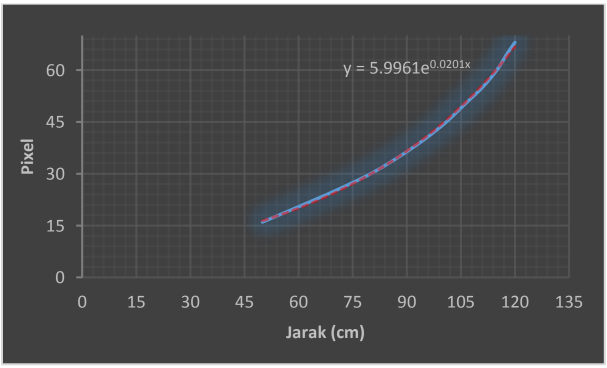


Fig. 7. Graph of the calibration Sensor

Based on the graph in Fig 7 is obtained an equation shown in (1), which is an exponential equation used to convert pixel values into a distance value (cm).

$$Y = 5.9961\ e^{0.0201x} \qquad (1)$$

Where *y* is the distance and *x* is the pixel value.

- Fuzzy Logic Algorithm

Fuzzy logic is applied for controlling the motor on the robot avoider. Fig 8 shows the stages of the design of fuzzy logic algorithm.

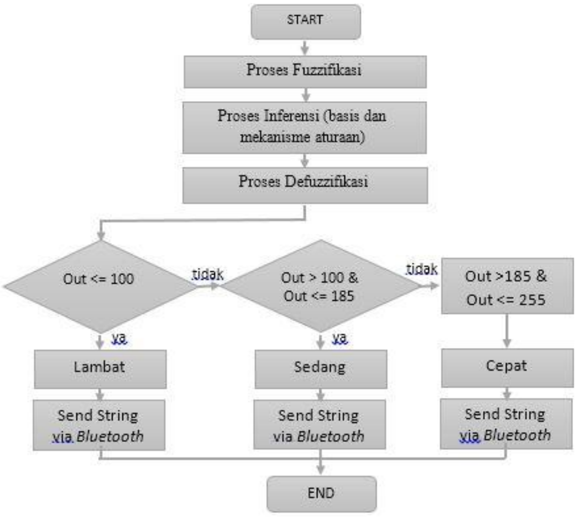


Fig. 8 Stages Design Algorithm's Fuzzy Logic

- The process of fuzzification

The Process is performed to convert an input form definite value (crisp input) into fuzzy input (linguistic variables) is usually presented in the form of associations *fuzzy* with a membership function respectively. Of the three parts of the sensor area created three groups according to their function and purpose of each. The determination of the distance of the linguistic variables is done manually. Formation of a linguistic variable based on the input of the camera sensor can be seen in Table 2.

TABLE 2. VARIABLE LINGUISTICS BY INPUT CAMERA SENSOR

Distance (cm)	Variable Linguistics	Information
0 to 45	Dekat (near)	Dk
18 to 67	Sedang (middle)	Sd
45 to 70	Jauh (far)	Jh

According to Table 2 illustrates that the compilation fuzzy is determined by membership function is dekat, sedang, jauh. The Input membership function graph shown in Fig 9.

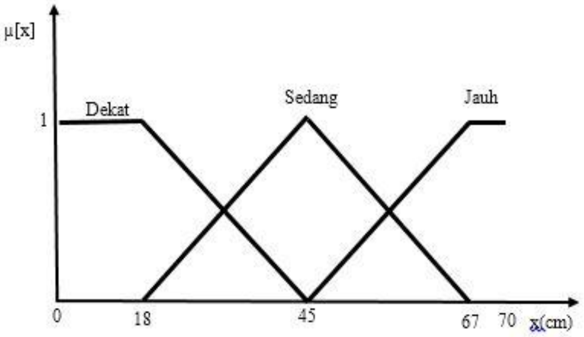


Fig. 9 Graph Input Membership Function

Based on the membership function as the formulation function as shown in (2) to dekat, (3) for sedang and (4) for jauh.

$$\mu\, dekat[x] \;=\begin{cases} 1 & untuk \quad x \leq 18 \\ (45-x)/(45-18) & untuk \quad 18 < x < 45 \\ 0 & untuk \quad x \geq 45 \end{cases} \qquad (2)$$

$$\mu\, sedang[x] = \begin{cases} 0 & untuk \quad x > 18 \\ (x-18)/(45-18) & untuk \quad 18 < x < 45 \\ (67-x)/(67-45) & untuk \quad 45 \leq x < 67 \\ 0 & untuk \quad x \geq 67 \end{cases} \qquad (3)$$

$$\mu\, jauh\, [x] \;=\begin{cases} 0 & untuk \quad x < 45 \\ (x-45)/(67-45) & untuk \quad 45 \leq x < 67 \\ 1 & untuk \quad x \geq 67 \end{cases} \qquad (4)$$

- Rule Base

In this study robot avoider has three parts of the sensor that is part of the front, left and right with three sets fuzzy. That is the rule base of these systems have a 27 basis rule. Table 3 shows the rule base on fuzzy logic systems are designed.

TABLE 3. BASIS OF FUZZY LOGIC RULES DESIGNED

Distance	Dekat (dt3)		Sedang (sd3)		Jauh (jh3)	
Dekat dekat	C	L	C	L	C	L
Dekat sedang	S	S	S	L	S	L
Dekat jauh	C	C	S	L	S	L
Sedang dekat	L	L	L	L	C	L
Sedang sedang	L	S	S	S	S	L
Sedang jauh	L	S	S	S	L	S
Jauh dekat	L	C	L	C	S	S
Jauh sedang	L	S	C	L	L	L
Jauh jauh	L	S	S	L	C	C

L: Lambat(slow), C: Cepat(fast), S: Sedang(middle)

- Mechanism Rules

After designing the next rule base is to use regulatory mechanisms to generate fuzzy output. Mechanism rules using Sugeno method for the calculation process are suitable for use as a robot control to avoid the obstacle. Functional implications were used that operation Max-Min on the function of a specific membership and generate fuzzy output as shown in (5).

$$\mu\ (y) = \max\ [\min\ [\ \mu_{A1}(input\ (i)),\ \mu_{A2}(input\ (j)),\ \mu_{A1}(input\ (k)), \ldots\ ]] \qquad (5)$$

The set of fuzzy output in the form of regulatory mechanisms output singleton with a range 0 to 255 are mapped into 3 linguistic variables. The third variable is slow with a value singleton of 100, while the singleton 185 and fast with singleton 255. The graphical *output* of used in the operation Max-Min is shown in Fig 10

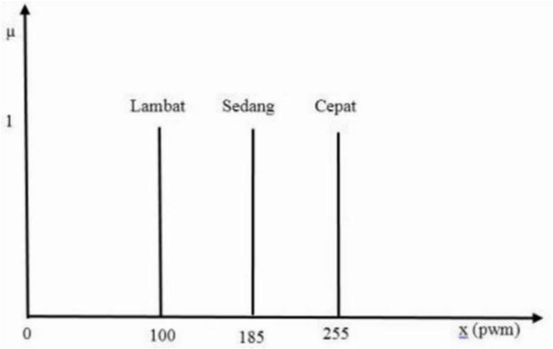


Fig. 10 Graph output membership function

- Defuzzification

To determine the defuzzification process steps accomplished by using the equation Weight Average for the method of taking the average value using a weighted form of membership degree. Where equation for defuzzification shown in (6).

$$PWM \;=\; \frac{\sum \mu(y)\, y}{\sum \mu(y)} \qquad (6)$$

Where the *PWM* is output value, *y* is the value of crisp and *μ(y)* is the degree of membership of a values crisp *y.*

4. RESULTS

Tests were conducted in this study consists of several stages.

A. Testing Laser Camera

Laser test is intended to determine the camera's performance in detecting obstacle with various angles obtained. Fig 11 shows the output of the camera to capture an object as an obstacle. From the test results corner, amounting to 18 in increments of movement every 10^0 starting from the point 0^0 up to 180^0 at different distances. The sensor is able to know the whereabouts of a hindrance given black color.

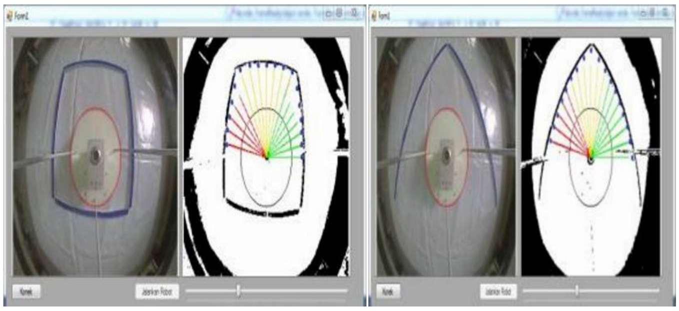
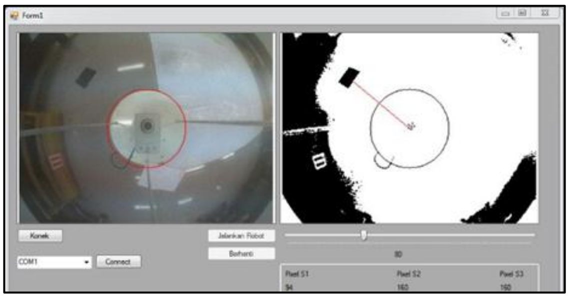


Fig. 11 Output Results Capture Camera Against Objects As obstacle

The next test is done with a single point of laser range finders on each sensor area to ensure that the obstacle can be detected by the system that has been created. There are several tests performed on each of the sensors is in the sensor area left as seen in Fig 12.



Pixel S1 94
Pixel S2 160
Pixel S3 160

Fig. 12 Experiment Camera Sensor Detects Obstacles in the Left

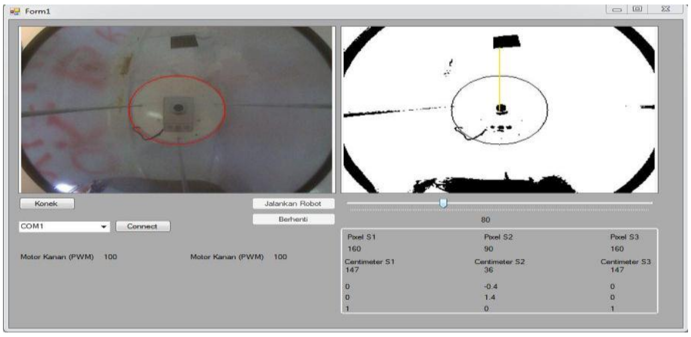
Fact distance between the robot with the obstacle on the left sensor is 39 cm and a pixel is read sensor is 94 pixels. To find the coordinates (x, y) at the pixel 94 with an angle of 30° is to do manual calculations using the (7) while to calculate the y coordinate used (8).

$$x = \cos\ (rad) * j \qquad (7)$$
$$y = \tan\ (rad) * x \qquad (8)$$

Where *j* is valuing the pixel and *rad* is the radian (rad = (angle * phi) / 180°).

Based on the results of testing that has been done shows that the value of radians on coordinates (x, y) is 0523 x is 81 and y is 47. So the point coordinates (x, y) from the value of the pixel 94 is a 30 ° angle (81, 47).

In the second experiment performed obstacle detection stage in the middle sensor as seen in Fig 13.

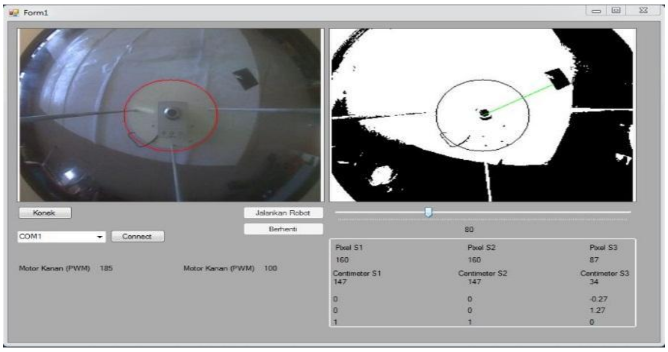


Motor Kanan (PWM) 100 Motor Kanan (PWM) 100

Pixel S1	Pixel S2	Pixel S3
160	90	160
Centimeter S1	Centimeter S2	Centimeter S3
147	36	147
0	-0.4	0
0	1.4	0
1	0	1

Fig. 13 Experiment Camera Sensor Detects Obstacles In the Middle

In the middle sensor testing, the actual distance between the robot obstacle is 36 cm and a *pixel* that is 90unreadable. Pixels Experiment Camera Image Sensor Detects Obstacles In The Right can be seen in Fig 14.



Motor Kanan (PWM) 185 Motor Kanan (PWM) 100

Pixel S1	Pixel S2	Pixel S3
160	160	87
Centimeter S1	Centimeter S2	Centimeter S3
147	147	34
0	0	-0.27
0	0	1.27
1	1	0

Fig 14 Experiment Camera Detects Obstacles In The Right Sensor

Test data on the right sensor for the actual distance between the robot obstacles is 34 cm and pixel read sensor is 87 *pixels*. To prove that the 87 pixels are 34 centimeters, then do the calculation using the equation $y = 5.9961e^{0.0201x}$ by *y* is the value of the distance in *centimeters* and x is the distance in *pixels*. The results obtained showed that the distance (y) worth 34.45 cm. Based on manual calculations show that the results obtained resemble the results of tests performed.

In the fourth experiment performed on all parts of the obstruction detection sensors as shown in Fig 15.

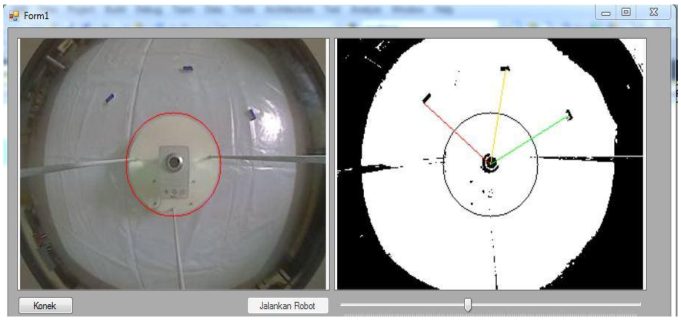


Fig. 15 Experiment Camera Detects Obstacles In each area sensor

Based on Figure 15 it can be seen that the hitch on each sensor area can be detected either by a system that has been created. This experiment proves that the designed system is able to run well.

B. Robot Navigation System Testing

Testing was conducted to determine the performance of fuzzy algorithm's for navigation systems used on the robot. Testing is done by running the robot on track or corridor with 1 round. The shape of the corridor to be used can be seen in Fig 16.

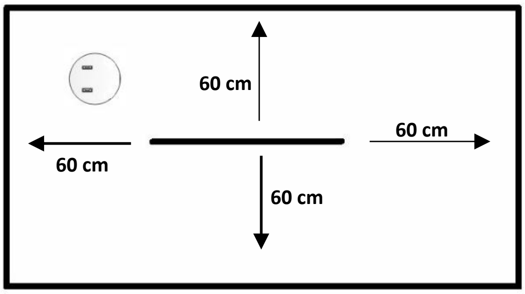


Fig. 16 The arena testing for testing robot motion

Fig 16 shows that the state in which the location of the robot avoider move. Arena installed a black object in which the distance between the object with other objects as far as 60 cm. So the object can be identified, then the object is given dark color. Background of the arena fitted with white or bright colors to produce contrast differences.

To get the robot ideal trail then performed manual measurements and distance between obstacles. Figure 17 shows the robot's path is ideal in corridors 1 lap.

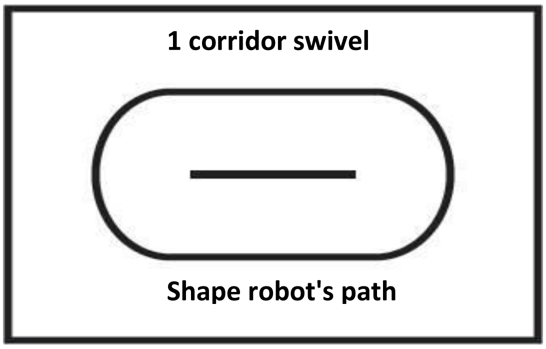


Fig. 17 Form of the Ideal line robot movement

Fig 17 is used as a reference for comparison of test results. The results that resemble the shape of the ideal track test results that most good. Test results of the first round of the corridor can be seen in Fig 18 and Fig 19.

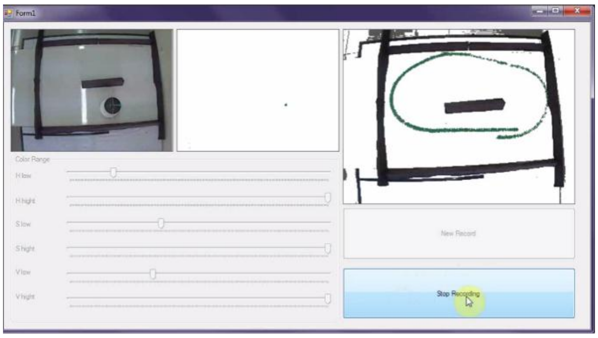


Fig. 18 Trajectory Experiment 1 Running Track 1 Round

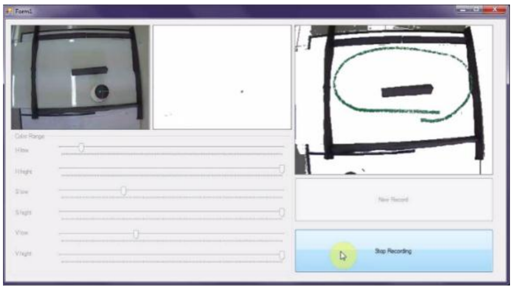
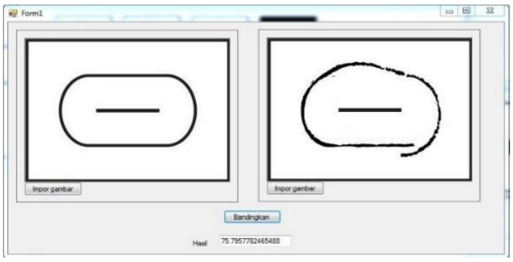


Fig. 19 Trajectory Experiment 2 Tracks 1 Round Track

To find out the test results was more similar to the ideal paths robot than used method of calculating the Euclidean distance, comparing the results of the test image with the image of the ideal robot's path. To calculate the distance Euclidian then used equation (9).

$$j(v_1, v_2) = \sqrt{\sum_{k=1}^{N}(v_1(k) - v_2(k))^2} \qquad (9)$$

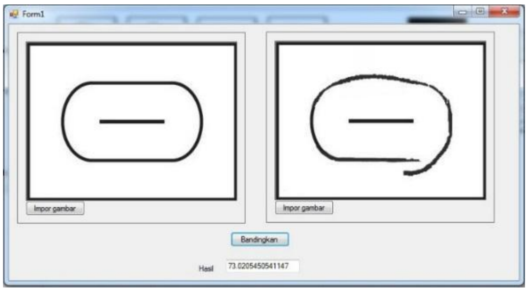
Where v_1 and v_2 is two vectors *(pixels)* that the distance will be calculated and N denotes the length of vector (pixel). To compute the Euclidian distance on the results of experiments with the robot ideal path taken by trajectory of each. The results showed that the better or similar trajectory generated, then the distance is getting smaller. Fig 20 is the result of the comparison in the test 1.



Hasil 75.7957782465488

Fig. 20. The comparison Trajectory of Test 1

Trajectory Comparison in Fig 20 shows that the results of Euclidian worth 75.796. Fig 21 is the result of the comparison Trackjectory on testing 2.



Hasil 73.0205450541147

Fig. 21. The comparison Trajectory Experiment 2 in this study

Results *Euclidian* based on Fig 21 is 75.796. Having obtained the value of each Euclidian then so do the maximum value search *Euclidian* distance. Fig 22 shows the maximum value outcome *Euclidian* distance.

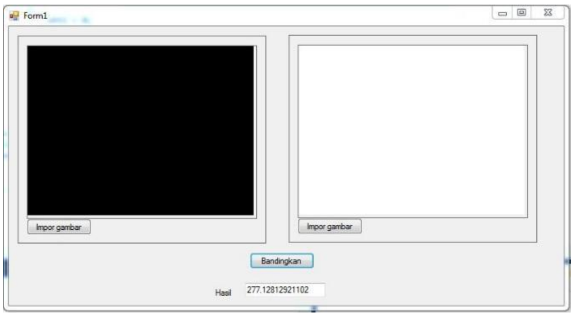


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Fig 22. Results of *Euclidian* distance maximum value

Based on the maximum value *Euclidian* distance can be searched percentage yield comparisons to find out the results trajectory that more closely tracks ideal robot. The percentage value can be obtained using the equation "10"

$$p = 100\% - ((a/b) \times 100\%) \qquad (10)$$

Where p is the percentage of similarity, a is the Euclidean distance, b is the maximum Euclidian distance

By use of the (10) percentage trajectory similarity can be calculated so that in one experiment obtained a percentage of 72.65% and for the calculation of the percentage of similarity in trial 2 was obtained 73.65%. Based on the percentage of the tests that have been done show that the similarity track actual robot approaching the ideal path.

5. CONCLUSION

Based on test results and observations on the robot avoider system uses system an omnidirectional vision can be concluded that the system can help reduce the amount of sensor on the robot. And the percentage of the system's success in detecting trajectory ideal of 73.15%.

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