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Painting robot with three axis motion

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Abstract: Using a brush, paint was put directly onto the painted surface. Occasionally, undesirable results occur, such as paint layering or streaks sticking around. Because spray guns produce superior paint results, a robot that can control the movement of the spray gun to apply paint was created. A painting robot with three axes of motion is similar to an arm. The x, y, and z axes allow the robot to move left-right, up-down, and back-front. It has a spray cannon as its end effector. The distance between components and the spray cannon is measured using an ultrasonic sensor; the test sensor distance readings have a bigger average error when the sensor monitors near distances, such as between 4 and 8 cm. The average inaccuracy decreases as the test reading distance is raised from 10 cm to 14 cm. A paint distance of 10 cm, an air pressure of 80 psi, and a spray gun arm movement speed of 25 rpm can all lead to better painting results. The maximum volume that can be painted is 97,517.5 cm3, with an average x-axis movement of 74.6 cm, y-axis movement of 14.8 cm, and z-axis movement of 88.2 cm. The arm's rotation is used to calculate the required angular rotation for painting components. The arm must rotate to the left to paint the component's left side at an angle of 10°, its back side at an angle of 100°, its right side at an angle of 190°, and only the front side at the necessary angle of 90°.

Keywords: Spray gun; arm robot; paint; ultrasonic

1. INTRODUCTION

Modern technical advancements have permeated every industry. In the industrial world, several products are mass-produced with extreme accuracy and precision, often by robots [1]. An arm robot is one kind of robot that is utilized in the industrial sector. A robot arm is a type of movement mechanism with a degree of freedom (DOF) that consists of multiple elements connected in series to an axis that can move in a circular or shifted pattern [2].

Paint is applied directly to the painted surface when painting with a brush. There are instances when the outcomes are unsatisfactory due to the uneven application of paint, which leaves behind paint streaks or paint that accumulates when the surface is touched. Using a spray gun will yield better painting results because it releases paint gradually or condenses it so that it doesn't build up [3],[4].

Motorcycle rim painting machine and automatic dryer is the name of the finished project [5],[6]. Three DC motors and one spray gun are used in this equipment to apply paint. For the spray gun to reach every part of the rotating rim, the first DC motor rotates the rim; the second DC motor shifts the rim's position from the right to the left; and the third DC motor moves the rim from the painting location to the drying location three DC motors and one spray gun are used in this equipment to apply paint. For the spray gun to reach every part of the rotating rim, the first DC motor rotates the rim; the second DC motor shifts the rim's position from the right to the left; and the third DC motor moves the rim from the painting location to the drying location [7]. Two fans are located in the drying area and are utilized to help dry the wheel rims [8]. The spraying of the paint is inconsistent due to the spray gun's inability to follow the rim's curve, which is one of this machine's drawbacks. As the spray gun's position cannot be altered while painting, this machine is also unable to modify the distance between the spray gun and the rim [9].

Drawing from earlier studies, a prototype robot arm was created to paint an ATMega 8535 microprocessor component that focused on three axes of movement: x, y, and z [5], modifying the painting distance with an ultrasonic sensor. Spray guns are useful for painting pre-determined parts before they are used. The robot arm model is utilized since it facilitates easier spray gun reach of painting components due to the movement of each joint and link.

2. METHOD

To gather the essential data for this research, it is necessary to perform literature reviews and investigations into previously constructed machines before building a robot. Robot testing is done to make sure the tool performs as intended and meets the desired outcomes [10].

2.1 System design

A block diagram and flowchart are required when developing a system, and the block diagram should be able to explain the system's overall operation. Three-axis movement in a robot block diagram Figure 1.

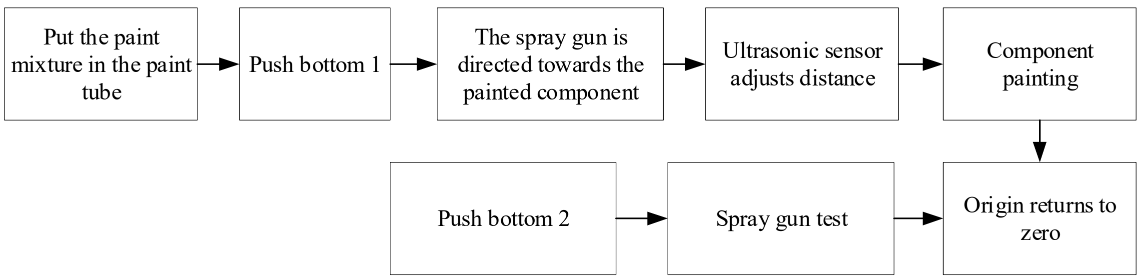


Figure 1. Block diagram

The block diagram indicates that the paint mixture must be put into the paint tube before the process can begin. The ultrasonic sensor controls the painting distance, and when push button 1 is depressed, the spray gun will move in the direction of the component that has to be painted. The spray gun will return to its starting location, or the arm's zero point, once the painting is complete. To determine whether the paint in the spray gun tube is still spraying or has run out, press button 2 [11].

When designing a three-axis robot, a flowchart that explains the intended control system's operation is necessary. The utilized flowchart is shown in Figure 2.

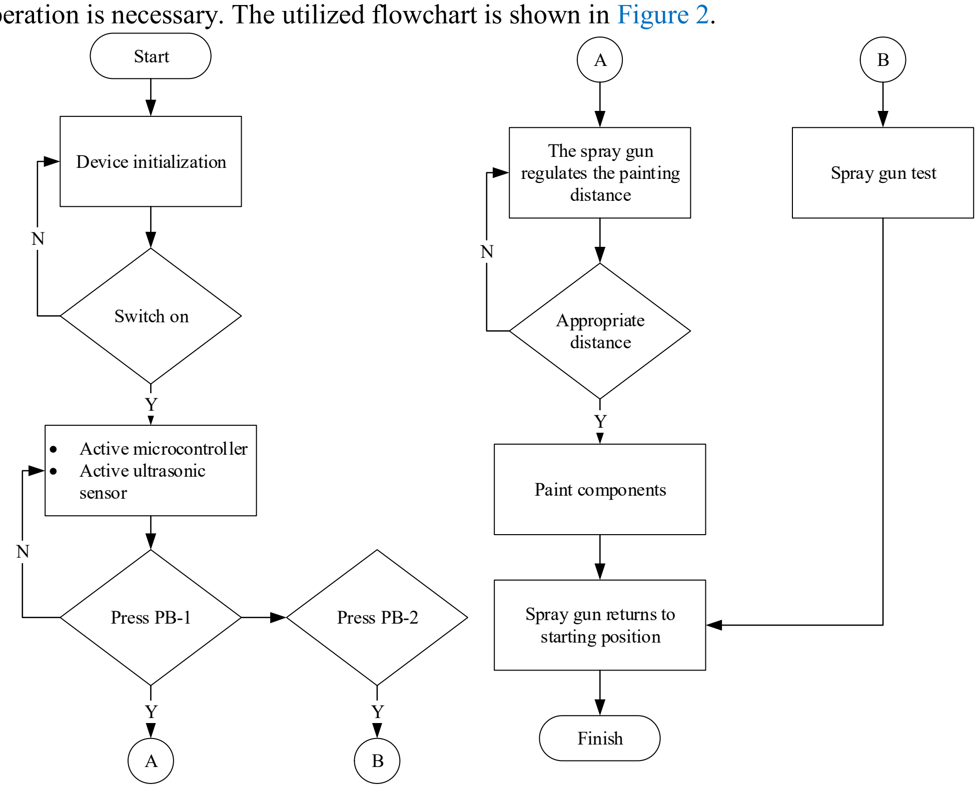


Figure 2. Flowchart

This robot's control system makes use of an ATMega 8535 microcontroller [12], an ultrasonic sensor to determine how far the paint gun is from the component that needs to be painted, and two pushbuttons: pushbutton 1 initiates painting and continues until the job is completed, while pushbutton 2 only serves as a test spray gun to make sure the paint is applied [13]. Is the spray gun tube empty or still available.

2.2 Mechanical design of a painting robot with three-axis movement

The mechanical design was carried out using Solidworks software to make it easier to build the robot and obtain the load mass from the torque of the motor that you want to move. The robot design from an isometric view can be seen in Figure 3 and the robot arm design can be seen in Figure 4.

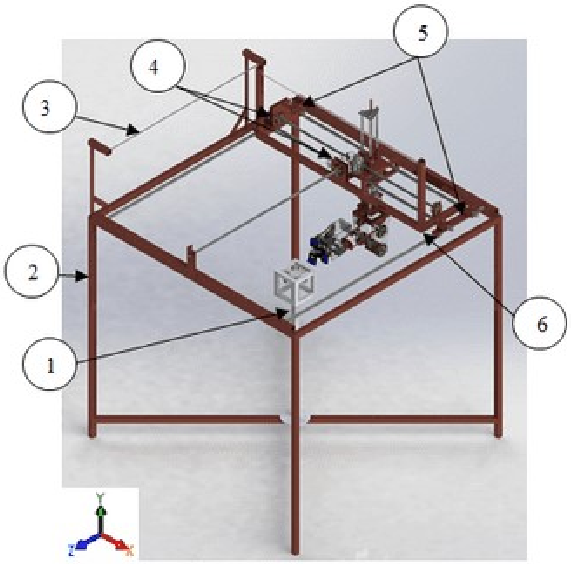


Figure 3. Isometric view of the robot

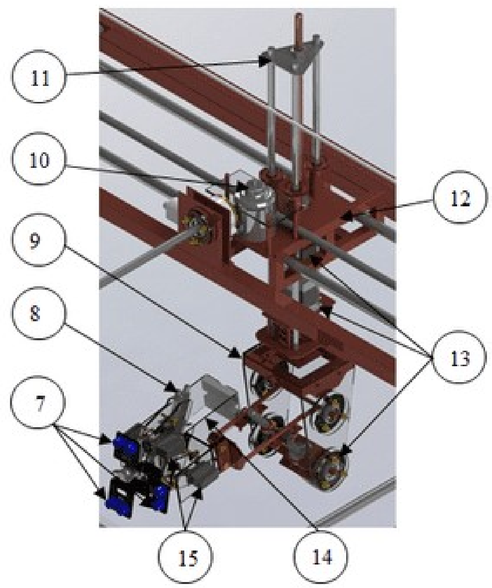


Figure 4. Robot arm design

Information:

1. Pole for placing components
2. Robot Framework
3. Hose hanger
4. DC motors
5. Sliding z-axis
6. Z-axis drive
7. Ultrasonic sensor
8. Spray guns
9. Arm twister
10. Paint tube
11. Y-axis drive
12. Arm position
13. Stepper motors
14. The base for spray gun holder
15. Servo motors

This three-axis robot was constructed using hollow iron measuring 30 mm by 30 mm for the frame, 1 mm thick iron plate, hollow iron measuring 20 mm by 20 mm, and 5 mm thick acrylic for the arms. M16x2 threads are used to move the robot arm along the x, y, and z axes. The robot arm's end effector is the spray cannon.

2.3 Electronic design

This electronic design is useful for activating the controller system and running stepper motors and servo motors [14]. The circuit used is a single chip circuit and a power supply circuit.

2.4.1 Single-chip circuit

The single chip circuit is used as a control circuit to activate several electronic components to easily adjust the desired arm position. Consists of a microcontroller, ultrasonic sensor, dc motor, servo motor, and stepper motor [15],[16]. The circuit image can be seen in Figure 5.

Figure 5 a single chip circuit, each electrical component has it is function, where the ultrasonic sensor is responsible for regulating the ideal painting distance [17],[18]. The DC motor controls movement along the x and y axes, the stepper motor controls movement along the z-axis and the arm angle, and the servo motor controls the rotation of the spray cannon and pulling on the lever. The ATMega 8535 microcontroller is utilized, and it controls the transmission of activation orders to sensors and motors [19].

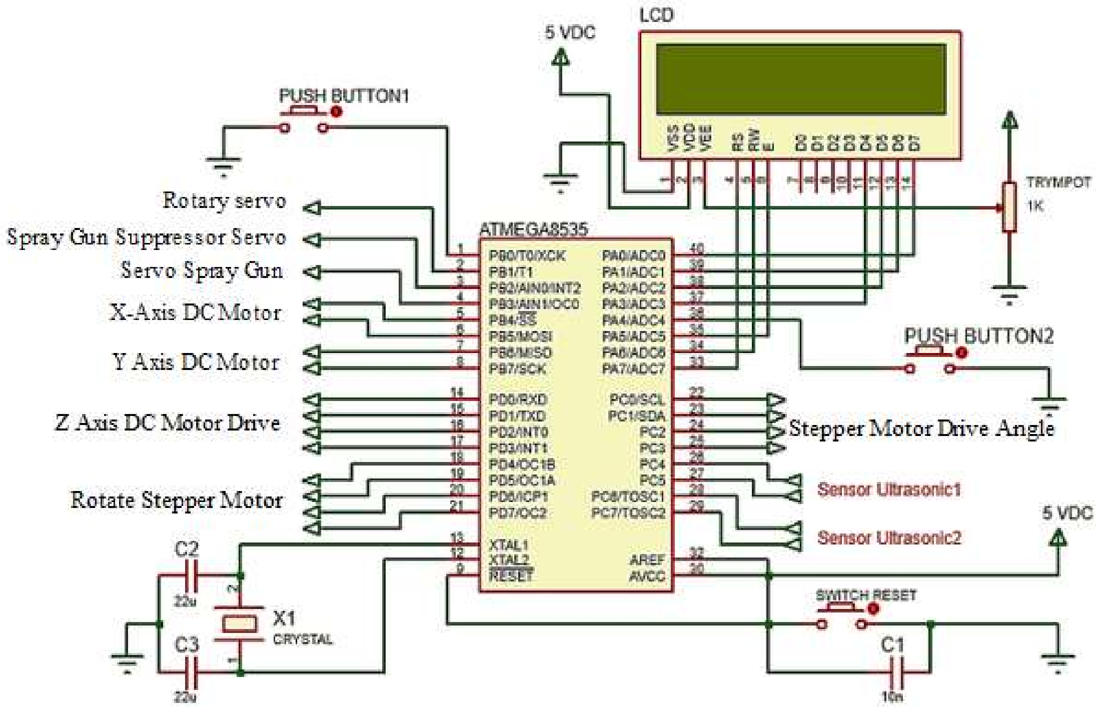


Figure 5. Single-chip circuit

2.4.2 Power supply circuit

The power supply circuit is a circuit used to flow and regulate the power/energy that will be supplied to the load. To see the power supply circuit, see Figure 6.

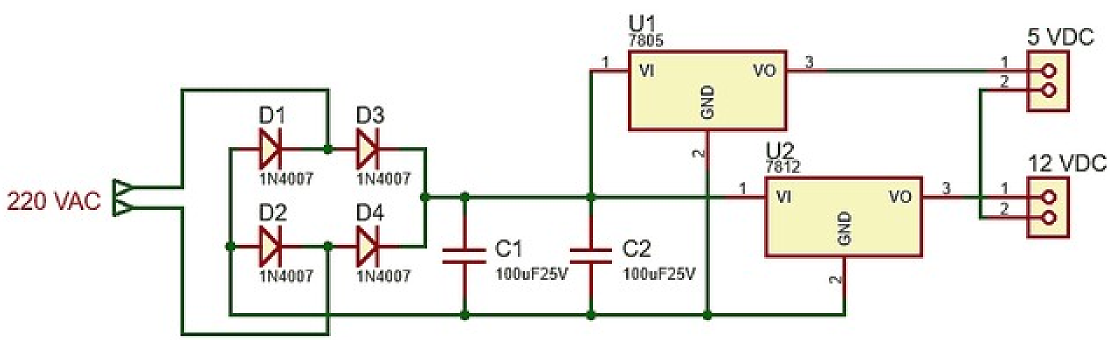


Figure 6. Power supply circuit

The input voltage of 220 VAC is transformed into two supply outputs, a 5 VDC voltage output using the 7805 IC regulator and a 12 VDC voltage output using the 7812 IC regulator, based on the power supply circuit shown in Figure 6. The microprocessor, sensors, and servo motors are supplied with power via the 5-volt direct current output. In the meantime, stepper motors and DC motors are supplied with an output voltage of 12-volts DC.

3. RESULTS AND DISCUSSION

After carrying out several series of designs, here is a prototype of a painting robot with three-axis movement. Figure 7 is a front view of the entire robot and Figure 8 is a front view of the robot arm.

Figure 7. Front view of a painting robot with three-axis movement

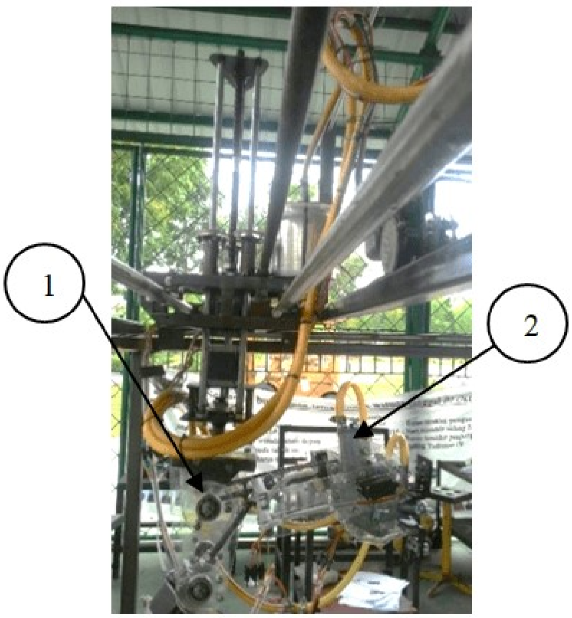


Figure 8. Front view of the robot arm

Information:

1. The physical shape of the robot arm
2. Spray gun

To find out the results of designing and making a Painting Robot with Three-axis movement, several tests were carried out as follows:

3.1 Sensor testing

Sensor testing was carried out by measuring the distance read on the ultrasonic sensor [12]. Sensor distance measurements were carried out at distances of 4 cm, 6 cm, 8 cm, 10 cm, 12 cm, and 14 cm in 5 trials. To obtain the average value of sensor testing error using equation (1),

$$\text{Average error value} = \frac{\text{total error overall}}{\text{number of tests}} \tag{1}$$

To obtain the average value of the sensor testing distance, use equation (2),

$$\text{Average value of distance} = \frac{\text{total Overall distance}}{\text{number of tests}} \tag{2}$$

To determine the average distance and average error from each sensor distance reading test that is conducted, equations 1 and 2 are required. Following the test Table 1 displays the sensor test results that were acquired.

Table 1. Sensor testing

Testing Distance (cm)	Trial-										Average	
	1		2		3		4		5			
	Distance (cm)	Error (cm)	Distance (cm)	Error (cm)	Distance (cm)	Error (cm)	Distance (cm)	Error (cm)	Distance (cm)	Error (cm)	Distance (cm)	Error (cm)
4	3	1	2,6	1,4	4,2	0,2	2,6	1,4	4	0	3,5	0,8
6	5	1	5,1	0,9	5,5	0,5	5,4	0,6	5,4	0,6	5,3	0,72
8	6,8	1,2	7,1	0,9	7,5	0,5	7,5	0,5	7,4	0,6	7,3	0,74
10	9,5	0,5	9,2	0,8	9,4	0,6	9,4	0,6	9,5	0,5	9,1	0,6
12	11,4	0,6	11,6	0,4	11,6	0,4	11,2	0,8	11,6	0,4	11,5	0,52
14	13,6	0,4	13,9	0,1	13,8	0,2	14	0	13,9	0,1	13,8	0,16

Table 1 it is known that the reading test distance of the sensor is 4 cm with an average distance read by the sensor of 3.48 cm, the test distance is 6 cm with an average distance read by the sensor of 5.28 cm, the test distance is 8 cm with an average distance read by the sensor 7.26 cm, Test distance 10 cm with an average distance read by the sensor 9.14 cm, Test read distance sensor 12 cm with an average distance read by the sensor 11.48 cm and Test read sensor distance 14 cm with the average distance read by the sensor is 13.84 cm.

There are still errors in the sensor readings, this affects the paint thickness results on the components because the painting distance is far or close. The sensor test graph can be seen in Figure 9 which explains the average level of error in measuring the sensor reading distance from 4 cm to 14 cm.

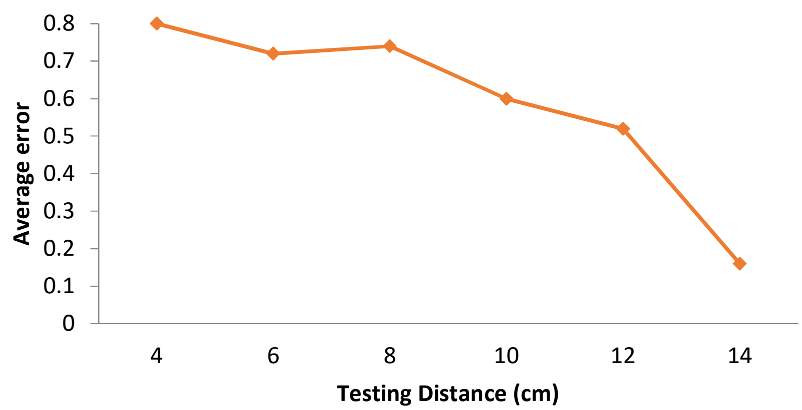


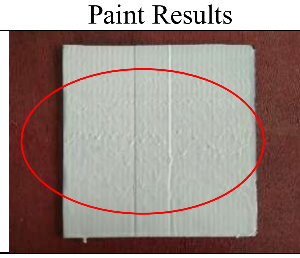
Figure 9. Sensor test graph

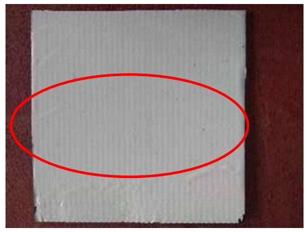
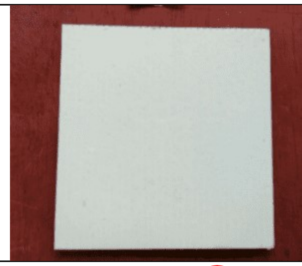
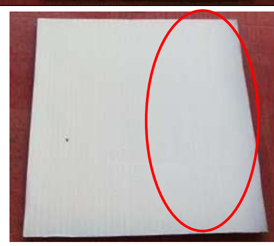
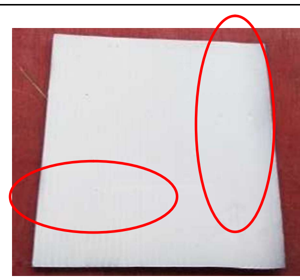
The trendline sensor testing graph shows that there was a significant inaccuracy at 4 and 6 cm in the distance reading test. After that, the error level decreased to 14 cm in the distance measuring test. When the sensor reads a very near distance, there is a larger error, and when it reads a considerable distance, there is a lower error.

3.2 Testing of painting results

To determine the optimal painting distance, painting distance testing is done. Because of the various painting distances, the painting results have variable thickness levels. Table 2 shows the levels of painting thickness.

Table 2. Paint thickness levels

No.	Paint Thickness Ratings	Paint Results	Information
1	Paint builds up too much		In the circle, you can see paint buildup on almost all components.

No.	Paint Thickness Ratings	Paint Results	Information
2	Paint is almost even		Chat stacking is only in the bottom area of the component located inside the circle.
3	Paint evenly		There is no paint buildup and the paint results are not streaky.
4	The paint is starting to streak		The results of the painting are faintly visible in the circle.
5	The paint is streaky		The components visible in the circle on the right and bottom have multiple areas that are not painted.

There are five different paint thickness levels: excessively stacked paint is the first, and nearly even paint is the second. Paint continues to accumulate on the component surfaces at these two stages. There is no accumulation or streaky paint on the third level when the paint is applied evenly. The paint is beginning to streak at the fourth level, and it is streaking at the fifth level. The paint results obtained at the fourth and fifth levels include component pieces that have been painted over. The third level is the best painting outcome based on the paint thickness table levels. The components were then subjected to a spray gun painting reach test. The components' measurements were 14.5 cm by 14.5 cm in length and width, and the spray gun's position for the component painting test was perpendicular to each other. Spray guns require 80 psi of air pressure, which is equivalent to 5.5 bar. The motor movement's painting speed on the x-axis is 25 rpm, the motor speed on the y-axis is 34 rpm, and the motor speed on the z-axis is 19 rpm. Table 3 displays the results of the painting range test.

Table 3. Testing spray gun painting range

Paint Thickness Ratings	Pengujian Jangkauan Pengecatan																	
	4cm			6cm			8cm			10cm			12cm			14cm		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Paint builds up	✓	✓	✓	✓	✓	✓												

Paint Thickness Ratings	Pengujian Jangkauan Pengecatan																	
	4cm			6cm			8cm			10cm			12cm			14cm		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
The paint is starting to spread evenly							✓	✓	✓									
Paint evenly										✓	✓	✓						
The paint is starting to streak													✓	✓	✓			
The paint is streaky																✓	✓	✓

Table 3 shows that for every test distance, the painting range test was conducted three times. Data obtained from tests at 4 cm, 6 cm, and 8 cm painting distances indicated that paint deposits persisted on the components. The painting results are even when tested at a distance of 10 cm. The paint results are erratic when tested at 12 cm, and 14-centimeter distances. The testing data indicates that the painting distance is 10 cm.

3.2 Testing the movement of the robot arm.

This test aims to determine the distance traveled by each axis, the test will be carried out on the movement of the arm on the x-axis, y-axis, and z-axis.

3.2.1 X-axis arm movement test

The test is carried out to find the maximum distance the arm can travel in the x-axis. A schematic of the test from a top view of the x-axis arm can be seen in Figure 10.

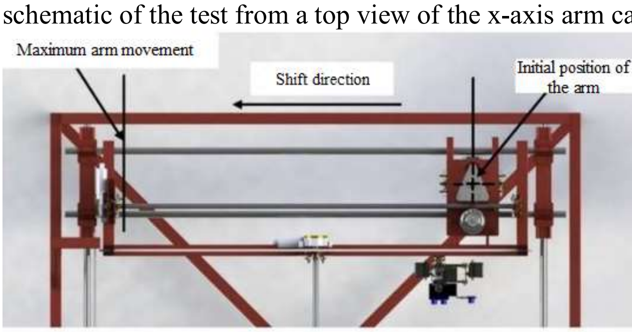


Figure 10. Schematic of the x-axis arm movement test

Figure 10, the initial position of the arm is on the right which will move to the left towards the arm's maximum movement. The movement test was carried out three times, the test data is obtained in Table 4.

Table 4. **X-axis arm movement test.**

Test to -	**Arm testing**	**Mileage**	**Duration**	**Motor speed**	**Error(Cm)**
1		73,8Cm	3 minutes 38 seconds	25rpm	4,2

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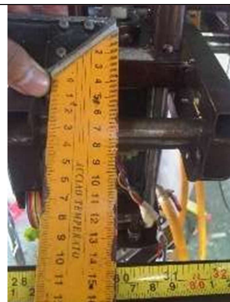
Test to -	Arm testing	Mileage	Duration	Motor speed	Error(Cm)
2		76,9Cm	3 minutes 38 seconds	26rpm	1,1
3		73,2Cm	3 minutes 39 seconds	25rpm	4,8
Total error					10,1

Following the test, the average arm movement distance (as calculated by equation (2)) was found to be 74.63 cm, and the average error distance (as calculated by equation (1)) was 3.367 cm. These results allow for the determination of the movement error percentage on the x-axis. utilizing equation (3) and the following planning distance of 78 cm;

$$\%\ \text{Axis motion error} = \frac{Average\ axis\ error}{Mileage\ planning} \times 100\% \quad (3)$$

$$\%\ \text{X-axis motion error} = \frac{3{,}37\ cm}{78\ cm} \times 100\% = 4{,}32\%$$

The first x-axis movement test resulted in 73.8 cm, the second in 76.9 cm, and the third in 73.3 cm. The percentage error in the x-axis movement was 4.32%. According to the three test findings, the thread was not centered on the motor shaft with the thread retaining bearing at the end of the thread, which resulted in the motor that turned the screw not rotating continuously, and as a result, the arm's travel distance varied.

3.2.2 Y-Axis arm movement movement

The arm movement test on the y-axis was carried out to determine the distance the maximum movement of the arm down from the initial position of the arm. The test schematic can be seen in Figure 11.

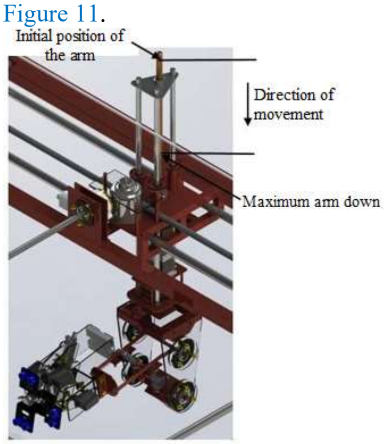


Figure 11. Schematic of y-axis arm movement testing

The movement of the arm on the y-axis affects the maximum height of the component that can be reached by the spray gun. The y-axis arm movement test was carried out 3 times, the test data obtained in Table 5.

Table 5. Testing of y-axis arm movement.

Test to -	Test to	Mileage	Duration	Motor speed	Error (Cm)
1		14,8Cm	33 Sec	34rpm	2
2		14,8Cm	33 Sec	34rpm	2
3		14,85Cm	34 Sec	32rpm	1,5
		Total error			5,5

Following the test, it was possible to determine the percentage value of movement error on the y-axis by calculating the average value of the distance traveled by the arm movement using equation (2), which was 14.82 cm, and the average value of the error distance using equation (1), which was 0.183 cm. utilizing equation (3) and a 15-cm planning distance of 1.22%.

After the test was completed, it was possible to determine the percentage value of movement error on the y-axis because the average value of the distance traveled by the arm movement using equation (2) was 14.82 cm, and the average value of the error distance using equation (1) was 0.183 cm. utilizing equation (3) and a 15-cm planning distance of 1.22%.

3.2.3 Z-Axis arm movement

The arm movement test on the z-axis was carried out to determine the maximum distance traveled by the arm on the z-axis. A schematic of the test from a top view of the z-axis arm can be seen in Figure 12.

The movement of the arm on the z-axis affects the maximum width of the component that can be painted, the z-axis arm movement test was carried out 3 times, and the test data obtained in Table 6 is as follows:

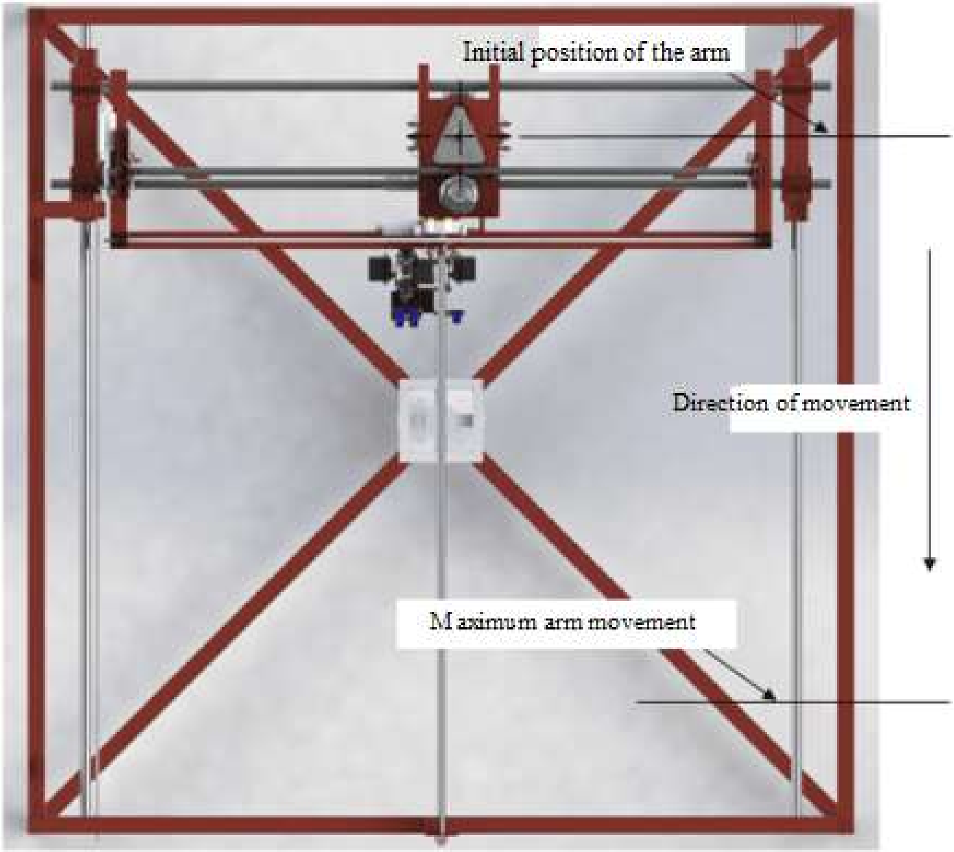


Figure 12. Schematic of the z-axis arm movement test

Table 6. Z-axis arm movement test.

Test to -	Arm testing	Mileage	Duration	Motor speed	Error (Cm)
1		89 cm	5 minutes 45 seconds	19 rpm	1
2		87,4 cm	5 minutes 37 seconds	19 rpm	2,6

Test to -	Arm testing	Mileage	Duration	Motor speed	Error (Cm)
3		88,1 cm	5 minutes 41 seconds	19 rpm	1,9
Total error					5,5

The average arm movement distance measured by equation (2) in the tests is 88.17 cm, and the average error distance measured by equation (1) is 0.183 cm. These results translate into a 2.03% movement error percentage in the z-axis when using equation (3) with a planning distance of 90 cm.

The first z-axis movement test result was 89 cm, the second distance was 87.4 cm, and the third distance was 88.1 cm. Because the thread is not centered on the motor shaft, the arm movement is inconsistent, which accounts for the variation in arm distance data between tests.

3.3 Maximum painting range of overall axis movement

The arm's maximum reach for the greatest volume of the component is the maximum painting range of movement along the entire axis. Component length, breadth, and height are all included in the painting range. The component's maximum width is determined by the direction of movement of the z-axis, the component's height is determined by the direction of movement of the y-axis, and the component's reach length is determined by the direction of movement of the x-axis.

The arm movement distance obtained previously can be seen in Table 7. This data is useful for finding the maximum volume of components that can be painted.

Table 7**.** Arm distance

No.	Move your arms	Side reach	Average movement distance traveled (Cm)
1.	x-axis	Long	74,6
2.	y-axis	high	14,8
3.	z-axis	wide	88,2

In table 7, the x-axis movement average is 74.6 cm, the y-axis movement average is 14.8 cm, and the z-axis movement average is 88.2. You can use the formula to determine the largest volume that a robot can paint.

Component volume = x-axis moving average. y-axis moving average. z-axis moving average (4)

Component volume = 74,6cm x 14,8cm x 88,2cm

= 97.517,5cm ^{3}

The maximum volume that can be painted by the robot is 97.517,5cm^3

3.4 Testing arm rotational motion

This test is carried out to find out how many degrees the arm can rotate to the right and rotate to the left so that the arm can find the appropriate painting position for the side to be painted. The test was carried out without the painting process and only carried out rotating movements of the arm. A schematic of arm testing can be seen in **Figure 13**.

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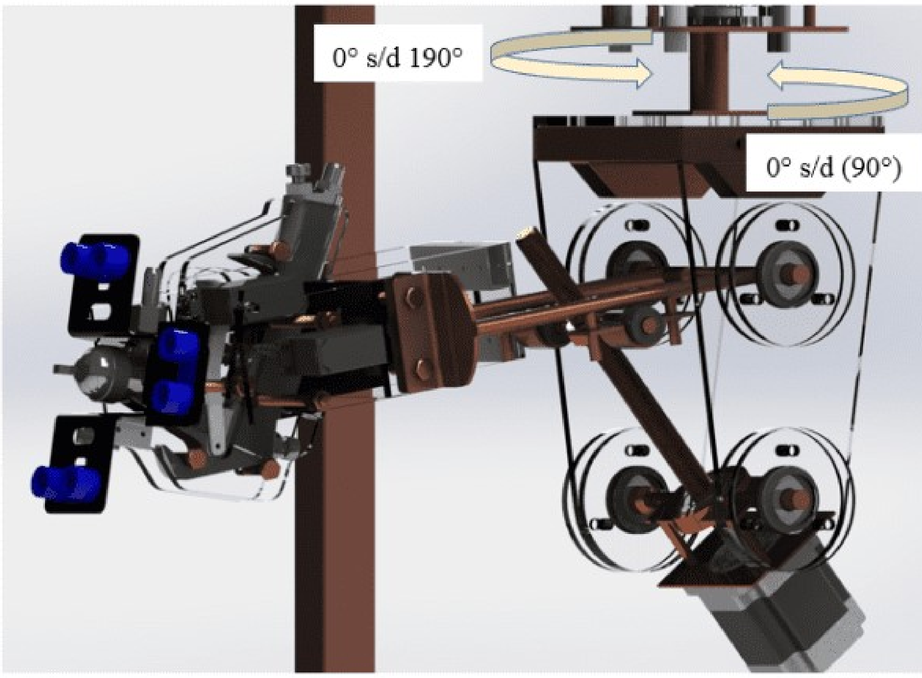

Figure 13. Schematic of arm rotation testing

Because the desired arm movement angle setting is better with a stepper motor than with a DC motor, stepper motors are used to drive arm swivels. However, errors still occur because the stepper motor's axis to the arms swivel is not very centered, resulting in excessive or reduced arm rotation when searching. There are two different kinds of tests: the first evaluates the right arm's rotational movement, and the second evaluates the left arm's rotational movement. **Table 8** displays the results of the right arm rotary motion test.

Table 8**.** Right arm rotational movement test

Angular Testing	**Angular Testing**					**Average**	
	Number -1	**Number -2**	**Nnmber -3**	**Nmber-4**	**Number-5**	**Perubahan sudut**	**Error**
10^{0}	9^{0}	8^{0}	9^{0}	9^{0}	9^{0}	$8{,}8^{0}$	$1{,}2^{0}$
30^{0}	30^{0}	$2{,}9^{0}$	31^{0}	32^{0}	28^{0}	30^{0}	$1{,}2^{0}$
50^{0}	50^{0}	48^{0}	51^{0}	52^{0}	51^{0}	$50{,}4^{0}$	$1{,}2^{0}$
70^{0}	65^{0}	68^{0}	67^{0}	65^{0}	67^{0}	$60{,}2^{0}$	$1{,}8^{0}$
90^{0}	89^{0}	92^{0}	90^{0}	88^{0}	91^{0}	90^{0}	$1{,}2^{0}$
110^{0}	107^{0}	105^{0}	106^{0}	108^{0}	106^{0}	106^{0}	4^{0}
130^{0}	129^{0}	132^{0}	130^{0}	128^{0}	125^{0}	$128{,}8^{0}$	2^{0}
150^{0}	149^{0}	153^{0}	150^{0}	151^{0}	152^{0}	151^{0}	$1{,}4^{0}$
170^{0}	172^{0}	172^{0}	167^{0}	169^{0}	169^{0}	$169{,}5^{0}$	$1{,}8^{0}$
190^{0}	187^{0}	187^{0}	188^{0}	186^{0}	187^{0}	187^{0}	3^{0}

Because painting on the left side of the component required an angle of 10°, painting on the back side required an angle of 100°, and painting on the right side required an angle of 190°, the right arm's rotating motion test was conducted between these angles. According to the testing table, the average angle change movement in the 10° angle test was 8.8 degrees, with an average error of 1.2 degrees. Similarly, the average angle change movement in the 110° angle test was 106°, with an average error of 40 degrees, and the test was conducted at a 190° angle. With an average inaccuracy of 30, the average movement of the angle change is 1870. Even though the test did not yield the necessary angle change movement, the spray gun was still able to reach the painting's components within an average inaccuracy. Refer to **Table 9** to examine the movement of variations in the left arm's angle.

Table 9. Left arm rotation test

Angular Testing	Test					Average	
	Number-1	Number-2	Number-3	Number-4	Number-5	Angle change	Error
10^0	10^0	8^0	9^0	12^0	10^0	$9{,}8^0$	1^0
20^0	18^0	20^0	21^0	20^0	19^0	$19{,}6^0$	$0{,}8^0$
30^0	29^0	31^0	32^0	31^0	30^0	$30{,}6^0$	1^0
40^0	39^0	40^0	42^0	42^0	39^0	$40{,}4^0$	$1{,}2^0$
50^0	50^0	48^0	51^0	51^0	48^0	$49{,}6^0$	$1{,}2^0$
60^0	63^0	63^0	61^0	62^0	60^0	$61{,}6^0$	$1{,}8^0$
70^0	78^0	75^0	74^0	75^0	77^0	$75{,}8^0$	$5{,}8^0$
80^0	80^0	83^0	82^0	82^0	81^0	$81{,}6^0$	$1{,}6^0$
90^0	91^0	92^0	90^0	92^0	92^0	$91{,}4^0$	$1{,}4^0$

Testing the left arm's rotating movement begins at an angle of 10° and goes up to 90°. This rotational movement is necessary solely for painting the component's front surface at the necessary 90° angle. An average angle change of 91.4° with an average inaccuracy of 1.4° is obtained from the 90° angle test table. When the arm is tested for rotational motion, an error occurs because the stepper motor, which is directly coupled to the arm, frequently loses connection, making the arm unable to rotate precisely. Additionally, the stepper motor cannot continuously receive activation signals from the microcontroller, which results in the motor heating up. and harmed.

3 CONCLUSION

Several findings may be made from a series of experiments conducted on three-axis painting robots, one of which is that the average inaccuracy increases when the sensor measures a small distance, such as between 4 and 8 cm. The average inaccuracy caused reduces at distances of 10 cm, 12 cm, and 14 cm measured by the sensor. When testing between 10 and 14 cm reading distances, the error is smaller. The painting distance is best at 10 cm, with the air pressure needed by the spray gun being 80 psi or the equivalent of 5.5 bar, because the painting is even and there is no paint buildup or streaky paint results at this distance. There was a percentage inaccuracy in the test findings for arm movement on each axis as well. For example, the x-axis had an error percentage of 4.32% and an average maximum arm travel distance of 76.9 cm. With a maximum trip distance of 14.8 cm on average, the y-axis had a percentage inaccuracy of 1.22%. The inaccuracy rate on the z-axis is 2.03%, and the average maximum travel distance is 88.2 cm. Tests of arm movement reveal that this robot can paint components up to a maximum size of 97.517 cm^3. Two experiments were conducted to determine the rotary arm movement required to paint the component's left side at an angle of 10°, its back side at an angle of 100°, and its right side at an angle of 190°. To paint only the front side of the component at the necessary angle of ninety degrees, the second arm rotation test, that is, the arm rotation movement to the left, is necessary.

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