

Automatic Wall Painting Robot with Multiple Colors

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Abstract— *The main aim of this research is to design and develop an automatic wall painting robot for painting multiple colours. In the designed robot, an automatic painting mechanism has been made for painting two different colours by the use of an air compressor and spray guns. Also, a vertical and horizontal systems have been made for the painting mounting of the spray guns. The performance of the developed robot was tested by five different testing which were DC motor testing, Stepper motor testing, Paint testing, Liquid level sensor testing, and efficiency testing. The designed project has the ability to paint an area of 0.270 m² in 26.760 minutes which has an accuracy of 96.476%. The efficiency of the painting system has an efficiency of 96.296% in terms of the painted area. The painting efficiency increased by decreasing the separation distance between the wall and the robot and fixing a pressure to be 4.5 bar. The overall efficiency of the entire system has been obtained which was 83.987%. The system has a strong mobility system for reducing the vibration generated by the stepper motors. There were three CNC linear lead screw 500 mm each fixed on the mobility system of the hardware. Two lead screws were fixed vertically and one lead screw was fixed into the two vertical sliders horizontally. The system uses a rocker switch 3-way to either select one of the two colors to be applied into the wall or leave the slider to continually move till it reaches a specific area to select the color to paint that special area.*

Keywords— Wall Painting Robot; DC motor; Air Compressor; sensors; Efficiency

I. INTRODUCTION

Wall painting is a repetitive process in which it requires the same procedure of painting that makes it boring for humans. Since wall painting is a tiring, dangerous process carried out by humans, makes it a perfect case for automation. For decades, painting depends on many factors that help humans achieve the process such as scaffolds which is used instead of ladders as a conventional method for painters to reach a specific height of a building. Also, manual wall painting requires extra work to achieve the process such as carrying painting materials, lifting painting equipment, pushing unnecessary stuff, etc. Moreover, carrying the painting equipment such as spray gun, roller, or a brush for a long time may end up in stress and backbone injuries due to the repetitive use of the same part of the body [1].

The construction industry is a labor-intensive which is carried out in dangerous situations; therefore, implementing robots in construction industries has been realized and it is grown rapidly. The automation has been introduced in the early '90s to the construction industries. Automation aimed to

optimize equipment operations, safety improvement, quality improvement, and so on. Painting, in general, has been implemented in industrial factories but not in construction purposes. Automation will have a great impact on construction fields since it uses machines instead of human labors to control systems and execute painting operations to improve the quality of the paint job. The painting chemicals may have the possibility of causing eye and respiratory system problems to painters. The appropriate reason for applying automation in the construction of buildings is to increase productivity and quality of the paint which varies between walls and rooms due to the fatigue of painters. To meet the current demand of the automation process, construction field, especially in interior buildings, need to be automated to ensure that the quality is always maintained as a robot is much less prone to error compared to humans [2].

To achieve the automation term in the industry, robots and automatic systems using sensors should be implemented. Nowadays, robots are being used in many applications such as medical, military, entertainment, etc. However, robots are not being widely used in construction fields since manual conventional methods are still used. The word robot implies different meanings to different people since they don't know much about it. A robot is a machine that resembles a human being and it is capable of replicating certain human movements and functions automatically. Robots can be used in different fields but the ones implemented in construction fields are known as construction robots which are smart machines which use sophisticated, and intelligent languages for their processors and microcontrollers. All in all, robots are designed and developed to improve the quality work and reduce the risks in the construction fields since they are very helpful in doing painting operations under dirty and dangerous conditions [3].

Researches have been conducted in the past regarding using automation for interior wall painting in the construction industry since exterior wall painting had been implemented in the construction industry. However, there has been no solid development due to certain gaps in ideology and technology. The nature of challenge for the automatic wall painting with multiple color will be to identify the dimensions of the wall, to ensure the painting of the entire wall, to ensure of having even coatings, thickness uniformity, and avoid any saturation, to ensure of keeping the paint inside the tank within a specific level of height, and to ensure to paint the wall with colors as desired. The system should consist of a simple control system that can reduce the vibration being produced by the movement

[4]. The research questions have been identified and are listed as follows:

1. Can the system work without any human assistance?
2. Will the system be able to achieve a better result than humans?
3. Can the robot move vertically and horizontally without any human assistance?
4. Will the robot be able to have an online checking system once needed?
5. Will the robot be able to cover all angles of the wall and ensure to paint them?
6. Can the robot ensure high quality of paint job compared to humans?

Therefore, the main aim for this research is to design and develop an automatic wall painting robot that is fast, precise, reliable, and helps to achieve low-cost painting operations. While the objectives is to: (i) design and develop a wheel-based robot with a spray gun system with multiple colors to paint the wall. (ii) design and develop a system for the spray gun to move horizontally and vertically. (iii) design a system to keep checking of paint level and send an alert. (iv) evaluate the reliability and efficiency of the system by investigating the consistency of the layers of paint along the whole surface.

[5] aimed to overcome the conventional methods of painting which uses human labor all the time as well as to reduce human efforts involved in the whole painting process. The vertical system implemented in this research uses a mechanism that runs through the chain- sprocket which holds the pneumatic mechanism that allows automatic painting of the wall. Sprockets are the main parts that give rotational movements to the chain. Sprockets are a rotating part that has teeth used in conjunction with a chain to transmit torque. While [6] used a mechanism that works on the principle of a scissor lift mechanism for the vertical system A scissor lift mechanism depends upon the elongation of collapsible mechanism to provide vertical elevation in Z-direction in ratio to a rotational or linear input. In this project, a scissor lift is constructed by using supports that can be linked and folded in a crisscross pattern. The mechanism of the scissor lift can be achieved through a different mechanism such as hydraulic process, pneumatic process, or mechanical process. On the other hand, [7] proposed a scissor lift mechanism for the vertical movement of the robot. Along with the scissor lift, the arm of the robot has an essential motion of 2DOF. The vertical motion is into the direction of the wall surface. The vertical motion in addition to the scissor lift is completed by the arm mechanism. The arm consists of two joints driven by stepping motors with fast D.C servo motors. The joint driving mechanisms are being inserted at each joint of the link arm. In addition, [8] implemented a vertical system that depends on cables which are fixed into wheels which are attached to the bottom of the frame. This robot aims to design a system for exterior wall painting in which it has the capability of painting interior walls since it has vertical and horizontal movements that allow the robot to cover all X-direction, Y-direction, and Z-direction. The wheel has a hole from the center to let the end of the connection rods be attached to it as well as to the bottom of the roller handle. In a study done by [9], the vertical system implemented in this robot has a mechanism of a lead screw.

Therefore, the painting setup is connected to the lead screw that moves vertically down based on the rotation of the lead screw. A gripper is the main part that holds the painting spray for the painting operations in which the gripper causes the spray gun to release the paint. The motor is the one responsible for the gripper to release the spray to paint the wall since it is already programmed through a microcontroller. The vertical system proposed by [10] uses a screwed sprayer movement stands for the vertical movement to align with the wall that is needed to be painted. Therefore, the vertical system of the robot is achieved through a screwed sprayer moving up and down as a rotation of a screw to allow the spray to paint the wall in the Z-direction. In a study of [11], the robot is very flexible due to its vertical movement mechanism. The robot consists of the screw, nut, and lifter screw that are held in two ball bearings and nut connected to the frame of the screw. The entire vertical system is placed on the base frame by using the pinion shaft, main shaft, and holder bracket. The functionality of the ball bearing is to hold the main shaft which is welded into the frame. A speed adjuster is used to obtain the required speed of the vertical system due to the ball bearings arrangement.

The mobility system and horizontal system for this robot as per [7] proposed consists of many things that give the robot the ability to do its vertical painting tasks by the arm of the robot. The mobility of this system has a movable base that fits the arm to have 3 DOF which are 2 arm joints for moving linear direction and one for rotational direction to adjust the robot to the wall. Many decisions were discussed about the number of wheels a robot should have. [12] have said that the mobility system is the main part of the whole system since all-electric and mechanical components are stored inside it. the mobility of the robot has many tasks but the important ones are to hold the upper portion of the system which is used to paint the walls and the other one is a storage house to keep all electrical connection circuits inside it. The robot proposed by [13] is mainly designed in a way that it is capable of achieving the painting mechanism in an efficient way in which less power is wasted due to the less number of moving parts used in the robot. The robot is mainly designed by using few sheets of steel welded together to make the base of the robot that stores the controller unit along with the spray gun, conveyor, and the rest of equipment used to build the robot. In a study of [14], a robot designed is considered a good robot since it is not very bulky and it is compact because of having such a high speed and pressure capabilities for the painting mechanism. the robot has two main parts which are the frame stand and wheel building. For the mobile platform of the robot, it consists of a frame stand, wheels, DC motors, battery, and control unit. The spray gun mount components are all fixed either into the frame stand of the robot or kept inside the base. [15] proposed a painting system for the robot that consists of a spray gun to paint the specified walls. The spray gun is fixed into the robotic arm to do the painting process. Therefore, the robotic arm is mainly implemented for the painting spray gun which is fixed at the tip. The paint is pumped from the bottom level in the paint tank passed through a solenoidal valve until lastly the spray gun is programmed to spray the paint.

II. PROPOSED SYSTEM METHODOLOGY

The block diagram for the system designed shows all the electrical components used for making the system. Fig. 1. shows the overall block diagram of the system;

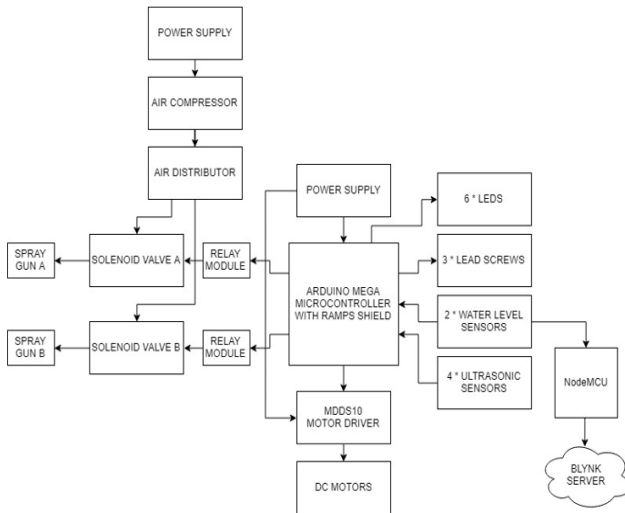


Fig. 1. Overall block diagram of the entire system

The main controller of the system is Arduino Mega microcontroller with a RAMPS shield for controlling the stepper motors movements. The main objective of the system is to paint the desired wall with multiple colors in which the system specifically can paint two colors. There are two single relays used in the system for switching on and off the solenoid valve according to the selection. The air from the compressor to the spray guns is controlled by a solenoid valve in which it takes the air from the compressor and gives it to the spray gun to spray the desired paint. There are four DC motors used in the system for the ground movement of the robot. All DC motors are controlled by the MDD510 driver. For using only one compressor for the entire system, an air distributor is used to give multiple outputs of air to different spray guns which can reach till 8 spray guns. There are two liquid level sensors used in the system for an automatic controlling of the painting operation according to the paint level inside the tank. For each liquid sensor, 3 LEDs are used to represent the state of Low, Medium, and High. Moreover, 4 ultrasonic sensors are used for controlling the movement of the stepper motors in which 2 ultrasonic sensors are fixed into the horizontal lead screw while the two others are fixed into one of the vertical lead screws. An IoT platform has been introduced to the system by using a NodeMCU for sending data to the hand-phones of the users to show the paint level inside the tanks of the spray guns.

As shown in Fig. 2. the schematic circuit diagram of the system has been made to give a clear idea of the connections made for the system works. The followings will be a brief illustration of the built 3D design of the actual prototype to give a better view of the entire hardware along with the necessary components used.

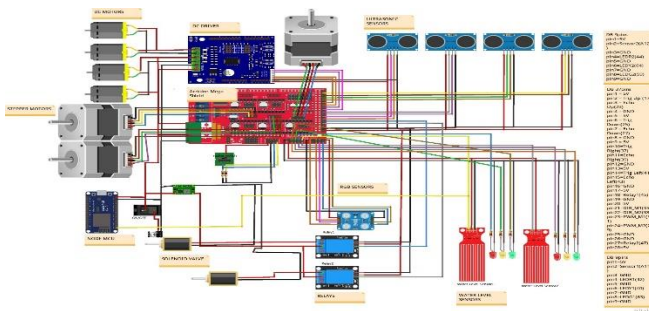


Fig. 2. Overall schematic breadboard diagram of the entire system

Fig. 3. shows the robot with its main control unit opened. The main control unit works as a cover for the mobility system that has all the connections made for the system along with the electrical and electronic components used.

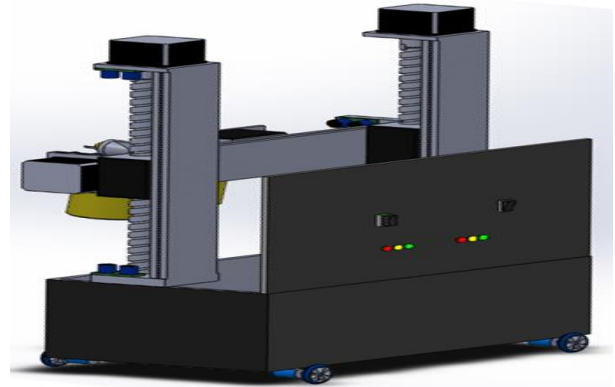


Fig. 3. 3D back-view of the designed robot

Fig. 4. shows the front view of the designed robot in which it shows the storage inside the mobility system.

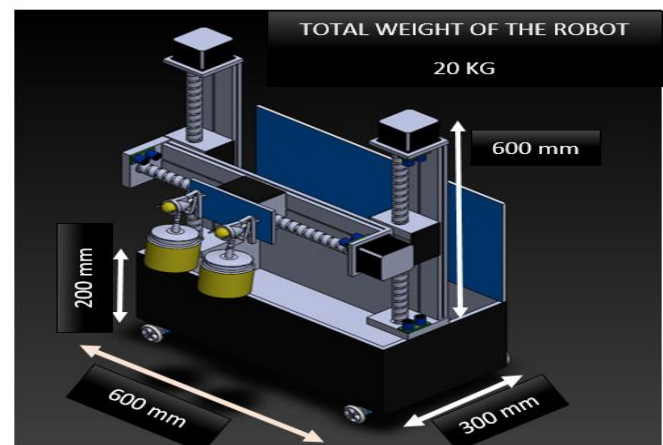


Fig. 4. 3D front-view of the designed robot

Fig. 5. shows the DC motors used for the movement of the robot in which 4 DC motors with a torque of 15 kgfcm each are used along with a 80 mm diameter wheels attached to each motor.

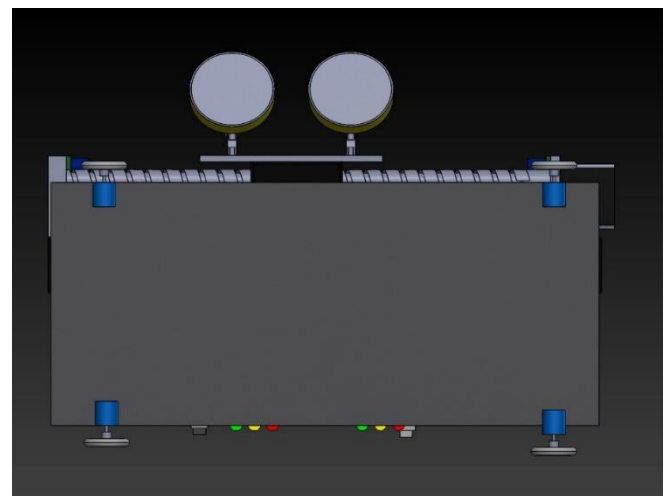


Fig. 5. 3D bottom-view of the designed robot

Fig. 6. shows a side-view of the designed robot in which almost all main devices such as spray guns, lead screws, etc.,

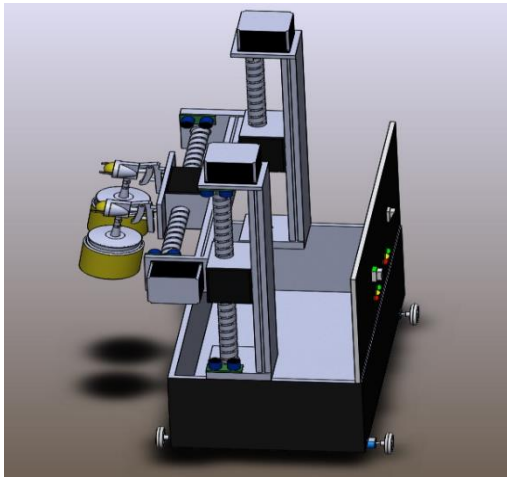


Fig. 6. 3D side-view of the designed robot

The Flowchart of the system will show the entire working principle of the automatic wall painting robot with two colors in an easy way for better understanding of the system.

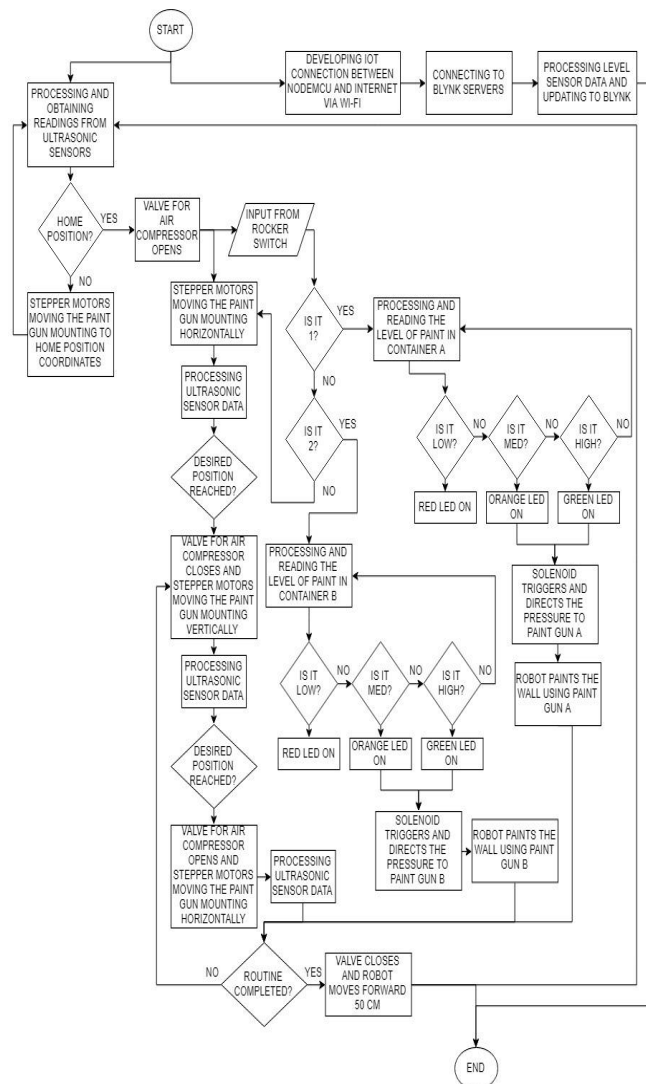


Fig. 7. Overall flowchart of the entire system

The automatic wall painting robot has been designed in a way that paints one color at a time. The robot has been designed with using many different parts which were all integrated to make an entire system that executes the four objectives of the project. The system can paint two colors once at a time by selecting the desired color from the rocker switch 3-way. The main control unit of the robot has an ON/OFF switch, a rocker switch-3-way, 3 LEDs for one spray gun, and other 3 LEDs for the other spray gun. The mobility system for the designed robot consists of a square chassis made up of aluminum profile with vertical aluminum support that holds the two vertical lead screws. There are three lead screws 500 mm each. Two are fixed vertically into the frame of the robot while the third one is fixed horizontally into the two sliders of the vertical lead screws. The spray gun mounting is fixed into the slider of the horizontal lead screw in which it moves in a rotated square wave pattern.

III. HARDWARE IMPLEMENTATION

A. GRAPHICAL USER INTERFACE (GUI)

Fig. 8. shows the main GUI made for the designed system in which it has two different options to choose. The first option is to monitor the level of the paint inside the tank which can show the reading under LIQUID LEVEL INDICATOR option which indicates 0. The second option is to choose the color wanted for the RGB sensor to detect. This enhancement was not completely working since the RGB sensor was giving a source of bad reading and it was not well integrated with the ultrasonic sensors used in the system. Also, the reading of the data for the liquid level sensor was not that accurate since the system is not stable and it produces some vibrations on the hardware which makes the readings inconsistent and inaccurate. Those two things could be better enhanced in future for making a better system that can be controlled remotely. Also, the RGB sensor could be implemented for a robot that is designed for making paint designs on the wall.

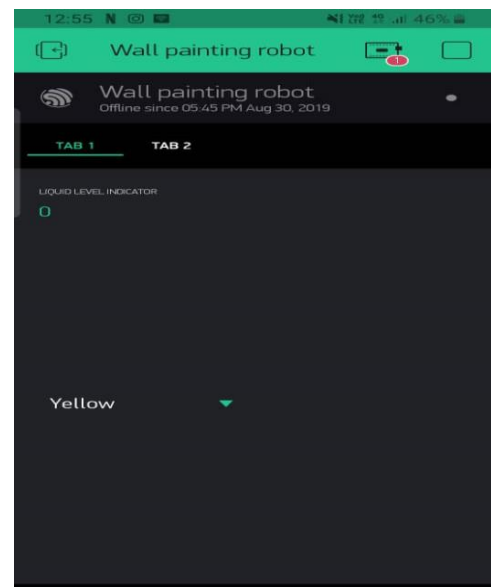


Fig. 8. GUI for the designed system

B. PROTOTYPE

Fig. 9. shows that the designed robot has two painting nozzles for spraying two different colors. There two vertical lead screws and one horizontal lead screw.



Fig. 9. Outer look of the designed robot

Fig. 10 shows the spray guns used for spraying two different colors along with the sensor used for detecting the paint level inside the tank. The ultrasonic sensors and lead screws used for the designed system are all labelled in the previous Fig..

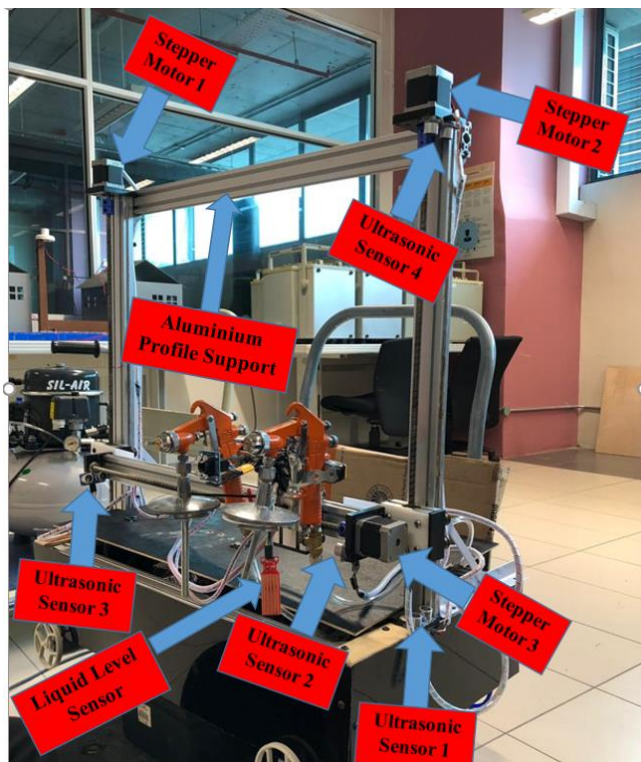


Fig. 10. Outer components used in the designed robot

Fig. 11. shows the solenoid valves used in the system which are two solenoids used for the spray gun. The air distributor is also shown which has two tube pipes connected to it. The black cover is the main control unit of the robot that has the rocker switch, power switch, and LEDs. The

NodeMCU is also shown in the Fig. along with two power supplies. The power supply used for the microcontroller is a 12V power supply while the 5V power supply is used for the NodeMCU.

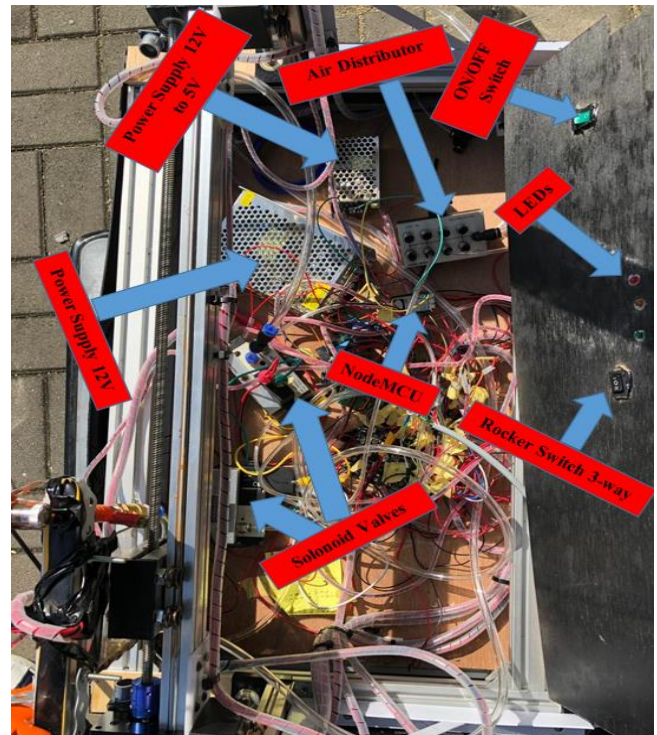


Fig. 11. Inner components used in the designed robot

IV. TESTING AND FINDINGS

A. Stepper Motor Testing

There are three stepper motors used in the system to achieve the second objective of the system which is to design a system for a vertical and horizontal movement of the spray gun mounting. There will be two different testing for the motors which are as follows;

1) Vertical Stepper Motor Test

This test will investigate on the accuracy of the vertical movement of the motor in which two stepper motors are used for the vertical system to obtain better performance.

Test procedure:

1. The system was switched on.
2. Initialization of home position was obtained by the carriages (sliders).
3. Horizontal distance was all cleared by the slider.
4. The upward vertical distances (delays) were counted for the vertical sliders till the end of the pattern.
5. Step 1 to 4 were done with load and without load for two complete patterns.
6. Results were compared and the accuracy of the motor was calculated.

The data collected were for two complete square wave patterns in which a total of 18 readings were recorded 9 readings for each pattern. The vertical distance between each upward movement (delay) was set to 50 mm except the last step which was 40 mm. The time for each cycle was measured for both with load and without load and The accuracy was obtained by the following formula;

Relative Accuracy % =

$$100 - \left| \frac{\text{Time with load} - \text{Time without load}}{\text{Time with load}} \times 100\% \right| \quad (1)$$

the average accuracy for the system was 77.642 % in which the limiting error of the system is within ± 6.222 seconds.

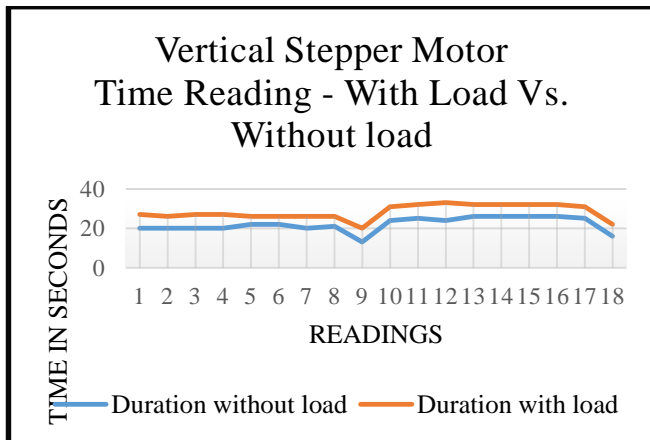


Fig. 12. Vertical stepper motor time reading graph

2) Horizontal Stepper Motor Test

This test will investigate on the accuracy of the horizontal movement of the motor. There is one stepper motor for the horizontal movement in which the slider crosses the horizontal distance 10 times till it finishes the pattern.

Test procedure:

1. The system was switched on.
2. Initialization of home position was obtained.
3. Time was recorded with load and no load for 20 times, which 10 times for each pattern, for slider to cross the horizontal distance to two complete square patterns.
4. Results were all tabulated and compared.
5. Accuracy was obtained.

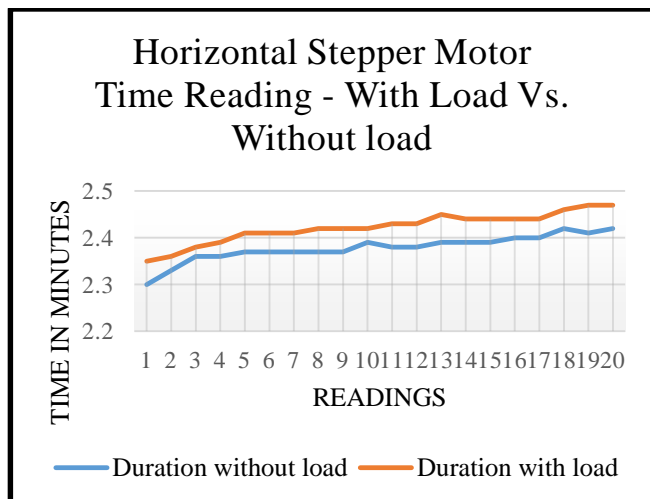


Fig. 13. Horizontal stepper motor time reading graph

Based on the data collected, the system assumed to be perfect since the obtained average accuracy of the system was 98.225 %. Formula (1) was used to obtain the accuracy. The horizontal testing was for two square wave patterns to obtain

accurate results. The average time taken for the carriage to clear 450 mm distance without load was found to be 2.376 minutes while with the load it was 2.418 minutes in which the difference time between them was found to be 0.041 seconds. Meaning that the limiting error for the system is within ± 0.041 seconds.

3) DC Motor Testing

For the designed system, there are four DC motors used for the movement of the robot on the ground. The motors are controlled by using an MDDS10 driver which is powered by 12V power supply. There are two different testing carried out for the DC motor on 10 different type of grounds. This test will investigate on the voltage of the DC motor when there is load and no load. For this testing, the voltage supposed to be 12VDC in each motor which was tested by using digital Multimeter device and also stated in the data sheet of the motor.

Test procedure:

1. The system was switched on.
2. The project was lifted up from the ground.
3. Motors were running.
4. Voltage was measured by using Multimeter.
5. Results were recorded and tabulated.
6. The project was put on the ground.
7. 10 different type of grounds were set.
8. Motors were running.
9. Voltage was measured by using Multimeter.
10. Results were recorded and tabulated.
11. Accuracy was calculated.

Fig. 14. shows a straight yellow line that represents the voltage without load which was 12VDC while the blue line shows the variations of voltage for the DC motors for the 10 different grounds.

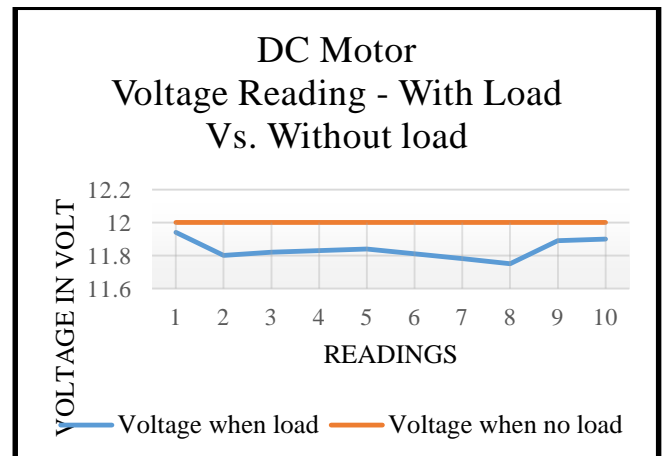


Fig. 14. DC motor voltage testing graph

B. Speed Test

Speed test is carried out to obtain the actual speed of the motor when the motor runs on full load which is the load of the robot which is 20 kg. The no load speed of the motor is 24 RPM. The load speed will be obtained by finding the linear velocity of the robot in which it will be used to obtain the load speed.

Test procedure:

1. The system was switched on.

2. The testing distance was set to be 500 mm (50 cm) for 10 different grounds.
3. Time to cross was measured.
4. Linear velocity was calculated for 10 different grounds by using the following formula;

$$\text{Velocity (V)} = \frac{\text{Distance in meter}}{\text{Time in seconds}} \quad (2)$$
5. Speed was calculated for all 10 different grounds by applying the following formula;

$$N_{\text{RPM}} = \frac{60}{2\pi \times r} V_{\text{m.s}^{-1}} \quad (3)$$
6. All results were recorded and tabulated.
7. Accuracy was obtained by the following formula;

$$\text{RELATIVE ACCURACY \%} = 100 - \left| \frac{\text{NO LOAD SPEED} - \text{LOAD SPEED}}{\text{NO LOAD SPEED}} \times 100\% \right| \quad (4)$$

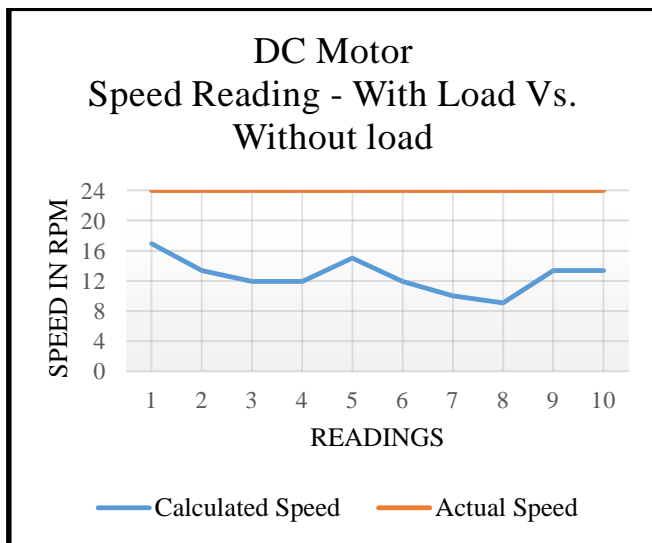


Fig. 15. DC motor speed testing graph

The DC motor system is applicable to use for such an application. There were 10 grounds used for obtaining the best accuracy of the system. Smooth floor was the best to obtain an accuracy of 70.625. The accuracy for the rest of the grounds were all below 60%. The average accuracy of the motors was obtained to be 57.419 % in terms of the speed.

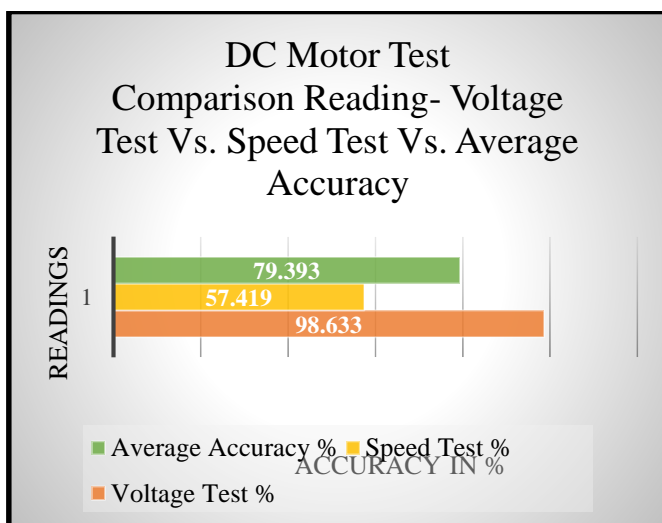


Fig. 16. Overall accuracy of the DC motor

C. Paint Testing

This test carried out to investigate on the painting quality according to the pressure used in the system. There are two spray guns were used in the system to spray two different colors. The diameter of the nozzle is 1.5 mm in which it has a spraying distance of 15 cm to 20 cm. The area of the actual wall that has to be painted is assumed to be 520 mm width and 520 mm length which is 0.270 m². The capacity of the paint tank is 1200 mL which is 1.2 L. The paint level used in the system is 1 L since 0.2 L kept empty for the circuit connection of the sensor.

Test Procedure

1. The system was switched on.
2. Initialization of home position was reached.
3. Desired color was selected.
4. Air compressor was on.
5. A distance of 20 cm was set between the robot and the wall.
6. Spray gun was started painting.
7. Different pressure values were used.
8. Painted area of the wall was measured.
9. A distance of 15 cm was set between the robot and the wall.
10. Step 1 to 8 were repeated.
11. All results were recorded and tabulated.

Based on the result obtained for the painting operation of the system, the system is capable of performing a good painting operation to reduce the cost of the traditional painting process and the hazards painters face of operating a manual painting process. Two tests were performed in terms of distance in which the separation distance used as 20 cm and 15 cm. The best accuracy obtained was when the pressure 4.5 bar for a 15 cm distance which was 98.077 %. When the pressure was set at 5 bar, the painted area exceeded the desired area by 30 mm for 20cm and 40 mm for 15cm. The rating scale was according to the area painted. The more area painted within the limited scale, the better the painting quality is. The average accuracy for the entire system according to all used pressure was found to be 46.291 %.

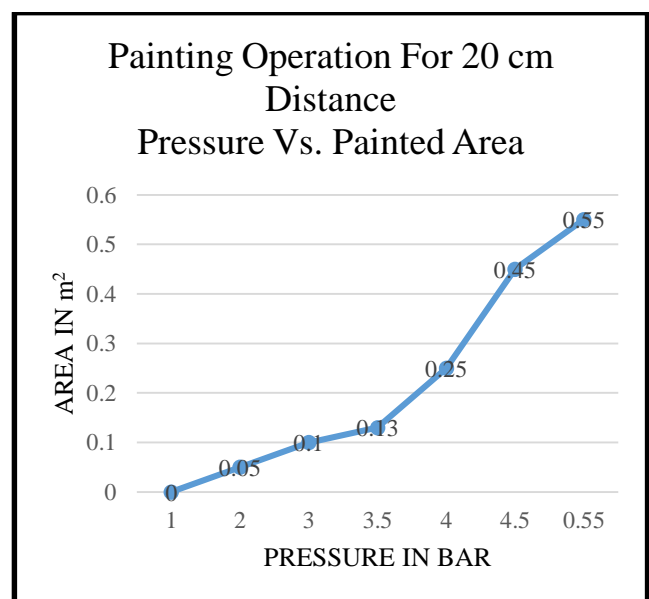


Fig. 17. Paint testing graph for 20 cm distance

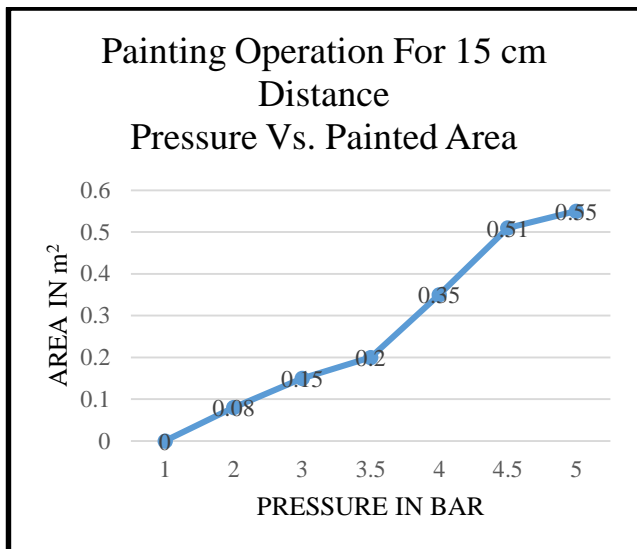


Fig. 18. Paint testing graph for 15 cm distance

V. DISCUSSION

First of all, the main objective was to design and develop a wheel-based robot with a spray gun system with multiple colors to paint the wall which was achieved successfully according to the hardware result. Developing a horizontal and vertical system was by fixing two lead screws vertically on the mobility system while attached the third one horizontally into the two vertical sliders of the lead screws. The system was working properly with an average accuracy of 96.476 % following the time it took to finish two complete square wave patterns. The system had an automatic controlling system to stop the painting operation once the paint inside the tank is below 0.25L. The system has an alarm system represented by LEDs fixed on the main control unit of the robot. Three colors are used to represent the level of paint inside the tank which are red, yellow, green which assigned for low, medium, and high paint level inside the tank respectively. The limitations of this project were mostly in the stepper motors and painting mounting. Stepper motors have less speed due to the smaller size of the motors and the heavyweight of the painting mounting and the upright positioning for two lead screws. Lead screws have better efficiency once they are kept horizontally in which the number of rotational steps is increased while on the contemporary if fixing them vertically

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