Autonomous Wall Painting Robot

Conference Paper · June 2020

DOI: 10.1109/INCET49848.2020.9154020

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2020 International Conference for Emerging Technology (INCET)
Belgaum, India. Jun 5-7, 2020

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***Abstract*—Interior wall painting is a common work in construction which consumes a lot of time and human effort. By replacing human manual operation, robotic painting was introduced to improve the accuracy, efficiency and to reduce the cost. In this paper, we introduce an autonomous wall painting robot which can paint the interior walls of a room, using paint sprayer with the help of a cascade lift mechanism. This cascade lift mechanism assists the paint sprayer to reach the required heights. The mecanum wheels with dc motors that are attached to the base of the robot, helps in easy movement of the robot, to move in all six directions with 2 DOF (degrees of freedom). The robot uses ultrasonic sensors to detect the distance and adjust to the walls, and to check whether the sprayer reached the top of the wall. The master controller controls the ultrasonic sensors, mecanum wheels, and all other parts of the robot. The overall system runs on AC power supply.**

Keywords— autonomous wall painting robot; ultrasonic sensors; cascade lift, spray painting.

I. INTRODUCTION

Painting work (commercial or residential dwellings), is physically quite intensive, requires consistent vigilance, and yet boring, due to the repeating actions of painting procedures; the work could be uncomfortable or unsettling because of harmful chemicals present in the paint or other solvents, which can be nauseating or cause respiratory problems to the workers. With its numerous benefits like quality control, repeatability, waste reduction, faster cycle times –automated painting could very well provide a way out. Concurrent upsides of automation include reduced labor costs and lower probability of blunders. These factors inspired the concept of an automated robotic painting system. This gadget aims to develop an interior wall painting robot. Key features of this autonomous robot include portability, and compact contour. The robot is designed using a few aluminum rods, spray gun, mecanum wheels and a master controller unit to control the entire operation of the robot. The elegant design of the robot gives better stability and minimum power loss is expected due to the less moving parts of the robot. The painting trajectory of the robot is in such a way that there will be less paint wastage. This robot is dependable, maintenance easy and easy to install in a working environment.

II. PROBLEM STATEMENT

According to the proliferation of building construction across India from the year 2010 - 2020.The growth rate was estimated to be 2.95 percent from 2010 to 2015 and 5.65 percent from 2015 to 2020 [1]. The real problems emanate when the demand for painters increases, and there are very few skilled laborers available for the onerous, demanding painting work. Painting is a time-intensive, burdensome task. Generally, most nations use manual labor for painting, which is hazardous to health, by overexposure to paints and other chemicals; paints contain high amounts of volatile organic compounds, which if inhaled or ingested, can lead to health ailments like asthma, infertility and neurological disorders. The process of painting is a time-consuming ordeal, whereas automation makes the task easier and simpler with a high production rate. So, as to overcome these problems, robotics and automation helps us to develop an autonomous wall painting robot which can help us to do painting with more precision and faster than human workers.

III. RELATED WORKS

In the research work [2], the author re-affirmed the idea of an automated interior wall painting robot, Robo Painter, with a robotic arm fixed to it. This arm is anchored to a base platform, into which 10 ultrasonic sensors are attached, to self-localize and navigate the walls. An Inertial Measurement Unit (IMU) is attached to its base, which monitors structural vibrations, for the detection of empty paint cups. The robot can perform non decorative and decorative paintings of an area (0.25 x 2.45) m2 can be painted within 10seconds.

The authors in paper [3] Presented AGWallP, a spray-paint based automatic wall painter, with inputs fed in, from a remote user. This robot uses a mechanism of a 2-D plotter (similar to 3-D printer mechanism) to paint the walls. The electronics sub-system of the robot consists of a master controller [4] Raspberry Pi 3 module that has a camera module fixed on it; the user can input the color of his preference to be painted on the wall and with the help of signal processing the camera module can capture the image of the wall to identify the wall dimensions.

The research paper [5] reported on the conceptual design of an automatic wall painting machine, with a paint sprayer. The robot frame is set on castor wheels; the vertical motion of the paint sprayer was achieved by using a threaded rod, which is attached to a stepper motor which converts the rotational motion of the shaft of the motor into linear motion. Thus it enables the paint sprayer to move up or down. A compressor is used to supply the paint to the spray rotor end.

The author in [6] proposed the design of an interior wall painting machine. This machine is portable, consisting of a conveyor shaft, spray gun, an air tank or compressor and a controller, to control the operations of the pneumatic machine. This machine uses a chain drive for transmission of power, and motion from a DC motor to the lead screw, for the vertical motion of the paint sprayer.

In the research work [7] the author showed the mode of a roller-based painting robot, which has a paint roller attached to an end of the arm that is anchored to the mobile base. The paper was able to show the working of the lifting process using flowcharts; it has a foldable structure with a weight of less than 3.5kg. The robot can paint at a rate of 0.15 m2/min is available at an affordable price.

In the research paper [8], Aris developed a full-scale mechanism for painting of ceilings. The mechanical design consists of a positioning module and an end-effector module. The positioning module contains X-Y-Z modules. For X and Y modules movement, the chain-sprocket mechanism is used and for Z module movement, the ball-screw mechanism is utilized. The End-effector module is the one which holds the spray gun. The Robot had a working envelope of (0.84 x 0.72 x 1.22) m3 is reported. Unfortunately the system can only paint the ceilings and there is no information revealed about its mobility.

In [9], the author presented a wall-climbing robot, for hull painting; this autonomous robot can do self-painting through an intelligent control and vision system. The paint system of the robot is controlled by a solenoid valve and pressure pump. For painting, the robot uses a permanent adsorption and AC servo motor to drive, so that the robot can be adsorbed on the magnetic surface and move around.

The prototype of an FPGA-based wall painting service robot is discussed in [10]. The master controller used in this robot is [11] Altera DE2 development board; for climbing walls, this robot used a suspension support system; obstacles like windows were avoided by an infrared emitting diode, and an NPN phototransistor; magnetic sensor was used to detect metallic windowpane frames.

In the research paper [12], the author presented a painting robot with monocular vision-based parameter estimation for mobile robotic painting in which he measured different parameters by using a single camera, a laser level (LL), and four single-point laser distance sensors (LDSs) to get the parameters such as wall plane equation, position of the paint-start point to get accurate and precise painting by the robot. To find the relative distance between the robot and the wall, the single image measurement was used. That is measuring the distance of the wall using a single camera, this is also called a monocular vision based system. In this paper we propose an Autonomous wall painting robot design that is unique, efficient, reliable, compactable, portable, and cost effective.

IV. System Architecture

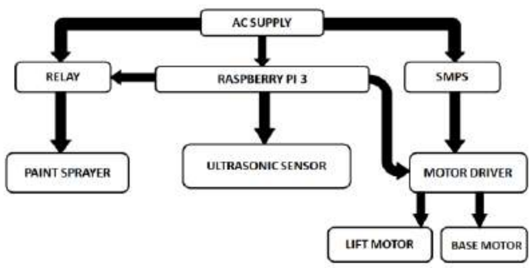


Fig. 1. System overview - Block diagram

The system architecture in Fig. 1 shows relay, SMPS, motor driver, paint sprayer, ultrasonic sensors, Raspberry Pi 3 and motors. The master controller for the whole system is Raspberry Pi 3. As shown in Fig.1 the system runs on AC supply, which is connected directly to a Raspberry Pi 3 module, an indirect supply of power to paint sprayer through relay and a switch mode power supply to the motor driver so as to trigger the actions of the lift and base motors (traction motors). Ultrasonic sensors are connected to the Raspberry Pi 3 module through which they are activated. Three ultrasonic sensors connected to the front, right and left side of the robot, one each. These ultrasonic sensors will send the information about the relative distance between the robot and the wall to the Raspberry Pi module through which further actions are triggered.

V. Design And Implementation

A. Mechanical design

A rectangular-shaped hollow aluminum bars of dimensions 3x1, 2x1, 1x1 as shown in Fig. 2 is used to build the cascaded double-stage lift and base. A paint sprayer is situated inside the lift. The double stage cascaded lift can be compact and portable, which enables painting of the desired height of the wall. mecanum wheel is used for the movement of the robot because it can accomplish the desired direction of rotation without the total rotation of the robot base.

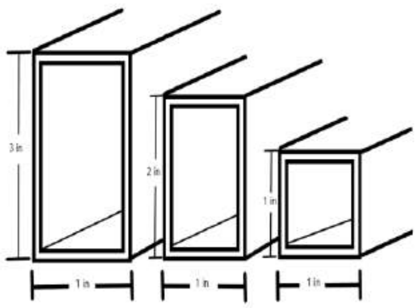


Fig. 2. cross-section and dimensions of aluminum bars

B. Mecanum Wheels

Mecanum wheel is a conventional wheel with a series of rollers attached to its circumference and the rollers have an axis of rotation at 45° to the plane of the wheel [10]. These wheels can move the robot instantaneously in any direction without rotating the base; therefore with this kind of wheels the robot can do the tasks with ease in a congested environment.

C. Cascade Lift

Cascading lifts are two stage lifts in which the first stage is situated inside the second stage lift which is connected with aluminum string and pulley Each string is connected to the top of the previous stage and the bottom of the next, this means that when the bottom stage goes up a little bit, the next stage lifts twice that high. Cascade lifts are good for relatively quick vertical lifting, but often have problems with slack and instability. In Fig. 4 the folded and extended structures of the cascade lift are shown in the figure the sliders in the lift helps for the smooth movement by reducing friction and power losses. These sliders are made with deep groove ball bearings which rolls over the aluminum profiles of the lift for easy movement. Fig. 3 shows the pattern in which the lift moves up and down and the robot moves in horizontal direction in order to get the wall completely painted.

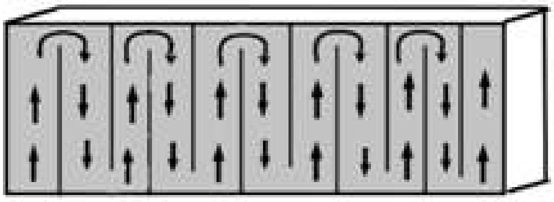
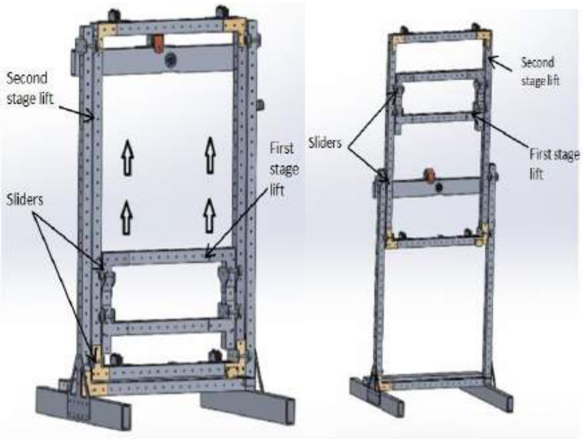


Fig. 3. Painting Pattern

D. Advantages of Cascade lift

The main benefit of a cascade mechanism is that it can lift the paint sprayers in two stages; thus cascade lift enables us to have compatibility and portability. In addition, a less volumetric space is needed. Since the paint sprayer is indirectly connected as shown in Fig.5 to lift motor, through various pulleys it provides passive assistance to the motor i.e. it decreases the stress on the motor



(a) (b)

Fig. 4. CAD model of cascade lift (a) normal structure of the cascade lift, (b) extended structure of the cascade lift

The folded and extended structures of the cascade lift are shown in Fig. 4.The sliders in the lift helps for the smooth movement by reducing friction and power losses.

E. Electronic design

The main electronic components used in the design of this robot include: Raspberry Pi 3 model B (master controller), ultrasonic sensors and motor drivers, Raspberry Pi 3 model B model is the master controller of this robot. This is the main signal controlling and processing hub, through which all the actions of other components are triggered, controlled and maintained. The specifications of Raspberry Pi 3 are as follows: it is a Quad Core 1.2GHz Broadcom BCM2837 64bit CPU, 1GB RAM, BCM43438 wireless LAN and Bluetooth Low Energy (BLE) on board, 100 Base Ethernet, 40-pin extended GPIO, 4 USB 2 ports, 4 Pole stereo output and composite video port, CSI camera port for connecting a Raspberry Pi camera, Micro SD port for loading operating system and storing data, Micro USB power source up to 2.5A

Ultrasonic sensors play an important role in measuring and maintaining the distance of the robot from the wall. For the movement of the robot and lift motor, DC motors are used because they have high starting torque and they are easier to control and cheaper than AC motors. Motor driver aids in controlling the action of base wheels and lift motor. Since DC motors are used here, a switch-mode power supply has to be used to switch AC power to DC. A relay is used to turn on and off the paint sprayer with the help of Raspberry Pi 3.

The complete CAD model of the robot is shown in Fig. 5 with four mecanum wheels, ultrasonic sensors, two at the front and one each at right and left, and there is a lift motor on the body of the robot which pulls the string attached to the pulley which in turn lifts the cascade lift at the front of the robot which is carrying a paint sprayer

VI. CALCULATIONS

This section is about choosing the idle dc motors for robot by calculating the various parameters such as wheel rotation speed, torque and power. These calculations are done by choosing the desired parameters values such as nominal speed, load lifting speed and the maximum slope of the floor. In this section all units are in SI system.

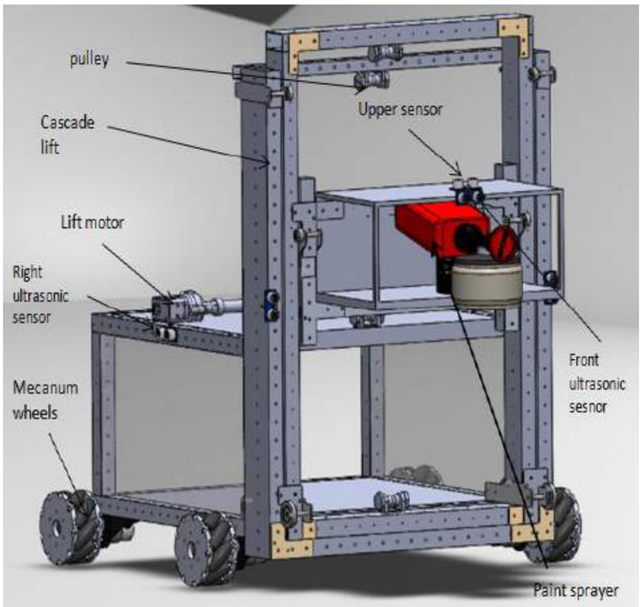


Fig. 5. Complete CAD model of the robot along with parts labeled

TABLE I. SHOWS DIFFERENT PARAMETERS OF THE ROBOT

S.no	Parameter Definition	Symbol	Parameter Values
1	Robot weight	m_r	7kg
2	Load weight	m_l	3kg
3	Total weight	m_t	10kg
4	Nominal speed	v_n	0.3m/s
5	Load lifting speed	v_l	0.5m/s
6	Max slope	k	12%

A. Calculating parameters for Traction Motors

Traction motors are the one which are used for the mobility of the whole robot.

Wheel rotation speed required to achieve the nominal speed.

$$NT = (60 \times vn)/ 3.14 \times dw \quad (1)$$

where, d_w is the external diameter of the wheel with 0.1m

$$FT = gk(mr+ml) \qquad (2)$$

where k is the maximum slope of incline, g is the gravitational constant in SI units

$$P = FT\times vn \qquad (3)$$

where F_T is the thrust force on motor and P is the power.

$$TT = ¼ \text{ x } (dw/2\times FT) \qquad (4)$$

where T_T is torque required for each motor

B. Calculating parameters for Lift Motor

Lift motor is the one which causes the vertical motion of the paint sprayer with the help of strings attached through the pulleys to the motor. Wheel rotation speed required to lift the load at 0.5m/s

$$NL = (60\times vl) / (3.14\times dp) \qquad (5)$$

where d_p is the internal diameter of the pulley with 5m.

$$FL = g(ma+ml) \qquad (6)$$

where m_l is the load weight which is considered as the weight of the paint sprayer with paint (3kg) and F_L is the thrust force on motor due to the load

$$TL = dP/2\times FL \qquad (7)$$

$$P = Fl\times VN \qquad (8)$$

where T_L is the required torque and P, power of the lift motor. The value of each of the parameters defined under sub sections 6.1 and 6.2 are listed in tables 2 and 3.

TABLE II. SHOWS THE CALCULATED SPECIFICATIONS OF TRACTION MOTORS.

S.no	Traction motor parameter definition	Parameter Values
1	Nominal rotational speed	6.002 Rad/s
2	Thrust force on motors	11.772N
3	Torque	0.147Nm
4	Power	0.8829 W

TABLE III. SHOWS THE CALCULATED SPECIFICATIONS OF LIFT MOTORS.

S.no	Lift motor parameter definition	Parameter Values
1	Nominal rotational speed	16.08 Rad/s
2	Thrust force on motors	29.43N
3	Torque	0.735Nm
4	Power	11.72 W

VII. PAINT SPRAYER

This paint sprayer has 12 different modes of spraying speeds, and modes to spray different types of paints. It can spray the paint with uniform thickness throughout its operation. It covers an area of 2.4m (8 ft). x 3m (10 ft) in 1 minute for stained paint and 5 minutes for Latex paint. The lift can move at a speed of 0.4m/s. The height of the lift is 3m. It takes 7.62s to cover an area of 3m (10 ft). in height and 0.20m (0.66 ft) in breadth. Therefore, the robot can paint 0.55m2 (6 sq.ft) approximately in 8 sec. The robot can cover (X x 0.203) m2 where the height of the wall is X m and 0.203 m is the length the paint sprayer covers. If the time taken by robot to cover the height is Y seconds, then

$$Y = X/0.4 \text{ s} \qquad (9)$$

VIII. PROGRAMMING FLOWCHART

The programming flowchart is shown in Fig. 7. The painting robot is activated by connecting to an AC power supply. Then by keeping the painting robot anywhere inside the room (for example in orientation 1 in Fig.6). It will take values from the front ultrasonic sensor and this sensor measures the relative distance between the robot and the wall. Then the robot will move forward up to a relative distance of 20cm between the wall and the robot. If the robot is placed very nearer to the front wall it will get adjusted back up to a relative distance of 20cm between the robot and the wall (orientation 2 in Fig.6) and then it will take distance values from the right and left ultrasonic sensors

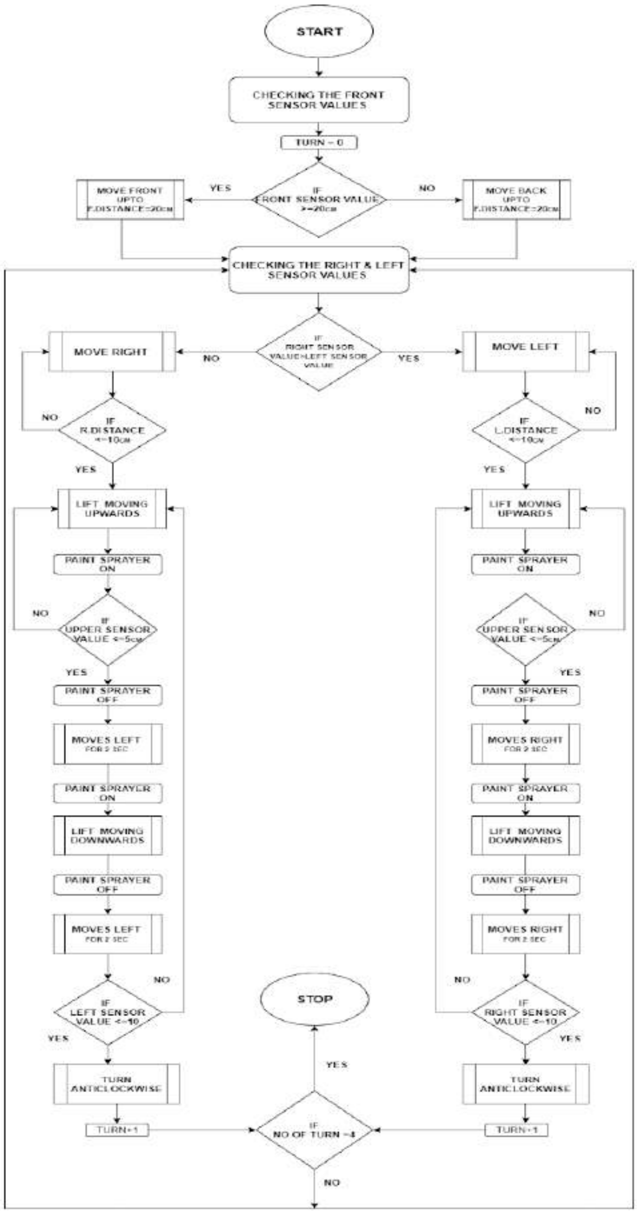


Fig. 6. Programming Flowchart

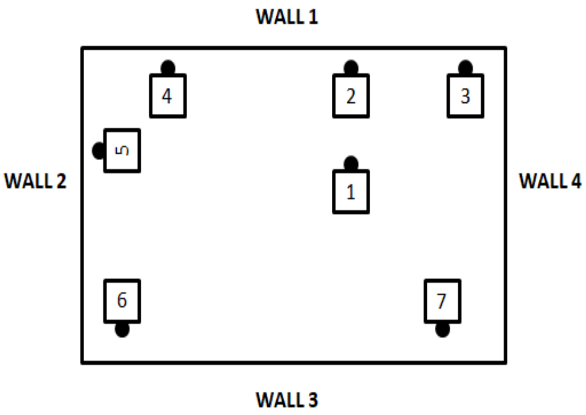


Fig. 7. Time-lapse positions of robot while painting

If the right-side wall is nearer as compared to the left-side wall. It will move right side up to the distance 10 cm between the robot and the wall. Now the robot is situated at one of the corners of the room (orientation 3 in Fig.6). Once it reaches a corner of a room the lift motor and the paint sprayer will get activated and the robot will start painting the wall. The upper ultrasonic sensor is situated at the top of the lift, to avoid the collision of the lift with the ceiling wall. If the distance between the ceiling and the upper sensor is equal to 5cm then the lift motor and sprayer will stop. Then the robot moves left for 2sec and the sprayer turns on (i.e., by the help of relay mechanism). Thereby lift comes down to the ground level and follows a pattern as explained in Fig. 3. As robot reaches the extreme left of wall 1 (orientation 4 in Fig. 6) it means that one wall is completely painted. Then the painting robot turns anti-clockwise by 90 degrees (if it comes from right to left) and starts measuring the front, right, left distances and gets adjusted with respect to the front and right wall (orientation 5 in Fig. 6). The same process is repeated with the rest of the walls.

IX. IMPLEMENTATION

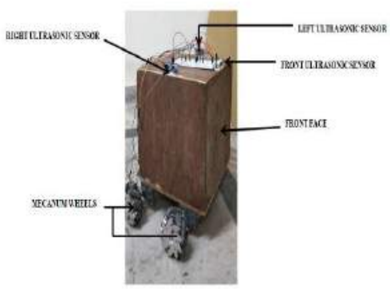


Fig. 8. Painting Bot Base

Fig. 9. Cascade lift

The autonomous wall-painting robot was implemented by a prototype version of the robot. It is made up of merging of the base (Fig. 8) with cascade lift (Fig. 9). The base is made up of a wooden box attached with four mecanum wheels. For the detection of the distance from the wall ultrasonic sensors are placed in the respective positions as shown in the Fig. 8. The cascade lift is attached to the front part of the base and paint sprayer is placed inside the paint sprayer holder in cascade lift. Cascade lift was built with the combination of 4x4 cm and 2x2 cm aluminum profiles. It consists of a single-stage lift which carries the paint sprayer and moves the sprayer up and down with the help of a DC motor which is placed on the top surface of the wooden box. The lift motor pulls the string which is attached to the load through a pulley to lift the sprayer. The lift also consists of an ultrasonic sensor at the front part of the sprayer to detect and maintain a constant distance between the front wall and the robot. Raspberry Pi 3 is used as the master control of this prototype and it uses SMPS. The completed prototype is shown in Fig.10 below.

X. EXPERIMENTS AND RESULTS

The autonomous wall painting robot test setup arena was created with a length 1.27m (50 inch) and width 0.5m (20inch) respectively. By using stopwatch the time taken by the robot to cover a distance of 1.27m was measured. These trails are carried out by 5 times. Average speed of the robot is measured with the average time calculated from the trails. In a similar way the speed of the paint sprayer that covers from top to bottom of the wall is measured. The data obtained from the test setup was used to calculate the below mentioned test results.

Fig. 10. Prototype of Autonomous wall painting robot

TABLE IV. SHOWS THE PARAMETERS OF THE ROBOT AND THEIR MEASUREMENTS

S.no	Parameters of Robot	Symbol	Values (m)
1	Height of the lift	h_l	0.635
2	Width of painting	w_p	0.15
3	Height of the base	h_b	0.3
4	Width of the base	w_b	0.3

Based on the test results we can see that the time taken by the lift to reach extreme top is 16.49 s and by the robot to cover 1.27 m is 25 s. The speed of the lift is 0.03 m/s and the speed of the robot is 0.05 m/s. For 2ft × 2ft wall, time taken by paint sprayer to reach top of the wall is 15.58 s and robot to move from A to B as shown in Fig.10 is 3 s, Time taken by paint sprayer to move from point B to C as shown in Fig. 11 is 15.58 s and by robot to paint wall from start position to C is 34.16 s. Therefore, total time taken by the robot to cover the wall is 1.18 minutes.

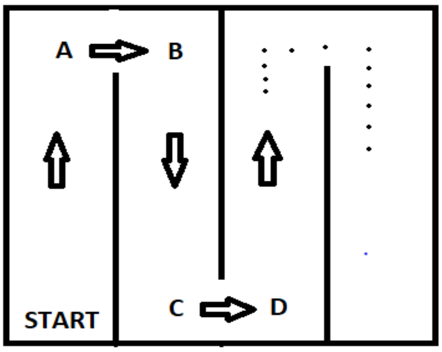


Fig. 11. Paint pattern.

XI. CONCLUSION

The design, implementation, analysis and testing of an autonomous wall painting robot to be used for painting the interior walls of the building is presented in this research work. The robot uses a sprayer attached with a tank filled with paint. The robot itself adjusted from the walls using an ultrasonic sensor. The cascade lift is used for adjusting height according to the wall and it also enables us to have compatibility and portability. The criteria for system design had been outlined and the prototype was implemented and tested. However, there is much scope for system improvement in the future to increase the painting rate and simplify the system design.

ACKNOWLEDGMENT

We take this opportunity to express our profound gratitude and deep regards to HuT Labs, Amrita Vishwa Vidyapeetham which provided guidance and space for us to complete this work.

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