ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645
Indian Journal of Science and Technology, *Vol 9(38), DOI: 10.17485/ijst/2016/v9i38/102580, October 2016*

Development of Exterior Wall Painting Robot

T. S. Mohammad Zaid and A . Arockia Selvakumar*

School of Mechanical and Building Sciences, VIT University, Chennai – 600127, Tamil Nadu, India;
md.zaid1992@gmail.com, arockia.selvakumar@vit.ac.in

Abstract

Objective: Exterior wall painting is one of the major tasks in con-struction field. For apartment building exterior wall painting is risky. Painter will be hanging on the wall with support of rope. While painting the painter has to slide down carefully, even sometimes need to move left and right along the wall. There is a chance of falling if not alert. Method: In this paper, research is carried out for development of exterior wall painting robot (PAINTBOT-EW). Hardware is divided into two sectors, robot and suspension system. Robot is fabricated by attaching paint feed roller to the frame. DC motor drives the roller ver-tically up and down on the frame using rotating disc and connecting rod. Robot is connected to the cables at top right and left corners. The other ends of cables are connected to DC geared motors through the pulleys mounted on the wall at required distance. UI part includes cre-ating Graphical User Interface (GUI) in MATLAB, coding the program and to control the movement of the robot using Arduino Uno. Find-ings: From experiments it is observed that painting robot covers 2 square feet area of wall approximately in 34 mins as the stroke length of the roller is found to be 28 cm. Alignment of robot while moving from one co-ordinate to other may vary but once it reaches the required co-ordinate it aligns itself straight. Motors which were fixed to the robot for movement; in earlier, robot was attached to the ground in order to reduce vibrations generated in robot. As well as continuous paint flow is maintained while painting using pump which is not possible in case of compressor used in earlier robot. Applications: Wall painting is carried out with 65% reduction in cost along with reduction in vibrations generated in the earlier model..

Keywords: Arduino Uno, Cables Supported, MATLAB (GUI), Roller based Painting, Wall Painting Robot

1. Introduction

In India many accidents takes place while exterior painting of tall buildings. It is difficult to paint in higher altitude, sometimes many casualties takes place because of loosening of rope or misbalancing. To avoid these kinds of casualties, we shift our focus towards the research for replacing human with robot in a painting system. In[1] have developed a wall painting robot that is controlled by Altera DE2 development board with the use of software Quartus II 8.1 and NIOS II IDE. The user friendly GUI has been generated using MATLAB. In[2] have proposed roller based painting robot which detects and paint the wall using two links manipulator actuated by servo motors and the path is recorded using GUI. Another mechatronics system was developed by Terauchi, et al. which works as a Cartesian co-ordinate robot in that the design as well as on-site trails is conducted to find effectiveness of painting[3]. Sorour, et al. have designed robotic arm for wall painting applications in that the mechanism is developed based on the trajectory. Lateral feed is provided using the omni wheel setup. Control algorithm is generated with initial assumptions as well as required movement[4]. In[5] have designed robotic system to paint picture from the computer, initially dots are drawn and then final drawing is done by spray gun. Cost of the painting process is estimated

*Author for correspondence

according to the paint design drawn in the computer. In[6] have modeled exterior wall painting robot and proposed its feasibility analysis. Variables and assumptions were made to analyzethe Benefit to Cost (B/C) ratio, Rate of Return (ROR) analysis and saving of annual cost. In[7] have studied in general on various types of robots used in construction industry based on that they have compared the cost benefit between the implementation of automation and other manual practices to improve safety and quality standards in construction using automation. In[8] have examined two types of robotics system for interior painting in which they suggested that the implementation of human-robot integration in painting task reduces 70-80 % of duration. In[9] have analyzed specific needs in painting and problems. In that they developed the sketch with roller, brush and color pencil for painting process. Based on the sketch they generated the screening matrix for each process to find which process is effective. Based on the literature survey the following inferences were drawn:

- In one of the research Altera DE2 board is used in development of robot which is much costly.
- The spray painting system used in the system has flaws such as compressor helps the paint to come out of the nozzle with pressure. In this process, as soon as compressor is switched on the response of out coming paint is very poor as paint will flow back to the container when compressor is switched off.
- Even while changing its position in X-direction robot has to move gradually by releasing unequal length of cable which leads to distortion in position due to this coat of paint is uneven.
- It is mentioned that replacement of conventional painting process with painting robot will lead to annual savings on cost of about 45%. Hence the painting robot can be developed in future.
- Two link manipulator mechanisms are developed which helps the roller to apply force on the wall in order to paint the wall with even coat.

In this research, stepper motors are replaced with DC motors and placed on the ground rather than inside the robot due to which the vibrations of the system will be reduced while painting. Similarly, the return flow of the paint in roller based painting will be avoided by using pump instead of compressor. Altera DE2 board is replaced with the Arduino Uno microcontroller for developing low cost exterior wall painting robot (PAINTBOT-EW). Further, the conceptual design of wall painting robot is discussed in Section 2, roller mechanism design is explained in Section 2.1, wall painting system overview is mentioned in Section 2.2, hardware and software implementations are explained in Sections 3 and 4 respectively, experimental proto type and summary of the exterior wall painting robot are discussed in Sections 5 and 6 respectively.

2. Conceptual Design of PAINTPOT-EW

Figure 1 shows the proposed system of wall painting robot which has a Crank wheel fixed at the bottom of the frame. Crank wheel has offset hole from its center. Both the ends of the connecting rod are connected to the crank wheel at offset hole as well as at bottom of the roller handle. Fixed support is provided for sliding of roller in vertical direction on which the roller will be sliding upward and downward. The geometrical assumptions are made as follows: Length of the connecting rod is more than the diameter of the crank wheel, there by resulting in sliding motion without disturbing the assembly. Supporting frame is fixed above the bottom of the frame which is slightly more than sum of radius of the wheel and length of connecting rod.

2.1 Roller Mechanism

In order to paint the wall, roller has to slide up and down. Figure 2 shows the mechanism utilized in the robot. By using inversion of four bar mechanism rotational motion is provided to rotating disc (crank), which induces the sliding motion to the roller handle. Fixed guide ways makes

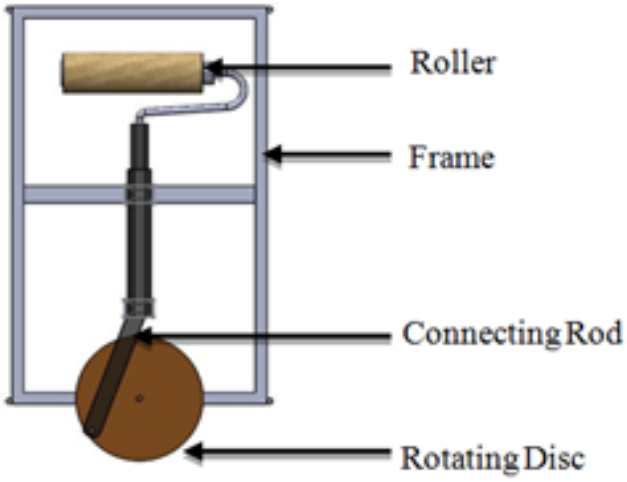

Figure 1. Proposed model of wall painting robot.

sure that roller moves in the straight (assigned direction). Link 1 (L1) is the fixed, Link 2 (L2) is crank which rotates above the center of the frame and then converted into linear motion. Lengths of the links are mentioned in the conceptual design section. Roller is guided with inclination of 20^0 from the frame towards wall to maintain, hardware and clearance (C) at initial position (i.e., to avoid contact with wall while gradually moving from one location to another) as shown in Figure 3. Stroke length (S) of the roller is purely based on the radius of the rotating disc (length crank), attained by calculating difference between top most and bottom most position of the roller. Distance from wall to pulley (L) is kept constant in entire painting process.

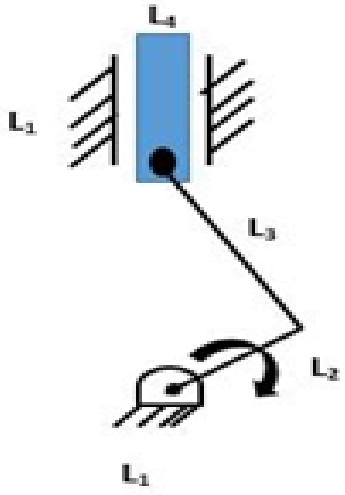

Figure 2. Mechanism for exterior wall painting robot.

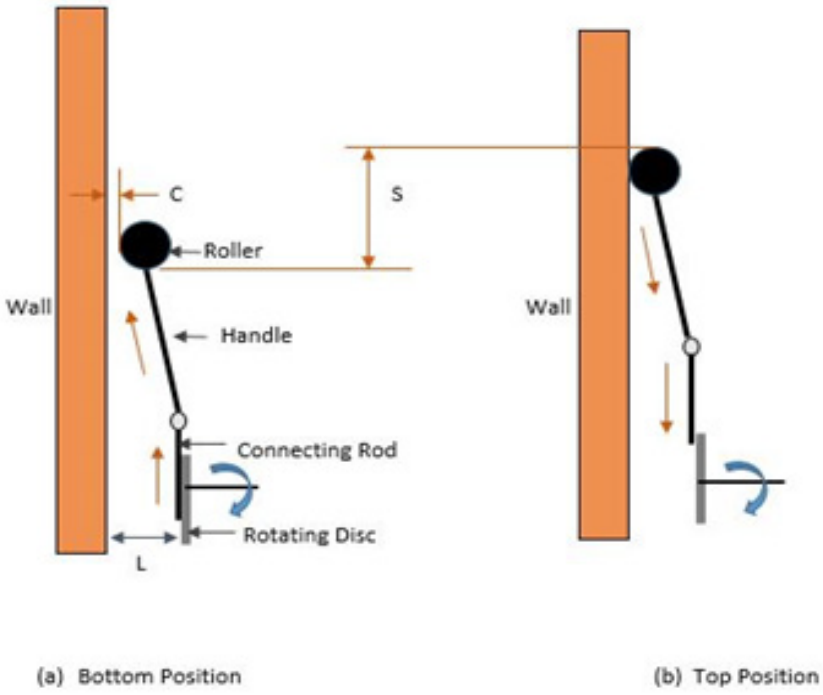

Figure 3. Side view of PAINTBOT-EW.

2.2 Torque Calculations

The required torque can be acquired by sketching free body diagram of the robot and system. Force multiplied with the perpendicular distance is the theoretical approach. Free body diagram of robot and system is as shown in Figure 4.

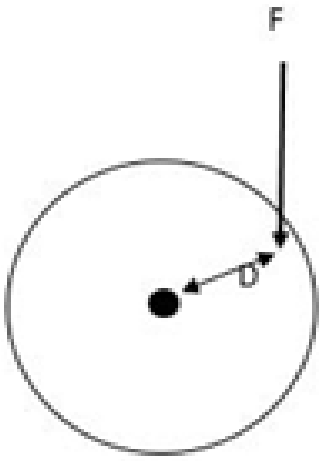

Figure 4. Free body diagram of robot mechanism.

Weight of the roller (W_R) = 0.45 kg.
Weight of the connecting rod (W_C) = 0.05 kg.
Total weight of the roller (F) = W_R+ W_C= 0.5 kg.
Length of crank (D) = 100.mm.
Torque required to operate the motor = 0.5 kg * 100. mm

= 5.kg cm

Torque required for Motor 3 including factor of safety.= 5*2 kg cm.
= 10.kg cm

Free body diagram of the painting system is shown in Figure 5. At any given angle tension in the rope will be the components for force acting towards gravity.

Total weight of the robot (W_T) = 1.8 kg.

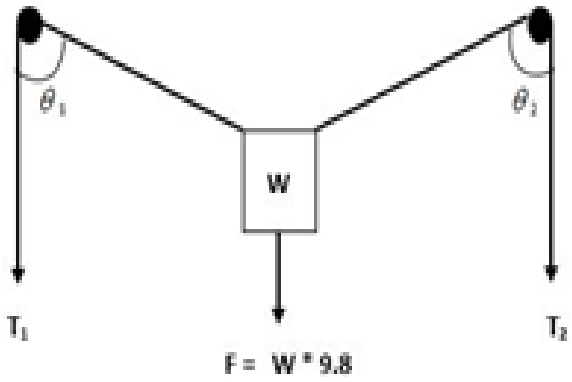

Figure 5. Free body diagram of overall painting system.

Force acting in Y-direction (F) = 1.8 * 9.8 = 17.64 N.

Maximum tension along the ropes T_1 and T_2 = 17.64 N.

Radius of the rope collector on each motor R_C = 50 mm.

Maximum torque required will be acquired at maximum tension (i.e., 17.64 N).

Torque for Motor 1 or Motor 2,

Required torque = $T_{1\,max}$ * $R_{C\,=}$ 17.64 * 50 mm = 88.2 N cm = 8.99 kg cm.

Torque with factor of safety = 8.99 * 2 = 17.98 kg cm.

Available motor in market is of 15 to 20 kg cm.

Hence motor 1 and 2 have selected with 20 kg cm torque to avoid flaws.

2.3 Overview of Wall Painting System

The Robot is designed to hang through the cables which are being supported by pulleys attached on wall as shown in Figure 6. DC geared motors are connected at the rear end of the cables to control positioning of robot at required co-ordinates. When robot is at initial position (0, 0), initial length of cable 1 is zero, whereas length of cable 2 is the distance between two pulleys (i.e. length of the wall). Required position of the robot is manipulated using geared motors. Robot has reciprocating mechanism in which the roller slides upward and downward motion for the given stroke length (S). Paint is transferred to roller through hose pipe from the inner cross section of the roller handle with the help of pump implemented in the system.

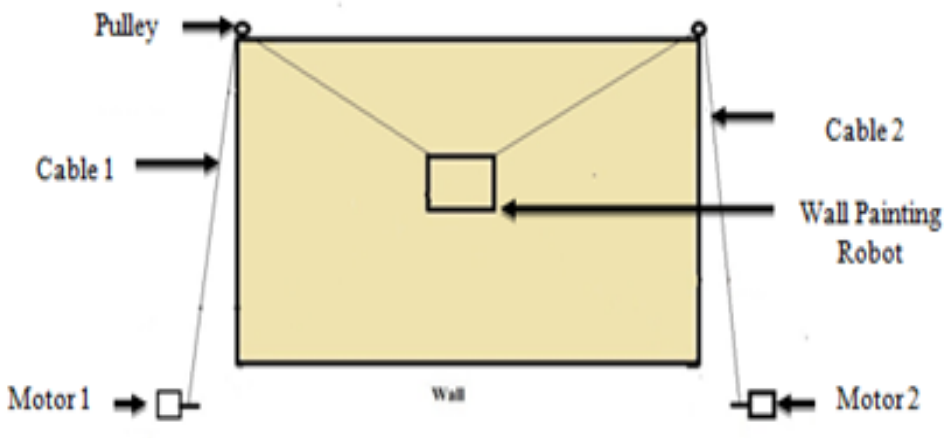

Figure 6. Front view of PAINTBOT-EW.

3. Hardware Implementation

Interfacing of Arduino, GUI (MATLAB), Motors, Driver IC, Relay module and pump is shown in Figure 7. Arduino is connected to system through USB Port, which receives input from MATLAB GUI. Output from Arduino is fed to the Dual Driver IC, which consequently controls motor 1 and 2 at required intervals. Arduino even controls pump via relay, which in result actuate the motors and pump when command is provided through GUI.

3.1 Power Supply

Output from Arduino is 5 V DC and motors are operated at 12 V DC. Driver IC will take 5 V DC from Arduino and supply 12 V DC to the motors when input is provided. Same in case of pump, it requires 230 V AC supply, relay takes 5 V DC input from Arduino and supplies 230 V AC to the pump. Switched mode power supply unit is used to provide 12 V DC supply.

4. Software Implementation

The overall painting system is controlled with MATLAB GUI. Coding is done in MATLAB to control motors and pump by accessing feedback from ultrasonic sensors along with user's input from GUI. The position of robot is computed by converting required angle of rope with respect to X-axis into time interval to actuate motors. To actuate sliding motion other Arduino present in robot is programmed using IDE software. In case of any obstacle being detected by sensors, system will forbid the motors to carry out further movement of robot.

4.1 Graphical User Interface

Graphical user interface allows user to provide inputs and start the painting process by simple clicking operation displayed on the desktop as shown in Figure 8. Also there are manual controls to operate the robot in case of emergency. The required delay is computed for each position by manual operation and fed into the automatic control.

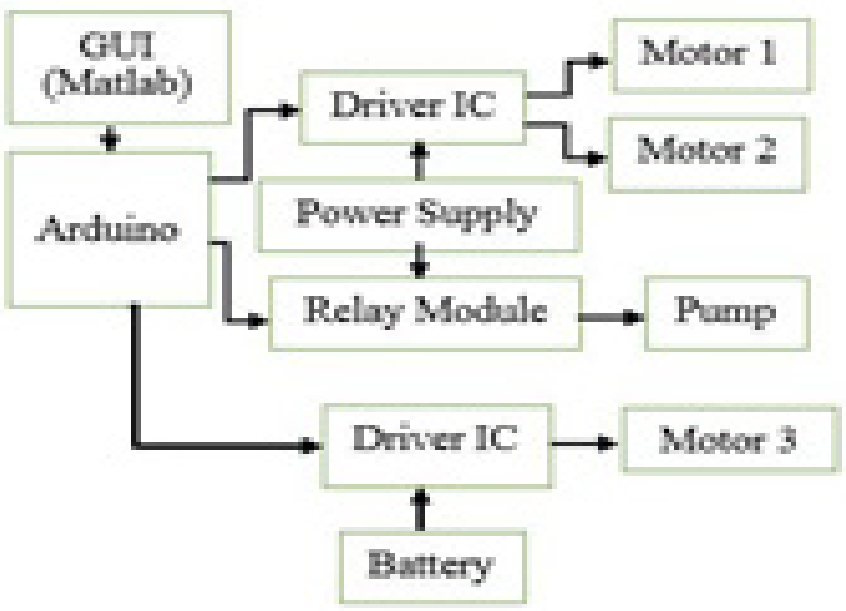

Figure 7. Interfacing of wall painting robot.

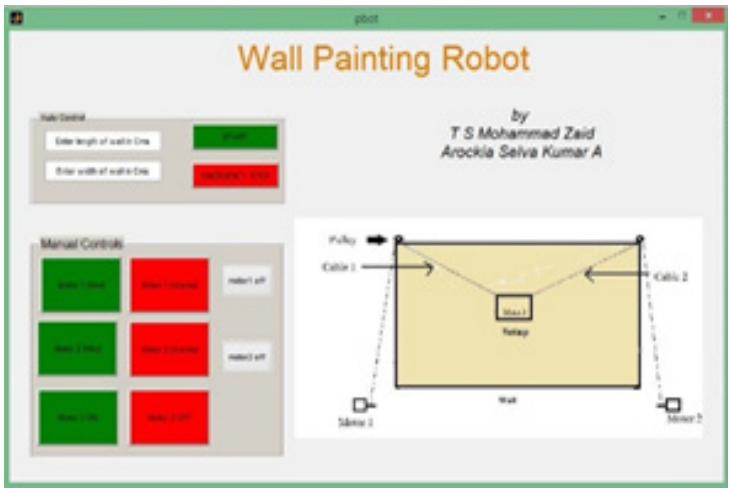

Figure 8. GUI to control wall painting robot.

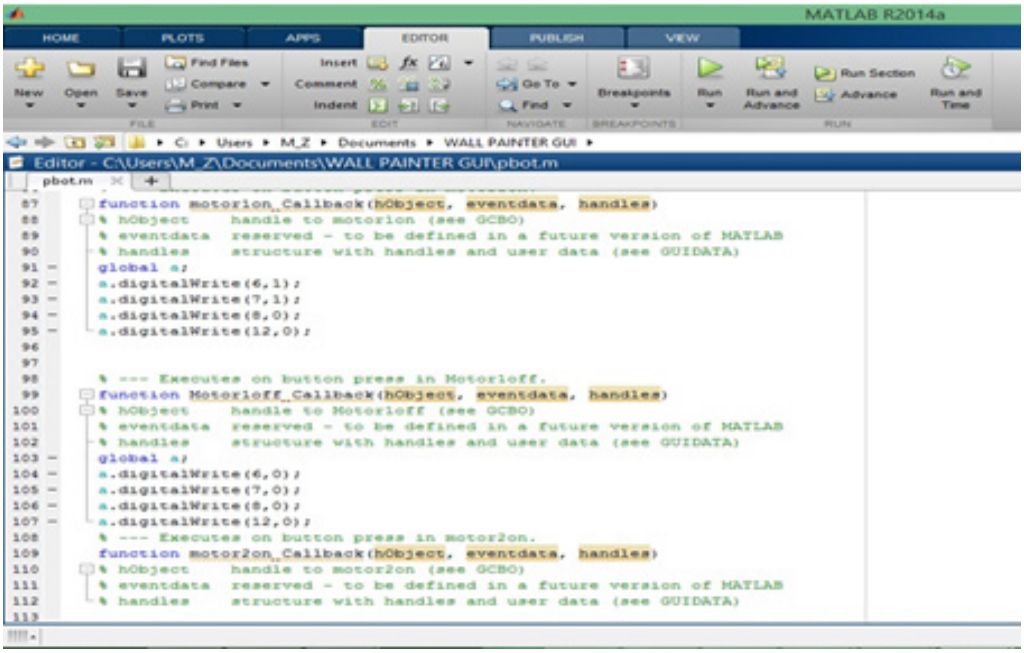

Figure 9. Programming in MATLAB.

User has to incorporate length and height of the wall as inputs. The programming and the flowchart to develop MATLAB GUI are shown in Figures 9 and 10.

4.2 Flowchart

The below flow chart explains the step by step advancement of wall painting process in Figure 10.

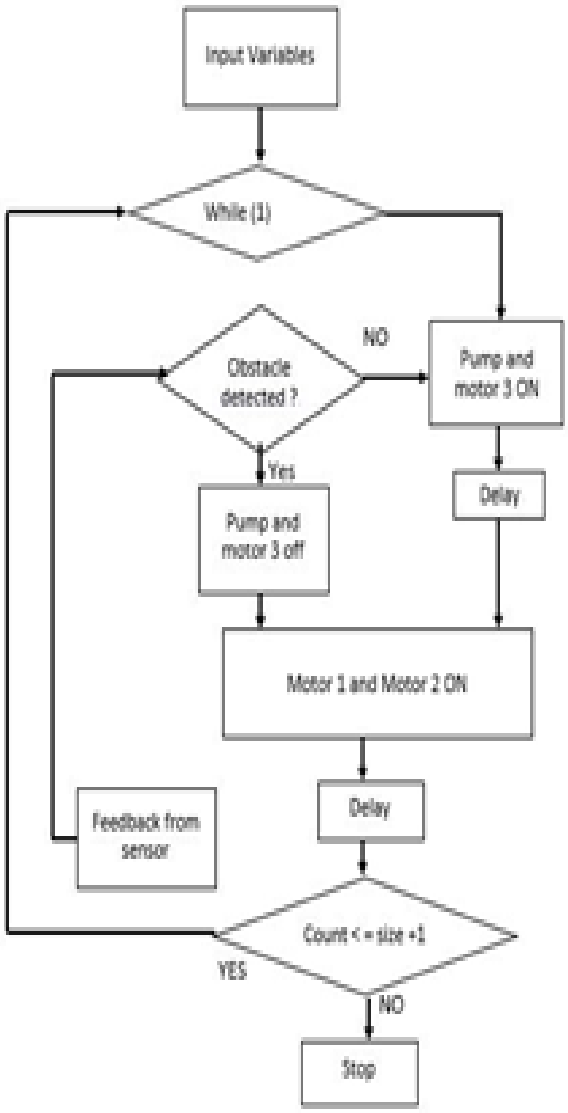

Figure 10. Flowchart of painting process.

3. Experimental Prototype

Prototype is fabricated as per the design and it is shown in Figure 11 and bill of materials is shown in Table 1. Robot is fabricated with frame on which the mechanism is placed. Motor 1 and 2 are fixed to the ground. Pulleys are fixed at top corners of the wall. Rope will pass through pulleys whose one end is fixed to the robots edge and the other to the motor fixed on the ground. Control system developed will actuate the motors to run the prototype depending on the commands provided by the user. User feeds command from the GUI based on the command rope winds and unwinds the rope to position the robot at required location.

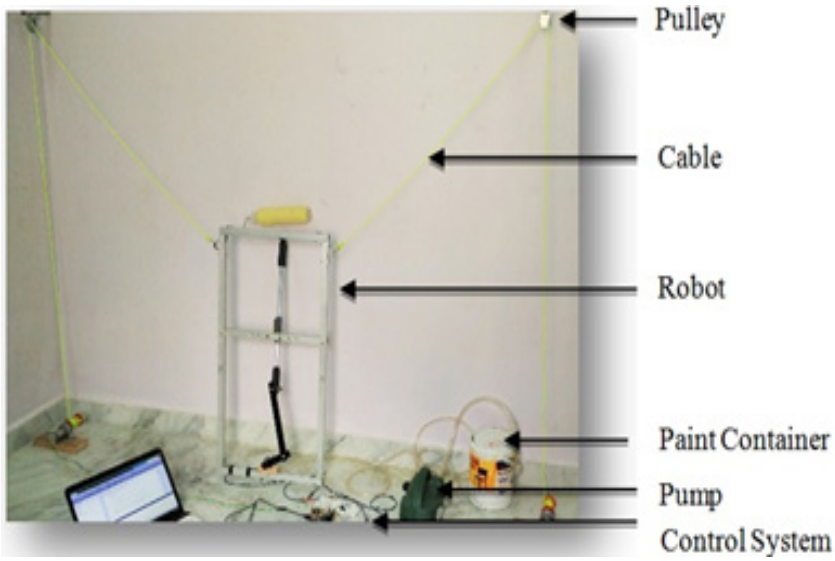

Figure 11. Experimental prototype of PAINTPOT-EW.

Table 1. Bill of materials

S. no.	Description	Specifications	Quantity
1	Controller	Arduino Uno	1 NOS
2	Relay	Jqc-3pc	1 NOS
3	Driver IC	L293D	2 NOS
4	Pump	-	1 NOS
5	Dc geared motors	20 kg cm torque, 60 rpm	2 NOS
6	Dc geared motor	10 kg cm torque, 60 rpm	1 NOS
7	Hose pipe	Dia 15 cms. length - 3 m	1 NOS
8	Hollow bar	Aluminium - 1 inch width, 2 mm thick	1 NOS
9	Switch mode power supply	230 V AC input- 12 V DC output	1 NOS
10	Roller	Sponge material	1 NOS
11	Connecting wires	-	25 NOS

6. Results and Discussion

An exterior wall painting robot is modelled and fabricated with roller mechanism using crank and connecting rod, pulleys, cables and DC geared motors. Apart from that it is controlled by Arduino Uno using GUI. Based on the development and experimental investigations the following results are discussed.

6.1 Motion Simulation

3D model is created and motion simulation is carried out using Solidworks. The motion analysis was carried out, based on the results, the geometrical parameters of the prototype of the wall painting robot was fabricated. To keep robot light weight 1 inch aluminium pipe is used.

6.2 Experimental Investigation

Based on the experiment conducted on the developed exterior wall painting robot the following points are observed:

- The stroke length of the roller is found to be 28 cm. From the design parameters, width of the roller is 24 cm. Hence area covered by the roller at one location is 672 square cm. 30 locations will approximately cover 2 square meters of area. Roller makes 3 vertical strokes which helps in avoiding the errors. It takes 8 secs. to finish 3 strokes. Hence time required to paint at 30 locations is 12 min.
- While gradually moving from one co-ordinate to other, robot will not be straight but when it reaches the desired final co-ordinate the robot itself aligns and straight till it tends to move for next co-ordinate.
- It takes 44 sec to move the robot from one co-ordinate to the other co-ordinate. Time taken to change the 30 locations is 22 min to cover 2 square meters area. Therefore total time taken to paint 2 square meters is approximately 34 min.
- In earlier model, motors were placed inside the robot to wind and unwind the rope in order to change the position of robot because of that vibrations generated during its operation. In this work, DC motors are fixed on the ground rather than on the robot, due to which the vibrations generated within the robot are less and it will not affect the painting process.
- In order to maintain continuous paint flow, in this system pump is used than compressor. The pump is controlled by the developed control system using Arduino. Whenever the pump is switched on, the paint flows to the roller. When the pump is switched off, the paint flow will be seized and blocks the return flow of paint which was not controlled by the compressor in the earlier system. When the robot moves to the next location, the paint immediately flows to the roller without any delay which makes sure that the area to be painted is covered completely.
- Proposed roller mechanism guides the handle of roller with inclination of 20 degrees which helps to apply the force on to the wall while painting. Hence the roller will be in contact with the wall while painting, which applies the even paint coat on to the wall.

6.3 Cost Analysis

Based on the existing model and the proposed model, the cost of each component is analysed and it is shown in Table 2. Here the cost is mentioned for the educational Altera DE2 board and commercial board again adds up

Table 2. Cost analysis

S. NO	Existing system	Cost in Rs.	Proposed system	Cost in Rs.
1	Altera DE2 Board	17,040/-	Arduino Uno	1,200/-
2	Compressor	2,000/-	Pump	2,500/-
3	Stepper motors(2 No's)	8400/-	DC Motors(3 No's)	2,350/-
4	Other Equipment	3200/-	Other Equipment	4,650/-
	Total	30,640/-	Total	10,700/-

the cost. As the function of controller is to switch the polarity of the motor and to run the pump, Arduino Uno is sufficient to perform the necessary task. Hence the proposed system is commercially good due to the low cost components.

7. Conclusion

An exterior wall painting robot is fabricated with roller mechanism using crank and connecting rod, pulleys, cables and DC geared motors. Apart from that it is controlled by Arduino Uno using GUI. Based on the development and experimental investigations following points are summarized:

- Motion simulation is carried out for the exact dimensions of the components.
- As high torque motors will have more vibrations, geared motors are fixed on the ground rather than fixing on the robot itself which leads to reduction in vibrations while operation.
- When pump is switched off paint will not flow back into the container from the roller as the paint in the hose pipe will be seized by the pump which makes the paint to flow immediately for the next location.
- Inclination provided in the roller mechanism will makes sure to apply force on the wall in order to maintain even coat of painting.
- Hazard to human is eliminated as there is no need of painter to be hanged on wall.
- Low cost controller, Arduino Uno is utilized in order to control the robot. Based on the development of PAINTBOT-EW, the reduction of total cost of the system is found to be 65%.

7.1 Future Scope

- Sensors can be used to measure the vibrations inside the robot.
- Frame can be re-designed in order to cover corners of the wall.
- Painting application can be extended for cleaning by replacing roller with the wiper.
- Multi-color based painting can be integrated.
- Encoders can be fixed at the motors to position the robot accurately at desired location.

8. References

1. Ean TB, Ragavan SV. PAINTBOT-FPGA based wall painting ser-vice robot prototype. Recent Advances in Intelligent Computation-al Systems; 2011. p. 777–82.
2. Mohamed A. Design of an autonomous wall painting robot. First International Symposium on Socially and Technically Symbiotic; 2012.
3. Terauchi ST, Miyajima T, Arai MK, Takizawa S. Development of an exterior wall painting robot capable of painting walls with inden-tations and protrusions. Automation and Robotics in Construction. 1993; 10:285–93.
4. Mohamed TS, Abdellatif MA, Ramadan AA, Abo-Ismail AA. De-velopment of roller-based interior wall painting robot. World Acad-emy of Science, Engineering and Technology. 2011; 5(11):2309–16.
5. Gokyu T, Takasu M. Development of wall painting robot. India SME Asset Reconstruction Company; 2014. p. 949–56.
6. Young SK, Jung MH, Cho YK, Lee J, Jung U. Conceptual design and feasibility analyses of a robotic system for automated exterior wall painting. International Journal of Advanced Robotics System. 2007; 4(4):417–30.
7. Kumar VRP, Balasubramanian M, Raj SJ. Robotics in construction industry. Indian Journal of Science and Technology. 2016; 9(23):1–12.
8. Kahane B, Rosenfel Y. Improved tools for robotic interior painting. Proceedings of the 16th ISARC IEEE International symposium; Madrid, Spain. 1999. p. 275–80.
9. Kamaruddin A. Prototyping of automatic wall painter in Asia crea-tive design project. Innovative Design Contest; 2013. p. 1–3.