ICMIEE20-170

Design and Construction of a Spray-Painting Robot

Md. Nazmul Hasan Jony, Md. Helal-An-Nahiyan
Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh

ABSTRACT
Despite the advances in robotics and its wide-spreading applications, interior wall painting or mechanical parts painting with the irregular surface has shared little in scientific research. However, it has a lot of applications in the automotive, construction, shipbuilding, and production industries. Therefore, this research presents the development and implementation of a spray-painting robot to print or coat on regular flat surfaces and irregular curved surfaces within a short time and at a low cost. A three-dimensional (3 DOF) cartesian robot is designed to solve the purpose accordingly. A sonar sensor is installed in the end effector of the robot to track the shape of the surface and keep a constant distance between the nozzle and the job surface. Three gear motors are used to control the 3 DOF cartesian robot that is controlled by Arduino. The spray nozzle can move in the workspace of the *x*-*y*-*z* cartesian coordinate space. Two chain-sprocket systems are used for the movement of the spray nozzle along the *x* and *y* axes; and a rack and pinion mechanism guides the motion of the nozzle on the *z*-axis. To maintain the user-defined certain distance between the nozzle and work surface, it can adjust up to 3 cm irregularity along the *z*-axis concerning the *x*-*y* plane. The experimental results demonstrate that the robot can move in the *x* and *y* directions smoothly and it can follow the surface track accordingly. Besides, it may offer the chance of minimizing or eliminating human exposure to difficult to reach the surface and unsafe and unhygienic environments.

Keywords: **S**pray-Painting, Cartesian Robot, Robotics, Automation, Safety

1. Introduction

Spray painting is a method of spraying a coating (paint, ink, varnish, etc.) through the air onto a surface. High-pressure liquid spray jets are directed to the object. In the early age of painting technology, paint was applied manually and dried for days at room temperature as it was dried by solvent evaporation. As mass-production made the process uneconomical, paint needs to be dried in ovens. Until few decades before lead, chromium and other heavy metals were mixed in automotive paint. Water-based acrylic polyurethane enamels are recently used as the basecoat with a clear coat as it is environment friendly. Airless painting requires a high-pressure pump using 300 to 7,500 psi pressure to atomize the coating through different tip sizes to have the desired atomization and pattern. This method is used by painters in heavy duty industrial and marine coatings. The painting chemicals may cause hazards to human painters like eye and metastasis issues. Additionally, the character of the painting procedure that desires recurrent work and hands uplifting makes it boring, time, and energy overwhelming. The foremost vital advantage of painting automation is that it is acquainted with saving power, energy, and materials and reinforcing the quality, preciseness, and accuracy. Once, the construction employees and robots get properly integrated into collaborative tasks, production time will be saved, and output will be higher. It would supply the possibility to avoid human workers underneath unsafe and unhygienic environments.

There are several pieces of research focused on developing painting robots. One of them was a prototype of an autonomous plastering robot that was trialed in a large-scale construction site [1]. It can measure the area of the surface and run its operations simultaneously, under the monitoring of an operator, using range mapping sensors. The time for plastering is expected to be less than 50% of that taken by manual work and the amount used is also reduced. Few more navigation systems were demonstrated in other researches [2] and [3]. A high ladder truck conceptual design was proposed by Kim, et. al. in 2007. In this concept, the print head moves along the ladder vertically (*y*-axis) and horizontal motion is done by moving the truck intermittently. The print head also adjusts distance from the wall moving along the *z*-axis. This idea is very applicable wherever ample space is obtainable to maneuver trucks [4]. In 2007, Naticchia, et. al. showed that automated painting is not only focused on upgrade productivity but also ensures quality. A high precision robot arm is required. An automated control system to transform the normalized coordinates of the colors to be regenerated into the movement speed of the end effector and valve opening module of the mixing board [5]. In 2008, Elattar, et. al. explained that workers cannot maintain greater efficiency as like robotic arrangement in painting [6]. In 2010, Johan, et. al. presented a technique for increasing the efficiency of an industrial manipulator that can paint a surface. The approach is based on the motive that a small error in the motion of the end effecter does not affect the quality of the job. It is more important to keep constant velocity throughout the path [7]. In 2013, the International Journal of Innovative Research in Science, Engineering, and Technology revealed a research article on automatic painting. The authors used a mobile platform mounting sprayer on that. IR device is utilized to sense wall presence and a solenoid valve is used for flow management [8]. In 2014, another paper by Thakar, et.

* Corresponding author. Tel.: +88-01701040772
E-mail addresses: nazmulkuet15@gmail.com

al. presented that manufacturing products need to coat for protecting from rusting and the spraying tasks take huge time and the skilled worker requirements emerged by day. Therefore, it requires developing a new idea of coating the job with the dipping process having a semi-automatic system being suitable and valuable for such industries [9]. An automatic spray-painting machine was developed by Swarkar, et. al. in 2018. The authors used a threaded rod for vertical motion of spray gun along the *y*-axis; rack and pinion mechanism and connecting rod was used for horizontal motion along *x*-axis [10]. Another painting automaton was developed by John, et. al. in 2018. The authors used an ultrasonic device to find the wall surface to start painting and a solenoid valve to manage the flow of air. It paints vertically on the peak and horizontally moving rock bottom frame. The movement is controlled through dc motors with the help of an Arduino board [11].

Most of the previous researches on painting automation dealt with interior/exterior wall painting. They shared a little research on specific object painting having an irregular curved surface. However, commercially lots of components like mosaic doors, automobile parts having a curved plane or surface need to be painted. Thus, a new painting robot is developed which can follow both even and uneven surfaces equally.

2. Design and Construction

2.1 Concept Design

A Computer-Aided design of the developed spray-painting robot is shown in Fig.1. The robot is designed considering the movement of the nozzle in the three-dimensional cartesian space. The Sonar sensor is used to detect jobs and maintain a fixed distance between job and nozzle. Three gear motors are used to provide required torque and motion in the three joints. The control unit is designed to be at the backside of the base. Nozzle movement is assisted by two chain drives in the *x* and *y* directions as shown in Fig.2. Besides, a rack and pinion drive regulate the motion of the nozzle in the *z*-direction.

The upper part of the whole moving body is supported on the upper link only and guided through it. The lower part freely slides through the lower lubricated angle bar.

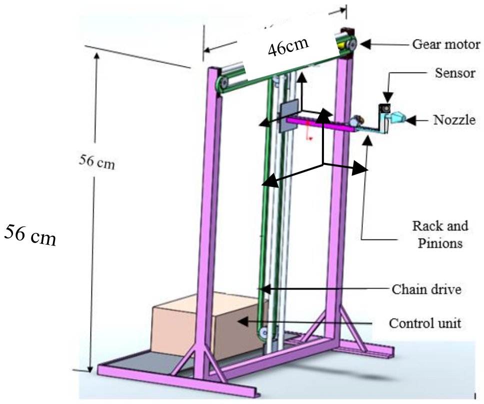

Fig.1 Conceptual Design of Spray-Painting Robot

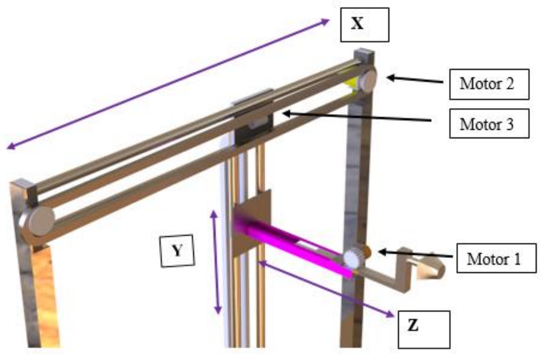

Fig.2 Direction of Nozzle Movement

The rack is designed in Solidworks having 32 teeth where pressure angle is used 14.5 degrees and pitch 3.5mm as shown in Fig. 3.

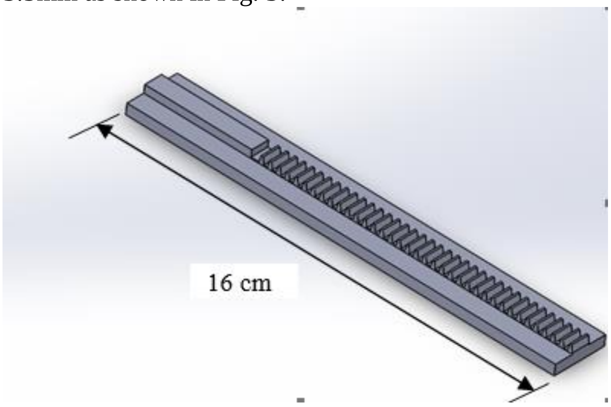

Fig.3 CAD Model of Rack

2.2: Manufacturing Operation

There are several manufacturing operations are executed to construct the system. Major operations are explained in the following section.

2.2.1 Cutting Operation

The cutting operation is done with a hand grinder for sizing the columns and links from Stainless Steel pipe, bar, and mild steel angle bar as shown in Fig.4. Two angle bars of mild steel with a length of 25 cm each are cut to be used as the base. Two SS hollow rectangular bars width of 25 mm are cut by 56 cm each to be used as column. Three guided links are made by cutting 8 mm dia. SS pipe to a length of each 46 cm.

Fig.4 Cutting Operation

2.2.2: Welding Operation

Arc welding joints shown in Fig.5 are done to make corner joints of metal sheets for clamping motor 2 and to weld the outer edge of pipe with sheet metal. Welded pipe of 9 mm diameter shown here concentrically moves along the upper link in the *x*-direction.

Fig.5 Welding Operation

2.2.3: Drilling Operation

The drilling Operation shown in Fig.6 is done to make bolted joints, couplers, and fastening clamps. Different sizes like 4.5 mm, 5 mm, 10 mm drill bits are used for various purposes.

<u>Drill Speed Calculation:</u>

rpm = (C x 4)/d

where,

speed = drill speed in revolutions per minute.

C = Recommended cutting speed feet per minute

4 = constant in all calculations for RPM (except metric)

d = The diameter of the drill itself

For example, if a 0.5in twist drill is to cut MS,

speed= (200 X 4)/0.5 = 1600 rpm

Thus, the drilling machine would be set up to drill as close to 1,600 RPM as possible. It is best to use the machine speed that is closest to the recommended RPM.

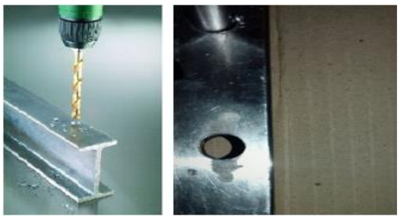

Fig.6 Drilling Operation

2.2.4: Tapping Operation

The tapping operation shown in Fig.7 is used to make inner threads of drilled couplers to fasten with bolts. At first 4.2 mm drill is done and tapped by M5 tap.

Fig. 7 Thread cutting

2.2.5: CNC Operation

Fig.8 shows the job after the CNC operation is done. CNC is used to make a rack with high precision of 1 mm face width of each teeth. A 0.5 mm end mill cutter is used to do the job.

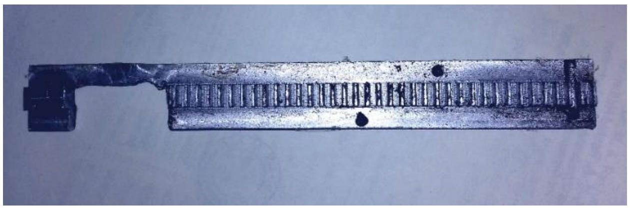

Fig.8 Rack after CNC and Post cutting operation

2.2.6: Chain-Sprocket Selection and Sizing

The Roller chain shown in Fig.9 is used in this project that transfers power from the motor shaft to the drive sprocket. It is made of nickel-plated plain carbon steel to prevent rust.

<u>Chain Length Calculation:</u>

Distance between two sprocket), C =18 inch= 46 cm

Number of teeth of the front sprocket, F = 10

Number of teeth of the rear sprocket, R = 10

Simple Equation (formula in Inch):

L = 2 (C) + (F/4 + R/4 + 1) [12]

Chain length = 2(18) + (10/4+10/4+1) = 42 inch=107 cm

Therefore, a 107 cm long roller chain is used.

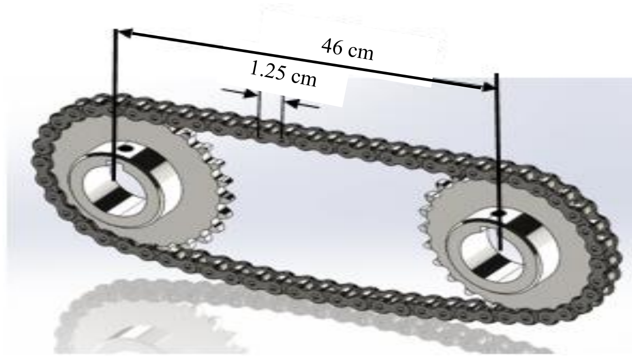

Fig.9 Sizing of Chain-Sprocket

2.3: Electrical and Electronic Components

Several electronic components are used to develop this robotic system and to control the system according to the user defend parameters. Some of them are as follows:

- Arduino UNO/ Arduino Mega
- Sonar Sensor(HCSR04)
- L298N Motor driver
- 12V Power Adapter
- DC Gear Motor

Sonar Sensor used in this device, having maximum range 4 m, consists of a transmitter, receiver and control circuit.

Performance Justification of DC Gear Motors:

- Motor-1 and Motor-2 are rated 12v, 60 rpm.
    - Rated torque = 12.23 Kg-cm
- Motor-3 is rated 12v, 90 rpm.
    - Rated torque = 6.5 Kg-cm

Paint head load, N_1=0.5 kg (Motor-1)
Horizontal sliding load, N_2 = 2 kg (Motor-2)
Vertical sliding load, $N_{3=}$ 1 kg (Motor-3)

Under lubricant condition between steel rod and steel surface-
μ_s =0.16
μ_k = 0 ; hence μ = 0.16
Frictional force, $F_f = \mu N_1$= (0.16 x 0.5) kg= 0.08 kg.
Torque needed= 0.08 kg x 2 cm (radius of pinion) = 0.16 kg-cm.
Hence, Motor-1 can easily do the job.

$F_f = \mu N_2$= (0.16 x 2) kg=0.32 kg.
Torque needed= 0.32kg x 4.85cm (radius of sprocket) =1.552kg-cm.
Hence, Motor-2 can easily do the job.

$F_f = \mu N_3$= (0.16 x 1) kg=0.16 kg.
Torque needed= 0.16 kg x 4.85cm (radius of sprocket) =0.776 kg-cm.
Hence, Motor-3 can easily do the job.

3. Control Circuit Diagram

There are two Arduino boards is used in the control unit as shown in Fig.10. Two h-bridge motor drivers are used to supply the power to the 12V motors. The Sonar sensor is connected to Arduino UNO to sense the distance of the surface.

At first, if the object, which is to be painted, is kept far from the programmed fixed distance, then the LED will blink. Next, the object is to be positioned correctly. When the object distance will be within the working range of the nozzle, the LED will be off.

Motor-2 will also start rotating in one direction and the nozzle will move from left to right corner of the object. Then, motor-3 will rotate clockwise to move the nozzle downward. Again, motor-2 will rotate in the reverse direction to move back. These steps will repeat until the last step of motor-3 would be at the bottom right corner of the object.
Along the journey of painting, wherever the sensor finds an uneven surface, motor-1 will maintain pre-defined distance by rotating in a clockwise/anticlockwise direction.

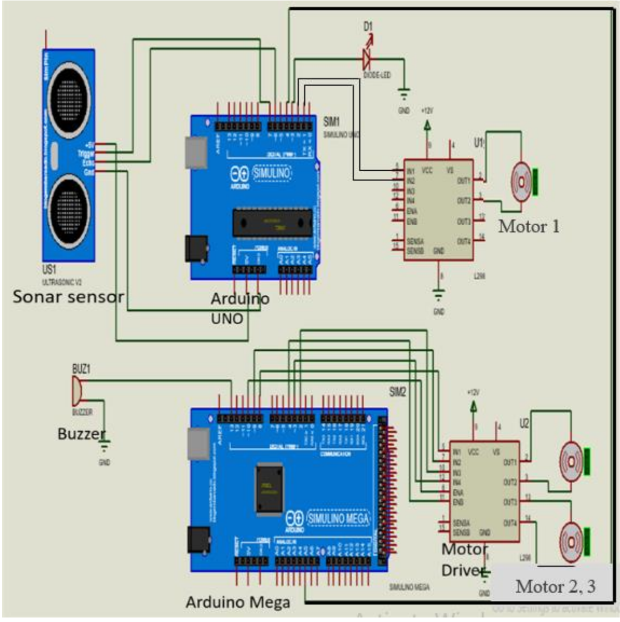

Fig. 10 Control Circuit Diagram

4. Final Structure

The actual structure of the developed system is shown in Fig.11 after assembling all the mechanical, electrical, and electronic components.

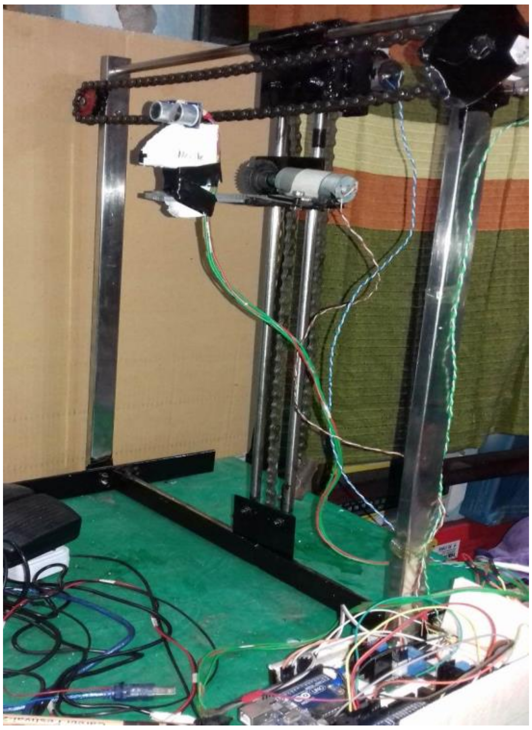

Fig. 11 Prototype of Painting Robot

5. Results and Discussion

An object having an irregular surface was set in front of the painting robot. The nozzle of the robot started moving from the top corner of the left side to the right and at the right end, it stepped downward and again moved to the left end.

Within 30 seconds it covered 198 cm^2(18 cm×11cm) area maintaining a constant distance (6 cm) between the nozzle and the surface.

To keep the constant distance at irregular (convex/concave) part, z directional motion worked precisely. It can adjust the maximum irregularity of 3 cm to the smooth part of the object.

6. Conclusions

The main idea of this project is to enhance the capability of painting on a flat and curved surface and to reduce human interference in the painting process in different industries like furniture, automobile, shipbuilding, and so on. The automatic painting process with less human interference improves accuracy and reduces expenses. The cycle time for the painting operation of a single component is reduced and the productivity of the paint booth is enlarged. Moreover, the system confirms its quick operation and smooth painting on the surface. Adding a rail system under the base of this robot can also be used in the painting of the exterior surface of a ship. Enlarging the size of the components, it can be used in large scale paint shop too. Overall improvement scope is highly available to make it capable of working in various conditions and applications.

7. References

[1] Forsberg J., Aarenstrup R., Wernersson A., A Construction Robot for Autonomous Plastering of Walls and Ceilings, *Proceedings of the 14th ISARC*, June 8 11, 1997.

[2] Forsberg J., Larsson U., Wernersson A., Mobile Robot Navigation using the Range-Weighted Hough Transform, *IEEE Robotics and Automation Magazine*, pp. 18-26, March 1995.

[3] Larsson, U., Forsberg, J., Wernersson, A., Mobile Robot Localization: Integrating Measurements from a Time-of-Flight Laser, *IEEE Transaction on Industrial Electronics*, vol. 43(3), pp. 422-431, 1996.

[4] Kim, Y. S., Jung, M. H., Chao, Y. K., Lee, J, Jung, U., Conceptual Design and Feasibility Analyses of a Robotic System for Automated Exterior Wall Painting, *International Journal of Advanced Robotic Systems*, vol. 4, no. 4, 2007.

[5] Naticchia, B., Giretti, A., Carbonari, A., Set-Up of an Automated Multi-color System for Interior Wall Painting, *International Journal of Advanced Robotic Systems*, vol. 4, no. 4, pp. 407-416, 2007.

[6] Elattar, S., Automation and robotics in construction: Opportunities and challenges, *Emirates journal for engineering research*, vol. 13 (2), pp. 21-26, 2008.

[7] Johan, P., Gravdahl, J. T., A Real-Time Algorithm for Determining the Optimal Paint Gun Orientation in Spray Paint Applications, *IEEE transactions on automation science and engineering*, vol. 7, no. 4, 2010.

[8] Keerthanaa, P., Jeevitha, K., Navina, V., Indira, G., Jayamani, S., Automatic Wall Painting Robot, *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 2, Issue 7, July 2013.

[9] Thakar, D., Vora, C. P., A Review on Design and Development of Semi-Automatic Painting Machine, *Int. Journal of Engineering Research and Applications*, vol. 4, Issue 4, April 2014.

[10] Swarkar, J. R., Belkhade, R. D., Dalal, V. G., Ghode, C. D., Maskar, S. L., Fulmali, S. M., Shelki, S. B., Design and Fabrication of Automatic Spray Painting Machine, *IJARIIE*, vol-4, Issue 2, 2018.

[11] John, J., Thomas, S., Saching, P., Shafin, M., Automatic Wall Painting Robot, *International Journal of Engineering Science and Computing*, vol. 8, Issue 6, 2018.

[12] www.parktool.com/blog/repair-help/chain-length-sizing

NOMENCLATURE

μ_s: Co-efficient of static friction
μ_k: Co-efficient of Kinetic friction
μ: Co-efficient of friction
N: Load
F_f: Friction force
MS: Mild Steel
LED: Light Emitting Diode
SS: Stainless Steel
ms: Millisecond
cm: Centimeter