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Abstract

This paper documents the design and implementation of a system to be used to spray all sides of any complex shaped object. The system is developed through a robotic mechanism. The mechanism is equipped with a paint spraying system, a curing system and a cooling system. The robotic mechanism has an ability to spray the object without any human interference. The spraying gun of the robotic system will be kept at a specific distance from the object to have a fine and neat finishing of the painted object and then the curing system will cure the powder paint on the surface of work piece and the cooling unit will cool down the work piece. This robot is designed to paint any kind of three dimensional objects under one cubic feet size.

Keywords: *Paint Spraying, Robotic Mechanism, Automatic Paint Curing, Auto Cooling*

1. Introduction

In industries like automobile, spray painting is used. Automation of the whole process of painting to get better, faster and more accurate results is desired [1]–[5]. Paint spraying robots and other industrial robots in general have a reputation of only being affordable to the largest and most technologically advanced companies. Today's reality, however, is far different as robots of all kinds are now highly viable for a full range of smaller, general industrial markets and applications. Robots, like other computer based equipment, are becoming more affordable day by day.

Hiroshi Kibaet. al. [6] describes the operation of an automatic spray coating apparatus for vehicle bodies comprises of two paint stations, for putting different coats of paint on to the car body. At station-1 coating robot for coating a front door on one of the sides and a coating robot for coating a rear door on the other side and the vicinity thereof. The second coating station being provided with two coating robots for respectively coating the other doors and the vicinity thereof, and at least one coating robot which coats the insides of an engine compartment and trunk, while the vehicle

body is standing still at least one of the first or second coating stations. A design of mechanical structure of a robotic mechanism is presented by [7]which can help people with disabilities. Another design of a robot used wireless system by recognizing hand motion [8] is presented and controlled by haptic technology for virtual environment.

Earlier, a problem of robotic mechanism positioning for local autonomy is addressed by [9] using a few basic assumptions regarding the working environment of the robot and the type of manipulation. This solution is achieved using a strictly trigonometric analysis in relation to a geometric representation of the mechanism mounted to a mobile robot platform. The control of the complete robotic mechanism, however, by the operators hand movement or motion or gesture is given in [10] whereas, a robotic mechanism with four degrees of freedom was designed to pick the objects with a specific weight and place them in a desired location [11]. This work, however, presents a design and development of a robotic mechanism for a complete powder coating system.

Section II presents design of the paint spraying robotic mechanism. Working of the robotic mechanism is discussed in section III. As the paper follows development of the paint spraying robotic mechanism is presented in section IV and section V covers the details of tests conducted on the developed mechanism and then results.

2. Design of Mechanism

In industries, painting is one of the most critical process as the object has to go through many workstations in this process. Robots are the obvious way to minimize the labor and time. Design of a paint spraying robot is based on assumption that the mechanism has five degrees of freedom. The robot consists of a powder coating unit, a curing system and a cooling system i.e. performing three tasks at a single workstation. Each of these functional parts further consists of various parts in this painting system. The detail and dimensions of these parts is given hereunder. Dimensions of these parts are selected adjustable with respect to the size of the object to be painted. The size of the base plate on which the object is to be placed is assumed and it limits the maximum size of the base of the object to be painted. The vertical and horizontal frames were designed to give pathway to the spray gun. Their dimensions limit the maximum size of the height and width of the object to be painted and the size of a spray gun. To paint the top surface of the object the gun will be pointing directly downwards. The size of the oven is also made according to the maximum dimensions of the object. The dimensions are as follows:

- The workspace of the robotic system is 30 cm x 30 cm x 30 cm.
- The size of the circular plate is selected as the size of the diagonal of the of work piece i-e; Diameter of Circle = 42 cm
- The length and width of vertical frame are calculated to be 80 cm and 50 cm. The size of the vertical frame is calculated according to the height of the object and the size of the gun because to paint the top surface of the object the gun will be pointing directly downwards so maintaining the distance of 15 cm between the top surface of the object and the end of the spray gun.

- The horizontal frame has a length of 54in and width of 18in. The length of the horizontal frame is set according to the number of stages that an object has to go through and also that one stage should not be affected by the other stage e-g the paint must not stick with the cooling fans or the heat from the oven must not affect the object before it is painted and the cooling fans, hence a specified distance is kept between each stage. For the length of the horizontal frame we have not only considered the distance between each stage but also the size of the gun and diameter of the base plate. When coating the front surface of the object, the gun is fully extended in the direction of the horizontal frame, so summing all these distances we get the length of the horizontal and vertical frame.

- The width of the horizontal and vertical frame is set according to the width of the object or work piece. The size if the oven is set according to the size of the object and also a specified distance is set between the heating rods in the oven and the surface of the object to get distributed heating throughout the surface and to get the best results.

- The dimensions of lead screws and some other small components are selected on the basis of dimensions of vertical and horizontal frames. All these dimensions listed below in the table are set to the best of accuracy and efficient design and cost effectiveness.

- The dimensions of the oven are calculated in such a way that the size of the circular plate is 42 cm and the minimum distance required between the work piece and the heating rods is 10 cm and the distance between the rods and the walls of oven is 8 cm.

Figure 1 shows the model of the paint spraying robotic mechanism designed n SolidWorks®. Figure 2 shows the rotations of motors which in result give the degree of freedom to the mechanism.

Table 1: Dimensions of items attached on Vertical frame

Item	Value
Height of Work piece (h)	30 cm
Length of Gun (l)	25 cm
Distance between Gun and work piece (d)	15 cm
Height of Vertical Frame (H)	90 cm

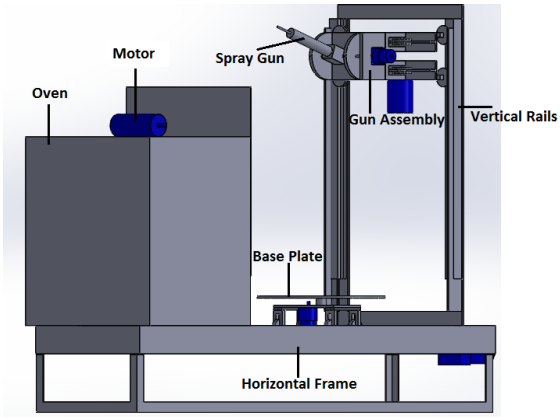

Figure 1: Solid Works Model of a Paint Spraying Robotic Mechanism

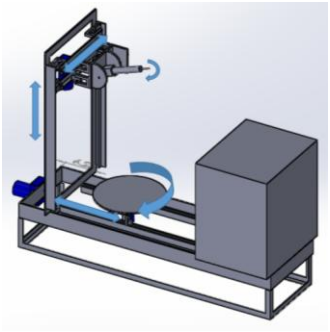

Figure 2: Rotation of Motors of the Paint Spraying Robotic Mechanism

3. Working of the Robotic Mechanism

The working of the painting system starts with the detection of the object that is to be painted. The size or dimensions of the object are within one cubic feet of volume. First the object is detected using the IR sensor that is attached on the frame of the painting gun. Once the object is detected then the painting process starts in steps. The first step is the object detection using the IR sensors as mentioned before. Then comes the painting process. In this process the object is painted using the paint spray gun. The object is placed on a round disc type plate. The plate can rotate about its own axis and also it can move towards and away from the painting gun. This means that the object can also rotate about its own axis and also it can move towards and away from the painting gun.

On the other side the gun can move in two dimensional plane that is perpendicular to the horizontal frame of the system. The gun can move up and down and also it can move sideways. With the help of all these motions of gun and the base plate, any object within one cubic feet of workspace can be painted.

After the object is painted completely then the process enters the curing phase. In this phase the object is allowed to heat up to a 180° C to 220° C and the powder paint, starts melting and makes linkage with other particles of powder and the surface of work piece and hence sticks permanently on the surface of work piece. For this purpose the work piece is heated for 5 to 8 minutes. For the purpose of curing of the painted object we are using heating rods which are commonly used in electric heaters and they are available in different voltage and current ratings. These heating rods can provide temperature up to 400° C. After the object is completely cured, then it enters the cooling phase where the work piece is allowed to cool down. This is done using small electric fans which will remain ON for 3 – 5 minutes. After the work piece has gone through the stages of painting, curing and cooling the object or the work piece can be replaced. Flow chart of working of the paint spraying robotic mechanism is illustrated in figure 3.

Figure 3: Flow Chart for the Working of Paint Spray Robotic Mechanism

A. Motion Description

There are six motors in our robotic mechanism. The direction of rotation of each motor is shown in the Figure 2. The function of these six motors is explained as follows:

a. Motor 1

It will allow the circular plate to move along the horizontal frame. The motor is attached with a lead screw which is producing the translational motion of the circular plate along the horizontal frame.

b. Motor 2

This motor is attached at the bottom of the circular plate. It will rotate the plate at an angle of 360° about its own axis.

c. Motor 3

It will allow the gun sub-assembly to move upward and downward with the help of lead screw which is attached at the shaft of the motor.

d. Motor 4

It will produce translational motion with the help of lead screw and allow the gun assembly to move right and left perpendicularly to the height of vertical frame.

e. Motor 5

It is attached with the gun and it will rotate the gun to get the desired position to apply paint properly on to the top surface of the object.

f. Motor 6

It is used in this system its purpose is only to lift up and down the gate of oven to prevent heat loss.

4. Development

Development of paint spraying robotic mechanism is divided into three main components, mechanical, electrical and programing.

A. Mechanical Components

Mechanical components mainly include iron sheet for the purpose of manufacturing of the frame of robot and oven. Angle iron is used for the manufacturing of the main frame of base of robotic mechanism and for the frame of object base. Angle iron is being used for its high stiffness, strength and ductility. For insulation of the oven glass wool is used.

B. Electrical Components

For controlling the motors H bridges are used. In oven a heating rod is used. A heating filament rod converts electricity into heat by using the resistive property of the metal wire. Electric current passing through the filament encounters resistance, resulting in heating of the rod and used in painting process. A 12 V DC fan is used to cool down the work piece once it has passed through oven.

C. Programming Components

Programming of this painting robotic mechanism is done on Arduino. Figure 4 shows the physical model of paint spraying robotic mechanism.

Figure 4: Physical Model of the Paint Spraying Robotic Mechanism

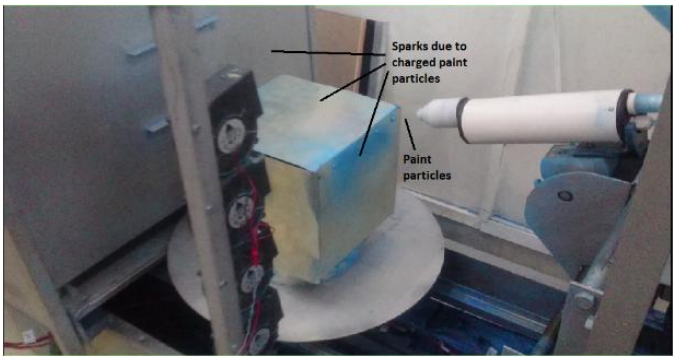

Figure 5: Painting on sidewall of the object using Paint Spraying Robotic Mechanism

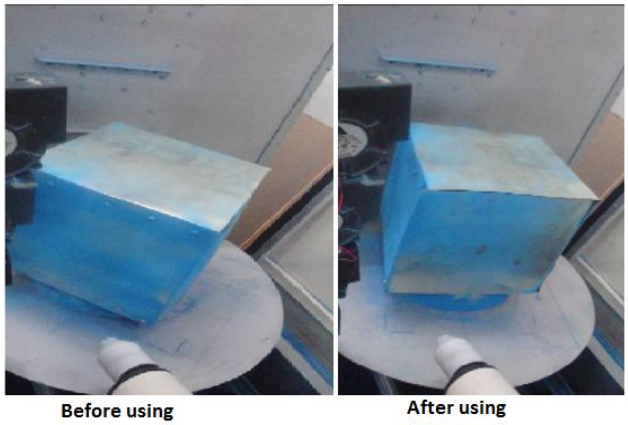

Figure 6: Painting on the sidewalls of the object

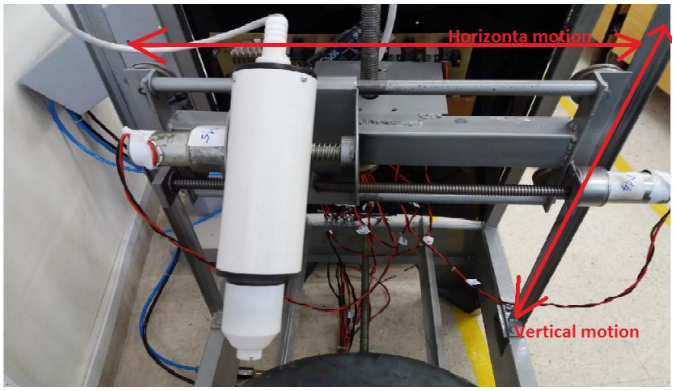

Figure 7: Motion of Gun in Horizontal frame and Vertical frame

6. Results and Testing

The main aim of this paper is to develop paint spraying robotic mechanism which can paint the object. The other main tasks include to bake the painted object in the oven and afterwards cool the object when it comes out of oven. For the purpose of testing a cube shape object is selected. An IR sensor is used to detect the object, as soon as the object is detected robotic mechanism starts spraying. Figure 5 shows the side of the cubical object being painted. As the painting starts there were sparks on the object and the base plate. This is because of the electrostatic charge paint particles that when collide with any metallic object in front of them, it produces spark.

Rotating the object at 90° angle for the purpose of painting caused problem. For this purpose, limit switches were used for the accurate turn of 90°. Figure 6 shows the comparison of painting sidewalls of the object before and after using limit switches.

Motions of the gun in the vertical x-y plane on the vertical frame and the motion of the trolley on the horizontal frame are not limited. Same technique for time delays is being used as used for rotation of the base plate. Limit switches are being used to restrict the motion of the gun in vertical frame and motion of the trolley in horizontal frame, so that the mechanism may not get damage by going beyond its limits. Figure 7 shows the motion of the gun in horizontal plane and vertical plane.

The other main task in testing of this paint spraying robotic mechanism is the shifting of painted object into the oven for the purpose of curing. Figure 8 illustrates this step of shifting of the painted object into the oven. The yellow in the image is of the heating rods that are used inside the oven.

Figure 8: Painted Object Entering Oven

Once the painted object gets out of the oven, it is being cooled down by using fans.

7. Conclusion

As proposed above, the paint spraying robotic mechanism was designed and developed. Tests were conducted on the cubical object. Results show that the

developed paint spraying robotic mechanism can be used for painting complex 3D objects. This paint spraying robotic mechanism is a very efficient one with unique and cost effective design. In Pakistan, where automation is very limited and especially when it comes to painting job, most of the industries are doing this job manually, but this advance painting system can paint most of the objects. By increasing the size of the system we can paint even bigger objects.

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