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Design and Development of a Wall Painting Robot for the Houses Wall

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Abstract
Nowadays robots are widely used in many applications such as military, medical application, factories, entertainment, automobile industries etc. However, the application of robot is still not widely implemented in construction industry. In construction industry, robots are designed to increase speed and improve the accuracy of construction field operations. It can also be used to do hazardous and dangerous jobs in construction. For example, currently house painting is done manually. This process can be simplified using a special dedicated robot. It is very difficult and troublesome for human being to work in an upright position, especially for painting, cleaning and screwing in the ceiling for a long time. Painting in an upright position is also very dangerous for the eyes. To overcome this difficulty, a wall painting robot system is proposed, designed and developed. The testing results indicate that the performance of the painter robot is better compared with that of using manual painting technique.

Keywords: construction robotics, electro pneumatic system, motor controlling, Painting machine.

1. Introduction
Despite the advances in the robotics and its wide spreading applications, painting is also considered to be the difficult process as it also has to paint the whole building. To make this work easier and safer and also to reduce the number of labors automation in painting was introduced. Above all these the interior wall painting has shared little in research activities. The painting chemicals can cause hazards to the painters such as eye and respiratory system problems. Also the nature of painting procedure that requires repeated work and hand rising makes it boring, time and effort consuming. These factors motivate the development of an automated robotic painting system. This project aims to develop the interior wall painting robot.

This automatic wall painting robot is not designed using complicated components. This robot is simple and portable. The robot is designed using few steels, conveyor shaft, spray gun and a controller unit to control the entire operation of the robot. This robot is compact because of high speed and pressure capabilities they have. They also have a very small weight to power output ratio and predictable performance i.e. losses are minimum due to less number of moving parts and so gives expected performance. Due to elegant and simple control systems it can control noise vibration and does silent operation and no vibration is produced.

It has longer life, flexibility and it is efficient and dependable, and the installation is simple and the maintenance is also easy. Some of the conditions that have to be considered while using this robot is that the system is operates in pneumatics, so it needs air tank or compressor and the electric shock is always there, which makes the machines ugly and dust and dirt are adhering to them. The life of the parts like seals, packing and gaskets etc., are very short but, they are essential to prevent leakage so that the system becomes costlier.

The development of service robots became popular recently due to the fact that the society needs robots to relax humans from tedious and dangerous jobs. In Egypt, as well as other developing countries, the increasing population stimulates the construction-related activities such as interior finishing and painting. Painting is classically done by humans and generally requires exhaustive physical efforts and involves exposure to dangerous chemicals. Chemicals can seriously impair the vision, respiratory system and general health of the human painter. These factors make painting an ideal candidate process for automation.

Mechanical System Design

The construction of the automatic wall painting robot consists of two main parts. They are

A). Mobile platform

1. Frame stand
2. Wheel
3. DC motor
4. Control unit

B). Spray gun mount

- IR Sensor
- Flow control valve
- Spray gun

1. Frame Stand and Wheel

The frame stand is the steel screwed in such a way that it can carry the whole equipment. The steels are screwed strongly in workshop. Four wheels are attached to the frame stand in order to move the robot in the direction specified. The movement of these wheels is controlled by the DC motor rotation which is controlled by the controller. Since it is obvious that if either the movement of front or back wheels are controlled automatically the movement of the other one will be controlled. Therefore, in this robot the movement of the back wheels is controlled using the DC motor such that the movement of entire robot is controlled.

2. Dc Motor

DC motors are widely used in speed and direction control because control of these motors are easier than other motors. The motion of a DC motor is controlled using a DC drive. DC drive changes the speed and direction of motion of the motor. Some of the DC drives are just a rectifier with a series resistor that converts standard AC supply into DC and gives it to the motor through a switch and a series resistor to change the speed and direction of rotation of the motor.

3. Control unit

The controller unit is used to control the DC motors and the movement of spray gun fitted on the conveyor belt. Controller unit is provided with the 12V signal and as soon as the supply is ON. The controller sets to setting mode and the moving and painting distance are given as input to the controller. The controller controls the rotation of DC motor based on the distances given in order to control the wheel and conveyor belt movement. When IR receiver receives the signal, the conveyor belt moves and the spray gun goes to ON condition and if the conveyor belt stops, the spray gun goes to OFF condition. It contains relays for the control of forward and backward movement of the DC motors.

4. Electrical and electronic system

There are main parts in the electrical and electronic system of the painter robot. They are: the power supply module, the sensor module, the electro-pneumatic system, an AC induction motor drive system, and a control panel. A proper distribution of power supply is required to activate the components of the system. The AC and DC voltage are supplied and distributed as depicted. Normally, a 12-volt direct current is required for most of the electrical and electronics components, such the sensors, the pneumatic valve and the limit switches. In this project a commercial switching power supply unit is used to convert the AC voltage from the mains source to a 12-volt DC source. The 12-volt DC output is distributed to activate the main controller, the sensors, the limit switches, the start/stop button, the indication light and the motor-driven relay. The AC induction motors are connected directly to the mains supply.

The sensors are used to determine the following:

(1) Does the arm reach the correct position for painting the ceiling? If the arm does not reach the correct position, the sensor will send a signal to the actuator to place the arm more accurately. This optical sensor is mounted on the *z*-axis.

(2) Is there any obstacle at the front, rear or side? If there is no obstacle, the sensor will send a signal to the actuator and the pneumatic valve to move the arm and to start the spray gun painting. If there is an obstacle, the sensor will send a signal to change the position of the arm. These optical sensors are used in the *z*-axis and the *x*-axis.

(3) Do the actuators move more than the maximum limit? To prevent over movement of the actuators, six electromechanical switches are used in the *x*-axis, the *y*-axis, and the *z*-axis.

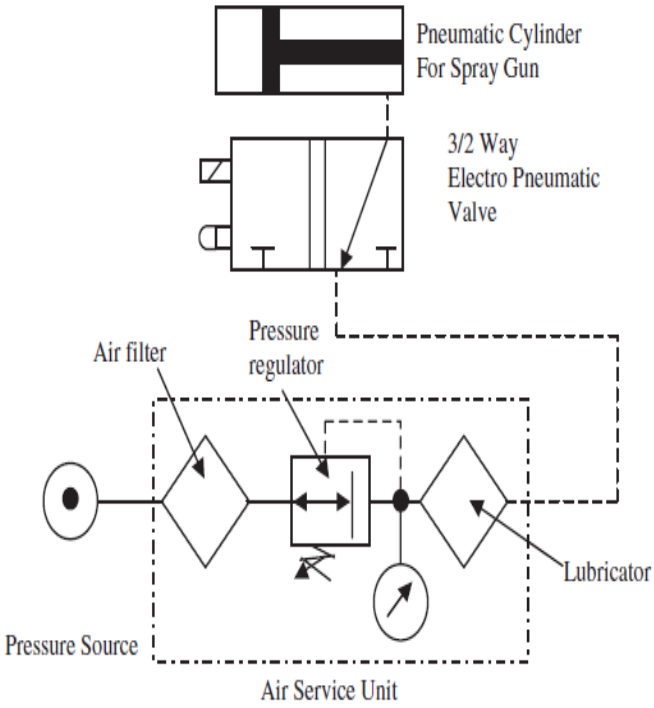

Fig 1: pneumatic system of the robotic system

The actuator of the robotic system consists of a spray gun and a single acting cylinder. When the output signal is fired, it will activate the 3/2-way normally closed valve. This will allow the air to flow through the valve and cause the piston of the cylinder to extend. When the piston of the cylinder extends, it will press the lever of the spray gun and the painting starts. When the output signal is removed, the 3/2 valve will deactivate and the piston of the cylinder will retract due to its spring tension, which will release the spray gun lever, and painting will stop. The actuator operates using the air compressor. The recommended air pressure is between 5 and 10 bars. It is necessary to use an air service unit that consists of an air filter, a pressure regulator and an air lubricator to protect the actuators.

The control panel is a thin metal box, which is mounted at the bottom of the system. All the electronic components, such as relays, the DC power supply unit, the PLC, the pneumatic valve and the capacitors, are fixed inside the control panel. The start button, the reset button and the indicator are fixed on the upper surface of the control panel. The indicator will turn on when the system goes into an unwanted state. The layout of the components inside the control panel is designed according to the following criteria:

(1) All the switches can be fixed in the panel;

(2) The devices can be easily wired;
(3) The wiring is neat, with proper connections to avoid the possibility of short circuits.

2.4.1 Power Supply Unit
The DC level obtained from a sinusoidal input can be improved 100% using a process called full-wave rectification. It used 2 diodes in this configuration. From the basic configuration we see that one diode is conducting while the other one diode is in "off" state during the period t = 0 to T/2 Accordingly for the negative of the input the conducting diodes. Thus the polarity across the load is the same. The filter circuit used here is the capacitor filter circuit where a capacitor is connected at the rectifier output, and a DC is obtained across it. The filtered waveform is essentially a DC voltage with negligible ripples, which is ultimately fed to the load.

5. IR sensor
IR sensor is used for this project. IR (Infrared) is the typical light source being used in the sensor for robot to detect opaque object. In this project, no programming, controller and soldering are required. IR Sensor (IR Receiver and IR Emitter) the basic principle of IR sensor is based on an IR emitter and an IR receiver. IR emitter will emit infrared continuously when power is supplied to it. On the other hand, the IR receiver will be connected and perform the task of a voltage divider. IR receiver can be imagined as a transistor with its base current determined by the intensity of IR light received. The IR transmitting circuit is used in many projects. The IR transmitter sends 40 kHz (frequency can be adjusted) carrier under computer control (computer can turn the IR transmission on and off). IR carriers at around 40 kHz carrier frequencies are widely used in TV remote controlling and ICs for receiving these signals are quite easily available.

2.5.1 IR Sensor Features:
- Input voltage: 5VDC
- Sensing Range: 15cm
- Output signal: analog voltage

6. Single Acting 3/2 Solenoid Valve
A solenoid is an electrical device that converts electrical energy into straight line motion and force. These are also used to operate a mechanical operation which in turn operates the valve mechanism. Solenoids may be push type or pull type. The push type solenoid is one in which the plunger is pushed when the solenoid is energized electrically. The pull type solenoid is one in which the plunger is pulled when the solenoid is energized. The Solenoid control valve is used to control the flow direction is called cut off valve or solenoid valve. This solenoid cut off valve is controlled by the electronic control unit.

7. Mechanism
This is project mechanism work on principle of **"**SCISSOR LIFT MECHANISM". A scissors lift uses linked, folding supports in a criss-cross 'X' pattern, known as a pantograph. The extension is achieved by applying pressure to the outside of a set of supports located at one end of the lift, elongating the crossing pattern. This can be achieved through hydraulic, pneumatic, mechanical or simply muscular means. It may require no power to return to its original position, but simply a release of the original pressure.

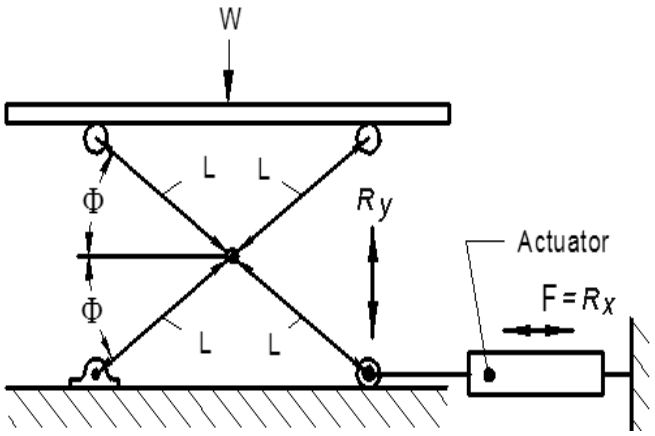

Fig 2: Scissor lift mechanism

8. Paint supply section
This consists of a paint pump, paint tanks (for primer and overcoat), a compressor to drive the pump, and a reel to wind up the paint hose. The paint pump is a lightweight airless type which greatly reduces the dispersion of paint mist.

9. End-Effector Module
The end-effector module is designed in such a way that it can hold a spray gun and operate the spray gun during the operation. A single acting pneumatic cylinder is attached to the lever. The lever can move up and down by the actuation of a cylinder. The proposed design is the end-effector module. Two hosepipes are attached to the spray gun. One of them is directly connected to a paint tank and the other is connected to an air compressor. The paint tank is a pressure vessel and is directly connected to the air compressor. The paint is moved through the hosepipe by air pressure. The air pressure that is used by the robotic system to perform the painting activity is 10 bar. This air pressure is kept constant throughout the operation to achieve the standard quality paint.

Experimental results
1. Painting movement of robot
Fig. 3 shows the movement path and coordinates of the end-effector of the robotic system, as determined by the control algorithm. During operation, at first the end effector (spray gun) will move from its home position O(0, 0, 0) along the *z* direction. It will continue to move until the upper sensor detects the ceiling. After detecting the ceiling, the *z*-axis motor will be stopped and the end-effector will reach point A(0, 0, 72). The detection distance of the photoelectric sensor between the spray gun and the ceiling can be adjusted. In this case, the detection distance was set to 20 cm. From this point, the pneumatic cylinder will trigger the spray gun for painting and at the same time it will move along the *y* direction until it touches the limit switch. After touching the limit switch, the movement of the end-effector and the painting will be stopped and it will reach point B(0, 30, 72). Now the end effector will change its position along the *x* direction from B to C(25, 30, 72). From this point the end-effector will move in the reverse direction along the *y*-axis and the painting will continue again until it reaches point D(25, 0, 72). After that it changes its position from D to E(50, 0, 72) along the *x*-axis. The same operations will continue until the end-effector reaches point J(100, 30, 72). After reaching this point, the end-effector will return to its home position following the path JKLO. To complete the painting operation the end-effector will travel five times along the *y* direction and four times along the *x* direction.

Fig 3: Three D view of the proposed robotic system

Fig 4: compressor are used in the robotic system

2. Tables

Table 1: Composition of material

Base plate (AISI TYPE 304 Stainless Steel)	COMPOSITIONS	
	Components	Wt %
	C	Max 0.08
	Cr	18-20
	Fe	66.34-74
	Mn	Max 2
	Ni	8-10.5
	P	Max 0.045
	S	Max 0.03
	Si	0.01

Table 2: Mechanical properties of base plate

Mechanical properties	Value
Modulus of elasticity	190 Gpa
Modulus of Rigidity	73.1 Gpa
Poisson Ratio	0.305
Unit Weight	76 Kn/m^3

Table 3: Specification of the proposed robot

Type of Robot	Cartesian
Robotic control	Automatic
Degree of freedom	3
Degree of Movement	4
Working Envelope	(100*30*72)cm
End effector actuation	Pneumatic

Table 4: Mechanical properties of the Body structure, Column and Links (Aluminium)

Sr No.	Material Properties	Value
1	Modulus of elasticity	71.1 Gpa
2	Modulus of Rigidity	20.9 Gpa
3	Poisson Ratio	0.3333
4	Unit Weight	26.6 Kn/m^2

3. Painting performance test

After integrating the total system, the painting test was performed. By observation it was seen that the painting quality depends on the air pressure, the paint–air ratio and the speed of the *y*-axis motor. The paint–air ratio can be adjusted by a screw on the spray gun. The speed of the *y*-axis motor can be adjusted by the inverter. The maximum painting area that can be painted by the robot is 7200cm2 in one positioning. To paint this area this painter robot takes 180 seconds. The painting quality is smooth and consistent. From this test it is observed that the single coating is enough to get the standard quality painting. To paint the same ceiling area manually takes more than 300 seconds and the painting quality is not so smooth. Good-quality painting requires at least two coats.

8. Conclusions

The painter robotic system has achieved optimum benefits with regard to reliability, safety appearance, and ease of use. All the objectives set up for this system have been achieved successfully. In terms of mechanical design, the *X*-axis, the *Y*-axis, the *Z*-axis module and the end-effectors module were designed and fabricated properly. All motor mountings and couplings were properly adjusted. All the prismatic joints were developed successfully. In terms of electrical and electronic systems, the power distribution module, the sensor module, the electro-pneumatic system, the AC induction motor driving system and the control panel were developed successfully. In terms of software development, the author had written a control program for the painter robot. This was indicated by the performance of the painter robot. Each movement of the painter robot was successfully controlled by the control program. It can be reprogrammed easily to cope with any changes in the process. A conclusion can be made that the painter robotic system had been successfully created to solve the problem of working in an upright position, which is very troublesome, boring, unhealthy and harmful to a human being if the working period is long.

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