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Design of robotic manipulator for painting purposes in automotive industry

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Abstract

This paper presents design of 6-DOF robotic manipulator for painting in automotive industry. The NX-CAD was employed as the software to model the robotic manipulator. Three questions were considerably taken into account before modelling the robotic manipulator and they include the following: 'how to define the problem the design of manipulator is going to solve?'; 'what is the purpose of the manipulator construction?' and 'what were the exact requirements?', as first , second and third questions respectively. The robotic manipulator analysis showed that the manipulator is more effective in achieving task; it is faster than human efforts and in its interaction with the environment. Through this, it will help reduce health hazard associated with humans that do work of painting by them not having direct contact with the paint (which is produced by chemicals) anymore but engage in handling other paint delivery equipment. Correspondingly, the designed painting manipulator will create cost-effectiveness of labour in automotive industry.

Keywords: Design; Robotic Manipulator; NX-CAD Software; Painting; Automotive Industry

1. Introduction

Robotic manipulators have witnessed a tremendous increase in painting applications during the last few decades. Robots are known for their accuracy and consistency, which may help the clean and uniform execution of tasks that humans are unable to duplicate [8]. Industrial painting robots typically feature an extensible frame having six degrees of freedom. Some studies looked at a four degree of freedom robotic manipulator for painting applications which includes kinematic and dynamic evaluations for the proposed robotic manipulator [2].

Spray painting is simply a painting technique in which the spraying device sprays solvents like paint, ink, varnish, etc., through the air onto a surface. The most common techniques used compressed gas, usually air, to atomize and direct the paint particles [13]. The spray guns evolved from air bushes, and the two are usually distinguished by their size and the size of the spray pattern they produce.

As the infrared (IR) also referred to as infrared light have heating property more like an oven with much higher efficiency and even heating capability, infrared lamps are used to dry paints on cars. Infrared radiation is an electromagnetic radiation (EMR) with wavelengths longer than the visible light but lesser than the microwaves, thus, cannot be perceived through the eye [10]. The speed at which infrared works in paint drying is one of the most significant advantages of infrared. The drying process takes only minutes, as it quickly and uniformly heats the surface and gives precise results while other methods such as air drying, will take hours [11]. Studies have shown that shorter infrared wavelength has higher productivity as the heat transfer rate is higher from paint to metallic portion of the car, which performs a drying operation from the inside out. Infrared radiation can be generated from both electric and gas

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sources. Today, powder coating is widely used by a number of industries, for example, automobiles, household appliances [1]. IR heating efficiency relies on both the coating spectral absorption characteristics and spectral emissions of the infrared source.

Medium wave infrared result in the quickest treatment, as experimental data indicates that the medium wave infrared emitters contribute to the fastest temperature increase. The curing kinematics analysis also reveals that with medium wave infrared emitters of 1.66um, the fastest transition in drying is attained [5]. Medium wave IR lamps are suitable for automotive drying and heat treatment because they first reach the surface of the automobile and heat up the substrate from inside out the solvents will pop off and create craters if the surface dries before the substrate as it so happens in typical convection process where air is heated to transmit energy to the part. By heating from inside, solvents are forced out in the air as the surface remains moist and thus craters are prevented. Medium wave IR provides a consistent heat distribution and therefore are ideally used for drying and curing large areas. The short-wave IR light pierces the surface just like the medium wave IR but with much higher piercing rate and faster temperature reaching potential, therefore, making it useful for trivial, targeted spot repairs. This form is ideally suitable for complex part shapes (non-line-of-sight heating) in which high energy IR allows quickly to heat up the substrate as IR have a disadvantage of not reaching its target in complex shaped objects due to its straight energy propagation [3].

The robot's movement has a significant impact on the uniformity of the painting thickness even when IR rapid treatment is conducted and even on its quality [4]. With paint, human workers are less uniform and economical, resulting in substantial paint wastage. It is also fascinating to observe that hand-controlled spray paint in one place always leads to overspray in another. Adopting a robotic manipulator that travels at a steady pace would preserve a lot of paint while still maintaining surface uniformity of paint [12].

2. Robot System

A fundamental robot system mostly characterizes the mechanics, control, and sensor design of robots. The mechanics of robot consist of the design and structure of manipulators, arms, end-effectors, actuators, power, and energy storage of the complete robot as well as the kinematics, dynamics, and recreation (simulation) of the robot. The control aspect of the robot system involves theory and implementation (hardware and software) [6]. On the other hand, sensors comprise design of sensor systems and algorithms for sensory data acquisition and analysis. The design of robot work object, air compressor and the paint that is used in the spraying process are inevitably involved in the spraying system.

Robots that are applied in industrial activities such as painting are called industrial painting. Painting robots are generally designed to have five or six axis, where three are for the base motions and the other two or three for applicator orientation. Hence, degree of freedom (DOF) of a device or machine is the number of independent parameters or inputs needed to specify the configuration of the machine.

3. Paint

Paint is any liquid that is liquefiable or has mastic composition which after application to subtract in a thin layer is converted to an opaque solid film [6], [7]. The painting robot process was done using Acylic enemal. Wooden board was used as the work object of the painting robot. During the pragmatic running of the painting after the design, materials such as safety glasses, hearing protection, filter mask with organic vapour, spray gun, air hose, pressure regulator, paint, solvent, angle grinder with cap brush, wire brush and paint object, were employed in the process and also to give required safety.

4. Robot Hardware System

The control aspect of robot system, especially in this case of designing robot manipulator for painting purpose, is the vital hardware part of robot. The robot manipulator cannot be designed for effective operation without these components.

4.1. Manipulator

Manipulator is the core body of the robot. A manipulator is made up of different links, joints, and other structural elements. The research work was achieved using a robot whose weight is roughly 195kg. The robot is endowed with an operating system that controls every aspect of the robot, such as motion control, development and execution of application programs communications. Also, the robot is equipped with optional software for application support.

Figure 1 The robot manipulator

4.2. Actuator

Actuators act like the muscle (power) of the manipulator. Their control is done using the robot controller. They convert stored energy into movement [9]. The robot controller actuator uses air compressor when operational.

Figure 2 Spray gun

4.3. End-Effector

Any device of a robotic manipulator whose end is designed to interrelate with the environment is the end-effector. It is a contrivance used to perform the programmed application based on the required task. A Spray gun is attached to the robot and it is used as the end-effector for the painting robot. The spray gun served as a suction feed. It has a standardized nozzle value of Φ1.5mm, with operating pressure range of 3-4bar, air consumption of 3.5-6cfm, the paint capacity of 750cc, fluid flow is about 120-160(ml/min), and a spout distance of 200mm.

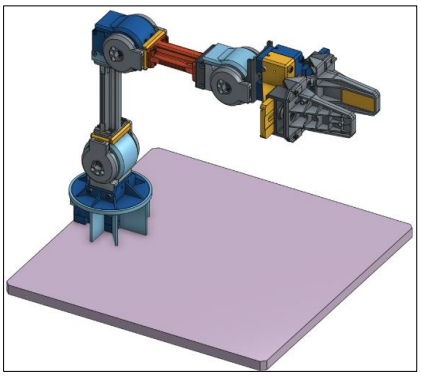

Figure 3 Structure of the end-effector

4.4. Other Hardware Systems

The other hardware systems include sensor, controller, processor, software and painting and object. Sensors are used to collect information about the internal state of the robot or to communicate with the outside environment. Also, sensors are integrated into the robot to send information about each joint or link to the controller, which determines the configuration of the robot. A-24VDC Omron relays was used as the sensor to send signal to the directional control valve indicating when to activate the air compressor. The signals are usually sent to Omron relay from the input/output signal controller of the robot [5].

Controller of the robot was used to control the motion of the manipulator. Its data are collected from the computer and hence, control the motion of the manipulator, and coordinates motion with the sensory feedback information [12].

The processor is the robot's brain. This did the work of calculating the motions of the robot joints, determines how much and how fast each joint must move to achieve the desired location and speeds, and oversees the coordinated actions of the controller and the sensors. The processor is a computer, which works like other computers, but is dedicated to a single process. It requires an operating system, programs, monitors, and have capability of a computer processor. The Flex Pendant is used as the controller for the Robot. It works as the operating device for the robot. All application task and they program are being uploaded into the flex pendant.

4.5. Degree of Freedom of the Robot (DOF)

In kinematics of mechanism, the number of degrees of freedom is very important and should be determined before applying any other effect. On that note, the DOF of the robot arm employed in this research is determined using this given equation.

$$F = \lambda (n - j - 1) + \sum f$$

Where the following parameters found in the equation have the following values:

F = Degree of freedom =?
λ = Degree of freedom of the space = 6
n = number of links = 7
j = number of joints = 6
f = degrees of relative motions = 6

Therefore,

$$F = 6(7 - 6 - 1) + 6 = 6$$

4.6. Orientation and Dimension

Orientation of a rigid body, like a robot, about its fixed frame is described in no singular manner. To give an explicit description of the orientation of a rigid body, the motion a moving frame B with respect to a fixed frame A with one point fixed was taken into consideration. This kind of motion is rotation or spherical motion. The origin of the moving frame is fixed to that of the fixed frame as long as the generality remained same (no generality lost). Since the robot arm used is of six degree of freedom (6DOF), the robot arm was described in three dimensions (3D) in the following nautical names: Moving up and down (heaving); Moving left and right (swaying); Moving forward and backward (surging); Tilting forward and backward (pitching), Tilting side to side (rolling) and Turning left and right (yawing).

4.7. Denavit-Hartenberg Homogeneous Transformation Matrices

When the coordinate system of each link of a manipulator was ascertained, the two successive coordinate systems underwent a transformation by setting up a 4X4 transformation matrix. From the observation, the ith coordinate system could be seen to undergo displacement from the (i-1)th coordinate system by the subsequent successive rotations and translations.

Therefore, result of the transformation matrix i-1Ai gives a general solution:

$$i\text{-}1Ai = T(z,d)T(z,\Theta)T(x,a)T(x,\alpha)$$

4.8. Manipulator Design

To achieve the design of the efficient robotic manipulator for painting purposes in automotive industry purposed in this work, the following three questions were taken into consideration before embarking on the process. The first question was 'how to define the problem the design of manipulator is going to solve?' the second question was 'what is the purpose of the manipulator construction?' and the third question was 'what were the exact requirements?' The main body of the robot used in this research consists of the links, the joints, and other structural elements. The robot is equipped with an operating system Base OS. The essence of using Base OS is to control every aspect of the robot, including motion control, development and implementation of application programs communications.

The modelling of the robotic manipulator was accomplished in NX-Cad Software. This was used to empower designers to achieve faster results using more virtual product models and fewer, costly, physical prototypes. It is an advanced high-end CAD/CAM/CAE.

5. Results and Discussion

The robot manipulator was designed (constructed) using rigid links connected by joints with one fixed end and one free end to execute a specified task. The joints of this robotic manipulator were made to be movable gears that ensure there is relative motion between the adjoining links. Also, there are two linear joints to this robotic manipulator that ensure non-rotational motion between the links, and three rotary type joints that ensure relative rotational motion between the adjacent links. The manipulator was found to be made up of arm and body, and wrist. Arm and body consists of three joints connected together by large links. Also, they were used to move and place objects or tools within the painting work space. The wrist arranges the objects or tools at the work space. The structural characteristics of this robotic wrist include three compact joints.

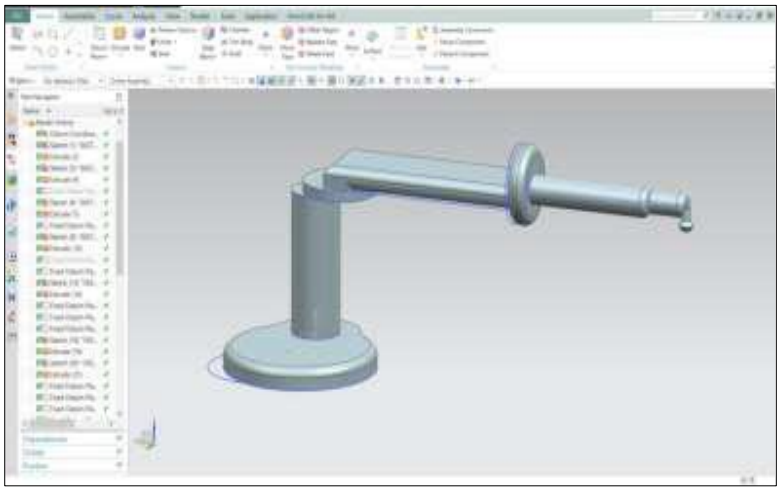

Figure 4 Modelled Manipulator in NX-Cad Software

6. Conclusion

The designed robotic manipulator which served as the end-effector was accomplished using NX-Cad Software. The robotic manipulator was tested to run a painting task in painting work space. The designed robotic manipulator has the efficiency of reducing cost and time and making better manipulator which boosted the painting task. The test result revealed that lesser paint was even used, thereby yielding higher production output with fewer manpower.

Recommendations

- It is recommended that robotic manipulator should be used in painting task to reduce health issues in human as result of having direct to paint (which is chemically made),
- The task a human could perform for days, robotic painting manipulator would achieve it using much lesser time

Compliance with ethical standards

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Disclosure of conflict of interest

The authors have no conflict of interest.

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