Advances in Machinery, Materials Science and Engineering Application X
M. Giorgetti et al. (Eds.)

doi:10.3233/ATDE240672

Development of 5 Axis Robotic Manipulator for Material Handling and Sorting

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Abstract. The creation and application of a 5-axis robotic arm intended for material handling and sorting tasks is shown in this work. Our 5 Degree of Freedom (DOF) robotic manipulator prototype was developed in response to the growing use of robotics in many industries to solve difficult problems. Now industries are using Robots in place of CNC machines. The manipulator's mobility is controlled using programming that makes use of open-source technology, particularly Arduino. Furthermore, to guarantee sufficient lifting capability, we integrated servo motors with different torque specifications at each joint and used Fused Deposition Modeling (FDM) 3D printing technology to fabricate the hardware components. Because of the use of the open source technology, low cost microcontroller (Arduion), and servo motor, the developed 5 DOF robotic manipulator is cost effective and reliable. For the study and research of transformation matrices, kinematics, and other related robotics issues, this articulated robotic arm is a useful tool.

Keywords. 5 axis articulated robot, arduino, servo motors, micro servos

1. Introduction

Robots are machines that are designed to sense their surroundings, gather data through a variety of sensors, and then make decisions on their own [1]. Modern civilization no longer views robotics as an exotic technology. Technical communities are gradually adopting and using robots as specialized machines [2]. These days, people use robots more and more to assist them with their laborious duties. In general, there are two types of robots: industrial robots and service robots [3].

Material handling and sorting are important jobs in many sectors, and because manual handling may be particularly labor-intensive, these operations are frequently automated by robotics and automation technology [4]. Furthermore, robotic manipulators have been developed as a result of the expansion of industrial operations [5]. Robots are employed in a wide range of other fields besides these, like the die-casting industry, where they draw out items, which calls for flexibility in motion and awareness of outside factors [6].

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So many studies have been conducted on industrial robotics because of their growing necessity. These technologies are more accurate than manual labor, increase production process flexibility and efficiency, and are available 24/7 [7]. Because the articulated robots can handle objects with such high precision and can also deliver solutions at a reasonable cost, their field of applications has expanded [8]. Industrial robots can be classified as mobile robots, multi-link robots, or combinations of the two systems [9].

We have designed and created an articulated robotic arm with five degrees of freedom (D.O.F.) that can work alongside people to solve a range of industry-related problems. Collaborative robots also known as COBOTs are very versatile in nature and easy to program [10]. COBOT technology has received worldwide attention in past few years [11]. Industrial COBOTs that are the building blocks of Industry 4.0, are responsible for transformation of organization production process and architecture [12]. Robots are also widely used in technical organizations because of their multitasking ability and autonomous operation [13]. Now a day, many organizations have started to use robots in production process instead of CNC machines [14]. Advancement in technology is making it possible for robots to mimic human skills and they are able to communicate with outside environment.

Deposition Modeling (FDM) i.e. 3D printing technology was used to produce hardware parts for 5 DOF robotic manipulator. Servo motors were used for mobility of joints. Motors were controlled using Arduino controller. The method used for creating the hardware, which included robot linkages, the base, and the end-effector, was additive manufacturing, or 3D printing. With this method, pieces are made by layering on material and then attaching each layer to the one next to it [15].

We used an FDM 3D printer to manufacture our articulated robot parts. FDM works by depositing material layer by layer from a plastic filament unwound from a coil [16]. Servo motors, connected at each joint, drive the robot's movements, and the robot is controlled by an Arduino board. Most industrial robots use electric actuators, like servo motors, with gear reduction mechanisms to transmit motion [17]. Controlled reduction with open-chain kinematic manipulators is discussed in [18]. Before the advent of open-source hardware and software, prototyping was complex and expensive [11]. However, open-source technologies like Arduino have made prototyping easy. The Arduino controller board controls the robot's motion along a particular trajectory, requiring forward kinematics and inverse kinematics to determine the end-effector's position in global space. For this, kinematic modeling is necessary, which involves determining the end-effector position without considering the forces acting on it [2].

2. Chronological Development of Robot

The CAD files for the parts of the robot for 3D printing can be downloaded from the following website: https://cults3d.com/en/3d-model/various/arduino-based-robot-arm-howtomechatronics.

2.1. 3D Printing of Parts

After downloading the parts, follow the procedure for 3D printing as outlined below:

- Download the STL files from the above website.

- Slice the STL files with appropriate parameters using slicer software.
- Save the sliced files with proper names.
- Set up the 3D printer with the correct parameters for the material's temperature.
- Upload the sliced file into the 3D printer and start 3D printing the parts.
- After completing the 3D printing process, remove the parts from the bed. Perform post-processing operations such as removing the supportive materials. For a good surface finish, polish the surfaces using 120-grit sandpaper. If desired, apply color to the surface of the part for aesthetic purposes. 3D printed parts are shown in figure 1.

Figure 1. 3D printed parts.

In this project, PLA material is used. The properties of PLA material, such as tensile strength, print temperature, and bed temperature, are provided in table 1.

Table 1. Properties of PLA material.

Sr. No.	Properties	Value
01	Tensile strength	Around 50-70 MPa
02	Flexural Strength	Usually in the range of 70 – 100 MPa
03	Elongation at Break	Around 3-8%
04	Density	Approx. 1.24 g/cm^3
05	Glass Transition Temperature (Tg)	Around 55 - 65°C
06	Print Temperature	Ranges from 190- 220°C
07	Bed Temperature	Between 40 - 60
08	Thermal Expansion Coefficient	Approx. 60 – 70 x 10-6/°C
09	Biodegradability	Biodegradable under right conditions

2.2. Integration of Parts

Steps followed for integration of various parts are given below:

a) Integrate the 3D printed parts and connect the electric actuators (servo motors) for actuation.
b) Connect the servo motor wires to the designated pins on the Arduino UNO. The ground wires of the servo motors, which are black, should be connected to the common ground. The VCC wires of the servo motors, colored red, should be connected to the common 5V pin. Connect the signal wires of each servo motor,

which are orange, to the PWM signal pins of the Arduino UNO. The pin-out configuration is provided in table 2.

c) Connect the Arduino UNO to the PC/Laptop via the Arduino USB cable.
d) Open the Arduino IDE. If the Arduino IDE is not installed on the system, it can be downloaded and installed from the official Arduino website: https://www.arduino.cc/en/software, selecting the latest version suitable for your operating system.
e) Using the Tools option in the menu bar, select the board as Arduino UNO (or select the board you are using). Then, select the port to which the Arduino is connected.
f) Open a new file and write a suitable program to actuate all six servo motors in coordination with each other so that they can perfectly actuate the joints of the serially connected links.
g) Compile the program by clicking on the checkmark button, then click on the upload arrow button to upload the code to the Arduino UNO. This will allow the robot to operate and perform operations according to the uploaded program.
h) The robot can move according to the desired angles given to the servo motors for rotation. These angles can be determined using the inverse kinematics of the robotic arm.

Table 2. Connection of signal pins of servo motor with Arduino pins.

Servo motors	**PWM signal pins of Arduino**
Servo motor 1	Pin no. 9
Servo motor 2	Pin no. 10
Servo motor 3	Pin no. 11
Servo motor 4	Pin no. 3
Servo motor 5	Pin no. 5

Integrated 5 D. O. F. articulated robotic arm is shown in figure 2.

Figure 2. 5 D. O. F. articulated robotic arm.

Block diagram of robotic system is shown below in figure 3.

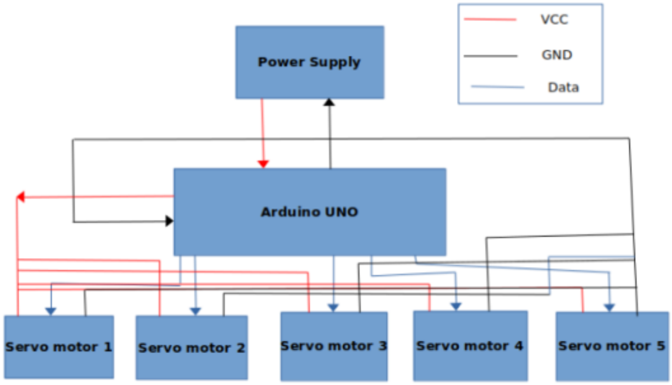

Figure 3. Block diagram of robotic system.

3. Kinematics of Robot

The robotic system consists of various fields of knowledge that one must understand to successfully comprehend the motion of a complex robotic manipulator. The inverse kinematics of a 5-axis robotic arm is helpful in determining the joint angles between the links to achieve the desired position and orientation of the end-effector. The process for determining the angles is outlined below:

Let's denote the joint angles as

$$\theta = (\theta_1, \theta_2, \theta_3, \theta_4, \theta_5)$$

Where each θ_i represents the angle of the i_{th} joint. The forward kinematics transformation from joint angles to the end-effector pose can be represented as:

$$T_{end-effector} = T_1 \cdot T_2 \cdot T_3 \cdot T_4 \cdot T_5$$

Where, T_i is the transformation matrix representing the i_{th} joint, derived using the Denavit-Hartenberg (DH) parameters or other methods specific to your robot. The position of the end-effector in the base frame is given by the translation components of $T_{end\text{-}effector}$:

$$P_{end-effector} = \begin{matrix} x \\ y \\ z \end{matrix}$$

The orientation of the end-effector can be represented using Euler angles (roll, pitch, yaw) or a rotation matrix.

4. Results

In the present work, a 5-axis robotic arm is developed with each joint linked to a servo motor, facilitating precise directional movement. The actuators were controlled by an open-loop system, which reduced overall costs and circuit complexity while producing precise movement. Hardware production expenses were greatly reduced by using additive manufacturing techniques. The resultant robotic arm proved to be capable of efficiently picking and placing objects and sorting jobs inside of its allotted workspace. Robotic manipulator developed is very cost effective and performing desired functions well. So, the development methodology used in the present work is quite effective.

It can be observed that the torque obtained and torque needed for each joint are very much related to each other. Different objects that are to be handled by the manipulator needs different torque value at each joint to work properly and avoid stalling. So, the correlation between needed torque and obtained torque is beneficial as this allow the optimization of power supply and ensure the required torque to each joint. The torque at each joint is given in the table 3.

Table 3. Relationship between torque and current at various joints of robot.

Joint	Torque (Nm)	Current (A)
Joint 1	4.8008	0.48
Joint 2	3.4135	0.3
Joint 3	1.5183	0.15
Joint 4	0.4778	0.4
Joint 5	0.1024	0.1

With change in load, minimum torque required at each joint to sustain that load changes. The right calculation of torque and current requirements makes it possible to provide sufficient power to run each motor efficiently.

5. Conclusions

After the development and testing of 5 DOF Robot, it was observed that developed robot is safe, cost effective and performing its desired functions well. The robot is very easy to design and develop because it uses servo motor that can be controlled easily with Arduino.

5 DOF Robot was made using 3D-printed components, servo motors, and Arduino microcontroller. Therefore, the overall cost is low at the same the efficiency and reliability are high because of simple design. So, this technology may be used to develop robots that can perform complex pick-and-place operations with minimum expenditures.

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