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## Design and Making of Pick and Place Robotic Arm Manipulator

#### Saroj Kumar Pandit, Amit Thakur, Tathagata Dey, Siddhartha Bhowmick

U.G. Student, Department of Mechanical Engineering, Dr. B. C. Roy Engineering College, Durgapur, India

U.G. Student, Department of Mechanical Engineering, Dr. B. C. Roy Engineering College, Durgapur, India

U.G. Student, Department of Mechanical Engineering, Dr. B. C. Roy Engineering College, Durgapur, India

Assistant Professor, Department of Mechanical Engineering, Dr. B. C. Roy Engineering College, Durgapur, India

**ABSTRACT**: This project explores the entire journey of building a robotic arm that mimics the movements of a human arm to perform tasks like picking up, placing, and manipulating objects. To achieve precise and flexible motion, the arm is constructed with multiple degrees of freedom. The design combines essential disciplines, e.g. mechanical structure, electronics, and programming to create a synchronized system where actuators and microcontrollers, Arduino Nano and ATmega328P, control the joint movements. Sensors are integrated to provide feedback and enable a higher level of automation. The manipulator is built using affordable components, making it both functional and accessible. The project aims to showcase how robotic arms can be effectively used in areas like industrial automation, education, and research. Throughout the process, students engage with core engineering principles including kinematics, dynamics, control systems, and mechatronics, reflecting the deeply interdisciplinary nature of robotics development.

KEYWORDS: Robotic Arm, Arduino Nano, Hardware-Software-Mechanical Design, Automation.

#### I. INTRODUCTION

Robotics technology has rapidly advanced in recent years, with its primary goal being to support humans in performing specific tasks more efficiently. Among the various types of robots, robotic arms are also known as manipulators and stand out for their ability to lift, hold, and move objects with high precision and accuracy. This capability makes them especially valuable in improving production quality and reducing operational time in industrial settings. In this project, a robotic arm is controlled wirelessly through Bluetooth technology. The system utilizes an HC-05 Bluetooth module interfaced with a microcontroller. A custom Android application is developed to send serial commands from a smartphone to the Bluetooth module, which are then processed by the microcontroller to control the servo motors accordingly. This setup enables intuitive, real-time control of the robotic arm, making it functional and user-friendly.

#### **II. LITERATURE SURVEY**

Robotic arms are playing an increasingly vital role in automating repetitive and precise tasks across various industries, helping improve not just productivity; but also safety and accuracy. The availability of microcontrollers like Arduino and wireless modules such as the HC-05 Bluetooth unit, building these robotic systems more accessible, particularly for educational and low-cost industrial applications.

For instance, Choudhari et al. [1] developed a robotic arm powered by Arduino Uno and servo motors, which could be wirelessly controlled via Bluetooth. Their design proved especially useful for tasks in hazardous environments and could be easily reprogrammed for different operations. In a similar effort, Bhujbal et al. [2] created a four degree of freedom robotic arm managed through an Android app, demonstrating its efficiency in pick and place functions.

Recent advancements in robotic arm control systems have increasingly leveraged smartphone-based interfaces for intuitive user interaction. Heamawatanachai and Mayang [3] demonstrated a six-axis robotic arm controlled via Bluetooth and Wi-Fi, applying forward and inverse kinematics to improve movement precision and efficiency over traditional methods.

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The role of machine learning in robotic manipulation has also grown. Nahavandi et al. [4] highlighted its impact on enhancing safety, reliability, and adaptability in sectors such as healthcare and agriculture. Similarly, the integration of IoT technologies has expanded the potential of robotic systems. Kumar et al. [5] developed a Wi-Fi-controlled robotic arm using the Blynk app, enabling effective remote operation during the COVID-19 pandemic.

Ensuring fault tolerance is crucial for reliable robotic performance. Quamar and Nasir [6] emphasized the use of AI and digital twin models for detecting and compensating system failures. In terms of interaction, robotic vision systems are improving collaboration between humans and machines. Robinson et al. [7] reviewed their use in gesture recognition and object handovers.

User interface development also plays a key role. Rottmann et al. [8] introduced ROS-Mobile, an Android app that simplifies the control of ROS-based robotic systems. Practical implementations continue to emerge, Dasgupta and Ghosh [9] showcased a four-axis robotic arm controlled via Android, while Chaitanya et al. [10] integrated a camera for real-time monitoring, expanding its remote-use capabilities.

#### **III. METHODOLOGY**

A robotic arm functions as a programmable manipulator designed to replicate the actions of a human arm. It consists of a series of interconnected links which are built with the elements of robot arm kit (Fig. 1), joined together by either rotational or revolute joints, similar to how our shoulders, elbows, and wrists move. These links form what's known as a kinematic chain or linkage, culminating at the tip in a tool or device called the end effector, which acts like a human hand. The end effector can be customized for a variety of tasks, such as gripping, welding, or spinning, based on the specific application. Robotic arms can operate autonomously or be controlled manually, depending on the system's design and purpose.



Fig. 3. (a) Servo motor (b) PWM Servo motor driver

Fig. 4. HC-05 Bluetooth driver





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The Arduino Nano (Fig. 2) is a compact, breadboard-friendly microcontroller board based on the ATMEGA328P, offering similar functionality to the Arduino Uno but in a smaller and more cost-effective form. It connects via a mini-B USB, lacks a DC power jack, and provides additional I/O pins. The Nano reads analogue/digital signals from sensors and converts them into outputs like motor control or LED activation. Code is uploaded easily via the Arduino IDE using a USB cable, with no external programmer needed. Its use of simplified C++ makes it accessible for beginners and ideal for DIY and embedded projects.

A servo motor (Fig. 3(a)) is a DC motor with a closed-loop feedback system that uses PWM signals (Fig. 3(b)) to control shaft rotation, with a potentiometer and control circuit setting angle limits. It's ideal for robotic arms due to precise positioning. The HC-05 Bluetooth module (Fig. 4) enables 2.4GHz wireless communication in master or slave mode, operating at 3.6V-6V with a 10-meter range. A half-size breadboard (Fig. 5) with 400 tie points and dual power rails is perfect for compact circuits. Using jumper wires (Fig. 6), components like the Arduino Nano and HC-05 are connected via power rails and proper TX/RX pin alignment for reliable serial communication.



Fig. 5. Breadboard





Fig. 7. Parts connection to Arduino Nano board



The hardware design involves using an Arduino Nano microcontroller as the main data processor, paired with the HC-05 Bluetooth module for wireless communication. Servo motors (180°) act as actuators for the robotic arm, controlled via a PWM servo driver. An Android smartphone sends control signals, while a barrel jack adapter supplies external





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power. Additional components include electronic parts like PCBs, connectors, cables, and a breadboard to mount and interconnect the Arduino Nano and Bluetooth module efficiently as shown in Fig. 7.

In our project, the robotic arm we designed, as shown in the image above (Fig. 8) features five Degrees of Freedom: the Base, Shoulder, Elbow, Wrist and Gripper. Each of these joints is controlled using a servo motor, which allows for precise angular movement. Servo motors are electromechanical devices that convert electrical energy into rotational mechanical motion, enabling the arm to perform tasks with controlled and accurate positioning.

To ensure the hardware would functioning correctly, an initial test was conducted by connecting a single servo motor to the microcontroller and sensor shield. Sample programs were uploaded using the Arduino IDE to verify that the microcontroller could successfully execute commands and control the servo. This preliminary testing helped confirm that the system was properly configured before full integration. The supporting software used in our work is the Arduino IDE to create the program in the microcontroller.

#### Table 1: The robot specifications

Sl. No.	Specification	Dimension
1	Dimensions	209 mm (L) $\times$ 165 mm (W) $\times$ 166 mm (H)
2	Weight	350 grams
3	Payload	150 grams
4	Degrees of Freedom (DOF)	5 (Base, Shoulder, Elbow, Wrist, Gripper)

#### IV. ANALYSIS, RESULTS AND DISCUSSION

To perform kinematic analysis, we use the Denavit-Hartenberg (DH) convention, which provides a systematic way to describe the relative positions and orientations of adjacent links. Each joint is described using four parameters:

 $\theta$ : Joint angle (radian), d: Link offset (mm), a: Link length (mm),  $\alpha$ : Twist angle (radian)

Table 2: DH parameters for the 5-DOF robotic arm

Sl. No.	Joint (i)	$\theta_i$ (rad)	$d_i \pmod{2}$	$a_i \pmod{2}$	$\alpha_i$ (rad)
1	Base	$\theta_1 = 0$	$d_1 = 0$	$a_1 = 0$	$\alpha_1 = \pi/2$
2	Shoulder	$\theta_2 = \pi/4$	$d_{2} = 0$	$a_2 = 100$	$\alpha_2 = 0$
3	Elbow	$\theta_3 = \pi/6$	$d_3 = 0$	$a_3 = 100$	$\alpha_3 = 0$
4	Wrist	$\theta_4 = 0$	$d_4 = 0$	$a_4 = 0$	$\alpha_4 = \pi/2$
5	End-Effector	$\theta_5 = 0$	$d_{5} = 50$	$a_5 = 0$	$\alpha_5 = 0$

Forward Kinematics involves determining the position and orientation of the end-effector given the joint angles. This is achieved by multiplying the individual transformation matrices for each joint. Homogeneous Transformation Matrix (HTM) for each link is derived from the DH parameters as follows.

$$T_{t-1}^{i} = \begin{bmatrix} \cos(\theta_{i}) & -\sin(\theta_{i})\cos(\alpha_{i}) & \sin(\theta_{i})\sin(\alpha_{i}) & a_{i}\cos(\theta_{i}) \\ \sin(\theta_{i}) & \cos(\theta_{i})\cos(\alpha_{i}) & -\cos(\theta_{i})\sin(\alpha_{i}) & a_{i}\sin(\theta_{i}) \\ 0 & \sin(\alpha_{i}) & \cos(\alpha_{i}) & d_{i} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \forall i = 1(1)5$$

$$(1)$$

The overall transformation matrix from the base to the end-effector is the product of the individual transformation matrices which is given by

$$T_0^5 = T_0^1 \cdot T_1^2 \cdot T_2^3 \cdot T_3^4 \cdot T_4^5$$
<sup>(2)</sup>

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We computed the position and orientation of the end-effector in the task space by calculating the final transformation matrix using equations (1) and (2) and data of Table 2. It is worthwhile to mention that the length of end-effector is neglected for the sake of simplicity in calculation.

From equation (3), we have the approximated coordinate of the end-effector position as (96.6 mm, 0, 167.3 mm) in 3D

space and its orientation concerning the reference base frame is 0



Fig. 9. Experimentation with the working model (a) Posing (b) End-effector configuration (c) Gripping (d) Lifting load

Although the robotic arm features only five degrees of freedom, it is still capable of performing a variety of tasks in three-dimensional space. These include pick and place operations, as well as push and pull actions. For pick and place operations, the end-effector is mechanical gripper that grasps objects using two fingers (Fig. 9). Despite its relatively simple joint structure, the arm can effectively manipulate objects weighing up to approximately 150 grams, demonstrating its practical utility in lightweight task applications.

To determine the joint angles required for our 5-DOF pick and place robotic arm manipulator to reach a specific position and orientation obtained above (equation (4)), we performed an inverse kinematic analysis as well. This process involves calculating the joint parameters that achieve a desired end-effector pose, based on the robot's geometry and kinematic configuration as per Table 2.





(5)

(6)

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Actual Reach of the end-effector from the base in the XZ plane is given by

$$r = \sqrt{X^2 + Z^2} = \sqrt{(96.6)^2 + (167.3)^2} = \sqrt{9331.56 + 27989.29} = 193.19 \text{ mm}$$

Using the law of cosine, we have

$$\cos\theta_3 = \frac{r^2 - a_2^2 - a_3^2}{2a_2a_3} = \frac{37322.38 - 10000 - 10000}{20000} = 0.866$$

 $\Rightarrow \theta_3 = \cos^{-1}(0.866) = \frac{\pi}{6}$  radian (elbow angle)

Shoulder angle is given by

$$\theta_{2} = \tan^{-1} \left( \frac{Z}{X} \right) - \tan^{-1} \left( \frac{a_{3} \sin \theta_{3}}{a_{2} + a_{3} \cos \theta_{3}} \right) = \tan^{-1} \left( \frac{167.3}{96.6} \right) - \tan^{-1} \left( \frac{100 \sin(\pi/6)}{100 + 100 \cos(\pi/6)} \right)$$
$$\Rightarrow \theta_{2} = \tan^{-1} \left( 1.732 \right) - \tan^{-1} \left( \frac{50}{100 + 86.6} \right) = \frac{\pi}{3} - \frac{\pi}{12} = \frac{\pi}{4}$$
(7)

#### **V. CONCLUSION**

The robotic arm, designed with five degrees of freedom (5-DOF), demonstrated smooth and effective movement, successfully responding to commands sent via the mobile app's slider controls. Even with only five functional joints, the arm is capable of performing essential tasks with accuracy and precision. However, addressing the jitter issue would further enhance its stability and performance.

#### **VI. NOMENCLATURE**

HC	High Speed CMOS (Complementary Metal-Oxide-Semiconductor)
PWM	Pulse Width Modulated
ROS	Robot Operating System
LED	Light Emitting Diode
USB	Universal Serial Bus
DC	Direct Current
I/O	Input/output
IDE	Integrated Development Environment
DIY	Do it yourself
GHz	Gigahertz
V	Volt
TX/RX	Transmitter/Receiver
HW/SW	Hardware/Software
RXD	Received Data
TXD	Transmit Data
GND	Ground (zero-voltage point in a circuit)
RST	Red, Second (or Yellow), Third (or Blue) phases
VIN	Input Voltage
PWR	Power
DH	Denavit-Hartenberg
DOF	Degree Of Freedom
L, W, H	Length, width, height





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 $c\theta_i$   $\cos\theta_i$ 

 $s\theta_i$   $\sin\theta_i$ 

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