IMPLEMENTATION OF A 5-DoF ARTICULATED ROBOT

MINI PROJECT REPORT

Submitted by

AJESH T (KTE22RAI004)

ANNUAY K PRASANTH (KTE22RAI011)

NITHIKRISHNA M(KTE22RAI024)

MOHAMMED SHAN P A (LKTE22RAI035)

to

APJ Abdul Kalam Technological University

in partial fulfilment of the requirements for the award of Degree of

BACHELOR OF TECHNOLOGY IN

ROBOTICS AND ARTIFICIAL INTELLIGENCE

RAJIV GANDHI INSTITUTE OF TECHNOLOGY
Department of Electronics and Communication Engineering
KOTTAYAM - 686501

April 2025

RAJIV GANDHI INSTITUTE OF TECHNOLOGY
Department of Electronics and Communication Engineering
KOTTAYAM - 686501

CERTIFICATE

The Mini Project entitled **IMPLEMENTATION OF A 5-DoF ARTICULATED ROBOT** is a bonafide work carried out by **AJESH T (KTE22RAI004), ANNUAY K PRASANTH (KTE22RAI011), NITHIKRISHNA M (KTE22RAI024), MOHAMMED SHAN P A (LKTE22RAI035)** during 2025-26, in partial fulfillment of the award of the B. Tech degree in Robotics and Artificial Intelligence from APJ Abdul Kalam Technological University, Rajiv Gandhi Institute of Technology, Kerala.

Guide | Coordinators

Head of the Department, ECE

ACKNOWLEDGEMENT

We would like to express our sincere gratitude to Prof. Anil Kumar C D and Prof. Nelsa Abraham for their invaluable guidance, support and encouragement throughout the development of this project. Their expertise and insights have been instrumental in successfully designing and implementing this articulated robotic arm.

This project was a collaborative effort, and we acknowledge the contributions of our entire team. Each member played a crucial role in the successful completion of the project, from designing and assembling the robotic arm to integrating the control system and software interface.

We are deeply indebted to Dr. David Solomon George, Professor and Head of the Department of Electronics and Communication, for providing permission and availing all the required facilities for undertaking the project in a systematic way. We wish to express our sincere thanks to our Principal, Dr. Prince A, for providing us with all the necessary resources.

Further, we extend our gratitude to all the teaching and non-teaching staff of the Department of Electronics and Communication for their cooperation and support throughout the project.

Finally, we express our thanks to our friends, family, and well-wishers who guided, helped, and encouraged us to complete this project successfully and on time.

ABSTRACT

This project presents the design and development of a 5-DOF articulated robotic arm for pick-and-place operations. The arm is constructed using PVC pipes for a lightweight and cost-effective structure and is actuated by MG996R and SG90 servo motors. The control system is implemented using an Arduino board with a PCA9685 servo driver, which allows precise motion control through PWM signals. A Python-based GUI (Tkinter) is developed for real-time user control, allowing intuitive manipulation of the robotic arm. The system is capable of lifting 150g payloads with a maximum reach of 65 cm. Kinematic and dynamic analysis ensures smooth and stable operation, while trajectory planning techniques optimize movement efficiency. The successful implementation of this robotic arm demonstrates the feasibility of low-cost automation for industrial and educational applications.

Contents

1 INTRODUCTION

Automation and robotics play a crucial role in improving efficiency and precision in various industries. This project focuses on the design and development of a 5-DOF articulated robotic arm for pick-and-place operations, built using cost-effective materials and components.

The robotic arm is constructed using PVC pipes, which ensures a lightweight and budget-friendly structure. It is actuated using MG996R and SG90 servo motors, controlled via an Arduino board and PCA9685 servo driver. A Python-based GUI (Tkinter) is developed to provide an intuitive interface for real-time user control.

With a maximum reach of 65 cm and a payload capacity of 150g, the arm demonstrates reliable motion for small-scale automation tasks. Kinematic and dynamic analysis ensures precise movement, while trajectory planning optimizes efficiency.

This project showcases the feasibility of a low-cost robotic arm for educational and research applications, with potential applications in automation, material handling, and robotics learning.

2 OBJECTIVES

- To design and develop a 5-DOF robotic arm capable of performing pick-and-place tasks.
- To construct the arm using PVC pipes, ensuring a lightweight and budget-friendly structure.
- To select and implement MG996R and SG90 servo motors for controlled and precise movement.
- To integrate an Arduino board and PCA9685 servo driver for efficient motor control using PWM signals.
- To develop a Python-based GUI (Tkinter) for real-time user control and intuitive operation.
- To achieve a maximum reach of 65 cm and a payload capacity of 150g for practical applications.
- To analyze kinematic and dynamic performance to ensure stability, accuracy, and efficiency in motion.

3 DESIGN PARAMETERS

3.1 Workspace and Task Planned

3.1.1 Workspace Considerations

- The arm covers a Spherical workspace with a 65 cm reach radius from its base.
- The height and extension of the arm allow it to interact with objects placed at different elevations.
- The gripper movement (SG90 servo motors) enables precise object handling.
- The design ensures clearance from obstructions to avoid mechanical interference.

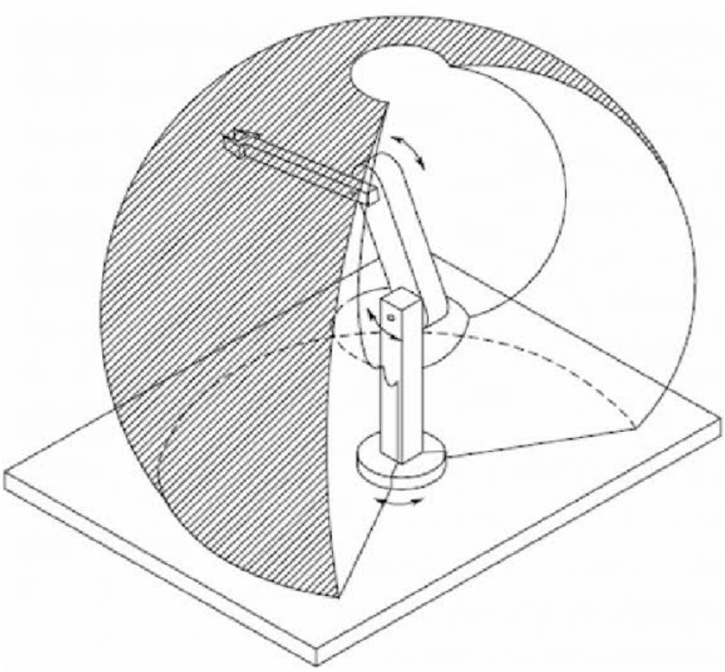

Figure 3.1: Workspace coverage of the robotic arm

3.1.2 Task Planned

- Pick-and-place operations for lightweight objects within the specified reach.
- Rotational base movement (MG996R) to extend coverage across the workspace.
- Controlled vertical and horizontal motion using articulated joints for smooth positioning.
- Gripping and releasing functionality for precise object handling.

3.2 Structural Parameters and Drawing

The robotic arm is designed using lightweight and cost-effective materials, ensuring stability and precision for pick-and-place operations. Below are the key structural details:

3.2.1 Materials Used

- **PVC Pipes** – Used for the main arm structure, ensuring a lightweight yet sturdy build.
- **3D-Printed Gripper** – Custom-designed for better precision and durability.
- **Arduino Uno** – Main microcontroller that processes signals and controls the motors
- **Servo Motors (MG996R & SG90)** – Provide rotational motion at different joints.
- **PCA9685 Servo Driver** – Used to control multiple servos efficiently
- **Metal Screws and Fasteners** – Used to secure joints and motor fittings.

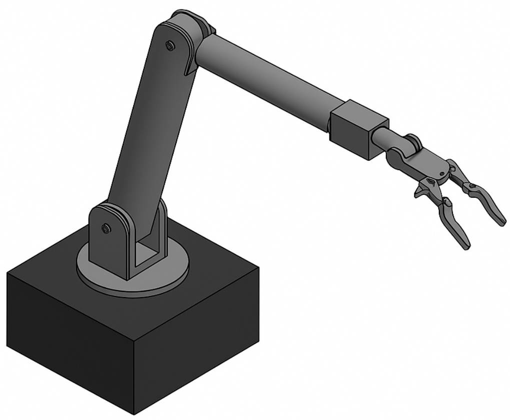

Figure 3.2: Structural design of the robotic arm using solidworks

3.2.2 ARDUINO UNO

The Arduino Uno is an open-source microcontroller board based on the ATmega328P. It is widely used in embedded systems and robotics due to its simplicity, reliability, and extensive community support. In this project, the Arduino Uno acts as the main control unit, processing inputs and sending PWM signals to control the servo motors via the PCA9685 module.

- **Microcontroller**: ATmega328P
- **Operating Voltage**: 5V
- **PWM Channels**: 6 (Used for controlling servo motors)
- **Digital I/O Pins**: 14 (Used for communication with PCA9685)
- **Communication Interfaces**: I2C (Used to interface with PCA9685 for servo control)
- **Clock Speed**: 16 MHz (Ensures smooth processing of control signals)
- **USB Interface**: Type B (For programming and power supply)

Figure 3.3: Arduino UNO

3.2.3 MG996R SERVO

- Used for Base, Shoulder, and Elbow Joints
  - Torque: 9.4 kg.cm @ 5V
  - Rotation Angle: 0° to 180°
  - Purpose: Handles high-load joints requiring more torque

Figure 3.4: MG996R Servo Motor

3.2.4 SG90 SERVO

- Used for Wrist Roll, Gripper Tilt, and Gripper Control
  - Torque: 1.8 kg.cm @ 5V
  - Rotation Angle: 0° to 180°
  - Purpose: Controls low load movements, making it ideal for gripper operations

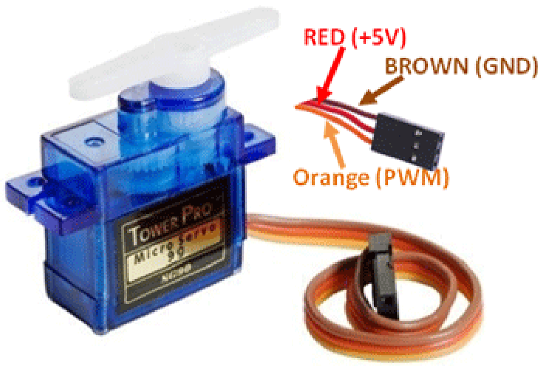

Figure 3.5: MG996R Servo Motor

3.2.5 PCA9685 Overview

The PCA9685 is a 16-channel PWM (Pulse Width Modulation) driver that allows precise control of multiple servo motors using only two I2C pins on the Arduino. It is especially useful in projects like robotic arms where multiple servos need to be controlled efficiently.

- **PWM Outputs:** 16 channels (can control up to 16 servos)
- **Communication Interface:** I2C (Uses only 2 Arduino pins: SDA & SCL)
- **PWM Resolution:** 12-bit (4096 steps) for smooth movement
- **Operating Voltage:** 2.3V – 5.5V (Compatible with Arduino Uno's 5V logic)
- **Output Frequency:** Up to 1.6 kHz (Adjustable for precise servo control)
- **External Power Support:** Can drive servos directly with an external 5V power supply

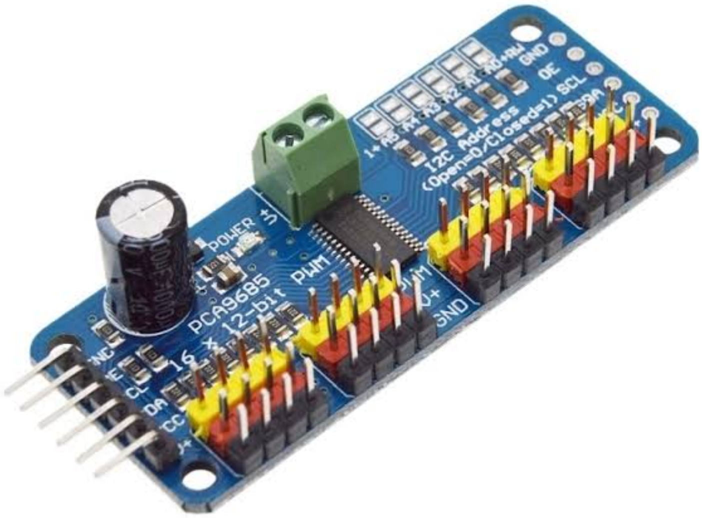

Figure 3.6: PCA9685 Servo Driver

3.3 Mechanics / Mechanical Parameters

3.3.1 Kinematic Parameters

- The robotic arm has **5 degrees of freedom (DoF)**, achieved using **revolute joints** at each link.
- The kinematic structure is similar to a **serial manipulator**, where each joint's motion affects the position and orientation of the end-effector (gripper).
- Forward kinematics were considered to estimate the workspace and reach (max ˜65 cm).
- Due to limited inverse kinematics computation, manual control via GUI was implemented.

3.3.2 Dynamic Parameters

- The robot is not dynamically balanced or simulated; motion is controlled using basic timed PWM signals.
- Each MG996R servo can exert torque up to **9.4 kg.cm**, which is sufficient to lift objects up to **150 grams** at maximum reach.
- The SG90 servos used at the wrist and gripper provide ˜1.8 kg.cm torque, suitable for lighter loads.

3.3.3 Velocity and Acceleration

- Servo motors are controlled using PWM signals with limited ramping features.
- Acceleration and deceleration were manually tuned through **timing delays** in code.
- Estimated end-effector speed is **moderate**, adequate for simple pick-and-place tasks.

3.3.4 Trajectory Planning

- The system follows a **point-to-point movement strategy** controlled via a Python-Tkinter GUI.
- No dynamic or path optimization algorithm (like splines or PID) was used.
- Movements are manually coordinated using **preset angles** fed through the interface.

3.4 Electrical / Electronics Control

3.4.1 Servo Motor Configuration

- **MG996R Servo Motors** are used for the **Base, Shoulder, and Elbow joints**, chosen for their high torque (9.4 kg·cm), which is essential for lifting and supporting the weight of the arm and the payload.
- **SG90 Servo Motors** are used for **wrist roll, gripper tilt, and gripper open/close**, where lower torque (1.8 kg·cm) is sufficient.

3.4.2 Control System Overview

- The system is controlled by an **Arduino Uno**, which acts as the main microcontroller.
- Since the Arduino Uno has limited PWM outputs, a **PCA9685 16-channel PWM Driver** is used to control all the servo motors through **I2C communication**.
- The PCA9685 generates stable and accurate PWM signals, ensuring smooth servo movement and reducing jitter.

3.4.3 Power Management

- Servos are powered using an **external 5V regulated power supply** to prevent overloading the Arduino.
- Power to the PCA9685 is split into logic (3.3–5V from Arduino) and motor power (5V from external supply).
- Capacitors were used to stabilize voltage and reduce electrical noise during operation.

3.4.4 Interface and Control Logic

- A custom **Python GUI using Tkinter** is used to send control inputs to the Arduino via USB.
- The interface allows users to manually adjust joint angles and trigger specific pick-and-place routines.

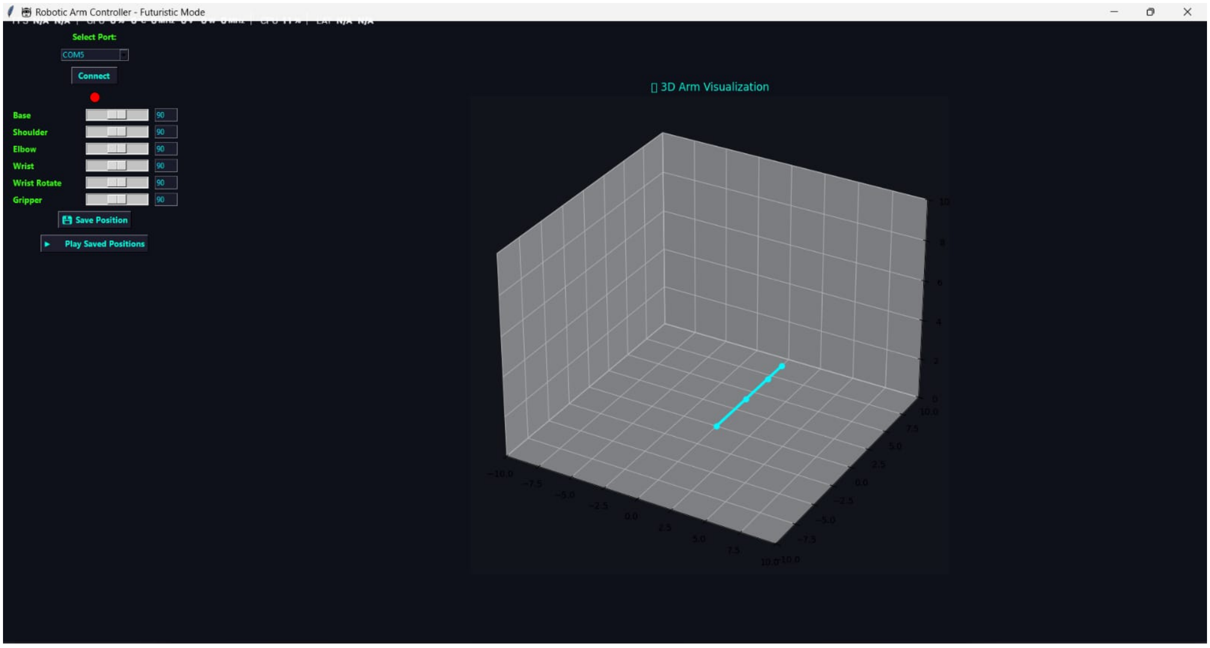

Figure 3.7: Python Tkinter GUI interface for controlling the robotic arm

4 COST INVOLVED

Component	Quantity	Cost
MG996R Servo Motors	3	1,350 (450 each)
SG90 Servo Motors	3	450 (150 each)
PCA9685 Servo Driver	1	490
Arduino Board	1	450
3D Printed Custom Gripper	1	300
Power Supply & Wiring	-	650
Total Cost	-	**3,690**

Table 4.1: Component-wise Cost Breakdown

5 RESULT

The 5-DOF articulated robotic arm was successfully designed and fabricated using PVC pipes, servo motors, and an Arduino-based control system. The arm demonstrated effective pick-and-place functionality with the following performance outcomes:

- The robotic arm achieved a maximum reach of **65 cm**, covering a sufficient workspace for basic tasks.
- It was capable of lifting loads up to **150 grams**, which is within the design limit of the MG996R servos.
- All Five degrees of freedom were individually controlled through a **Python-Tkinter interface**, allowing real-time joint manipulation.

Figure 5.1: Constructed 5-DOF Articulated Robotic Arm