Hand Gesture Controlled Robotic Arm Using Mediapipe and Raspberry Pi

# 1. Introduction

This project demonstrates a real-time hand gesture-controlled robotic arm using a webcam, Mediapipe for hand tracking, and Adafruit PCA9685 servo controllers with a Raspberry Pi. The system uses hand positions and gestures to control a 5-DOF robotic arm: shoulder, elbow, wrist1, wrist2, and gripper.

# 2. Components Used

- Raspberry Pi (any model with I2C support)

- PCA9685 Servo Controller (x2)

- MG996R Servo Motors (x6)

-NEMA 17 stepper motor

-A4988 stepper motor driver

- USB Webcam

- Python Libraries: OpenCV, Mediapipe, Adafruit\_PCA9685, Adafruit\_ServoKit

# 3. Functional Overview

The system captures video input from a webcam and uses Mediapipe to detect and track a single hand. Based on the hand's X, Y position, tilt angle, and palm openness, it maps these values to servo angles.

# 4. Control Mapping

- X-axis of hand: Controls Shoulder (channels 0 and 1, mirrored)

- Y-axis of hand: Controls Wrist1 (channel 1 of PCA2)

- Tilt angle (wrist to middle finger base): Controls Wrist2 (channel 2 of PCA2)

- Palm open/close state: Controls Gripper (channel 3 of PCA2)

- Elbow (channel 0 of PCA2): Kept at a fixed angle of 35°

# 5. Software Architecture

The software has two major modules:  
- Hand Tracking Module: Uses OpenCV and Mediapipe to process video and extract hand landmark data.  
- Servo Control Module: Maps landmark values to corresponding servo angles and controls the PCA9685 modules.

# 6. Servo Angle Mapping

Angle ranges are mapped as follows:  
- Shoulder: 35° to 80°  
- Wrist1: 45° to 100°  
- Wrist2: 0° to 180°  
- Gripper: 30° (open) to 105° (close)  
- Elbow: Fixed at 35°

# 7. Tables

### 7.1. Raspberry Pi to PCA9685 Connections

|  |  |  |
| --- | --- | --- |
| **Raspberry Pi Pin** | **PCA9685 Pin** | **Function** |
| Pin 3 (GPIO2 / SDA1) | SDA | I2C Data Line |
| Pin 5 (GPIO3 / SCL1) | SCL | I2C Clock Line |
| Pin 2 (5V Power) | VCC | Power Supply |
| Pin 6 (GND) | GND | Ground |

### 7.2. PCA9685 to Servo Connection (Example for One Servo)

|  |  |  |  |
| --- | --- | --- | --- |
| **PCA9685 Channel** | **Signal Pin** | **Servo Pin (Color)** | **Function** |
| Channel 0 | PWM0 | Orange/Yellow | PWM Signal |
| V+ Pin (next to PWM) | Power | Red | Power (+5V) |
| GND Pin (next to PWM) | Ground | Brown/Black | Ground (GND) |

## 7.3. Components and Description

|  |  |
| --- | --- |
| Component | Description |
| Raspberry Pi | Microcontroller board to run the control code |
| PCA9685 (x2) | 16-channel PWM driver to control multiple servos |
| Servo Motors (x6) , Stepper motor(1) | Used to control robotic arm joints |
| Webcam | Used for capturing real-time video for hand tracking |
| Python Libraries | OpenCV, Mediapipe, Adafruit libraries |

## 7.4. Servo Channel Mapping

|  |  |  |
| --- | --- | --- |
| Joint | PCA Address | Channel |
| Shoulder (Left) | 0x40 | 0 |
| Shoulder (Right - Mirror) | 0x40 | 1 |
| Elbow | 0x41 | 0 |
| Wrist1 | 0x41 | 1 |
| Wrist2 | 0x41 | 2 |
| Gripper | 0x41 | 3 |

## 7.5. Gesture to Movement Mapping

|  |  |  |
| --- | --- | --- |
| Gesture Input | Mapped Control | Angle Range |
| X-axis (hand left-right) | Shoulder | 35°–80° |
| Y-axis (hand up-down) | Wrist1 | 45°–100° |
| Palm Tilt (rotation) | Wrist2 | 0°–180° |
| Palm Open/Close | Gripper | 30°–105° |
| Fixed Value | Elbow | 35° |

## 7.6. PCA9685 Channel to Servo Mapping

|  |  |  |
| --- | --- | --- |
| PCA9685 Address | Channel No. | Connected Servo (Function) |
| 0x40 | 0 | Shoulder Joint 1 |
| 0x40 | 1 | Shoulder Joint 2 |
| 0x40 | 0 | Elbow Joint |
| 0x41 | 1 | Wrist Tilt |
| 0x41 | 2 | Wrist Rotation |
| 0x41 | 3 | Gripper |

# 8. Conclusion

This project integrates computer vision with robotic actuation, allowing intuitive hand-gesture-based control of a robotic arm. It is ideal for robotics learning, gesture-based interfaces, and semi-autonomous control systems.