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Prosthetic Arm Based On Servo Motor

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Abstract : The development of cost-effective and functional prosthetic limbs has become a crucial area of research in biomedical engineering and assistive technologies. This project focuses on the design and implementation of a low-cost, efficient prosthetic arm utilizing servo motors, the PCA9685 servo driver module, and the Arduino UNO microcontroller. The prosthetic arm is intended to replicate basic human arm movements such as gripping, lifting, and releasing with reasonable accuracy and responsiveness, especially targeting individuals with upper-limb disabilities in low-resource settings. The core mechanism of the prosthetic arm is based on multiple servo motors which act as artificial muscles to drive the joints of the arm, including fingers, wrist, and elbow. These servo motors are controlled by the PCA9685, a 16-channel PWM (Pulse Width Modulation) driver module that simplifies the control of multiple servos simultaneously without burdening the limited PWM outputs of the Arduino UNO. The Arduino UNO acts as the main processing unit, taking sensor inputs (such as from EMG sensors, flex sensors, or switches) and sending appropriate PWM signals to the PCA9685 to control each servo motor accordingly. One of the major advantages of using the PCA9685 with Arduino UNO is scalability and simplicity. With just two wires (I2C communication), up to 16 servo motors can be controlled simultaneously. This enables the prosthetic arm to mimic more complex and natural movements while maintaining low cost and compact hardware. Additionally, the use of the Arduino platform ensures that the system is accessible, easily programmable, and compatible with a wide variety of sensors and control schemes.

keyword - sensors, Prosthetic arm, Real-time control, Biomechanics, Gesture recognition, Signal processing.

INTRODUCTION

The loss of an upper limb has a profound impact on an individual's quality of life, significantly limiting their ability to perform everyday tasks and reducing their independence. Prosthetic technology has advanced over the years, offering solutions that help restore some degree of functionality. However, commercial prosthetic arms, especially those with advanced capabilities, are often expensive, complex, and inaccessible to individuals in low-resource settings. This has created a growing need for affordable, customizable, and easy-to-operate prosthetic solutions. The integration of modern microcontrollers, motor drivers, and affordable electronics provides a pathway to develop such cost-effective prosthetic limbs.

This project presents the design and development of a prosthetic arm based on servo motors, the PCA9685 servo driver module, and the Arduino UNO microcontroller. The primary aim is to create a low-cost, functional prosthetic arm capable of performing basic arm and finger movements such as gripping, holding, and lifting objects. The choice of servo motors allows for precise control over joint movement, enabling the replication of natural hand motions. Each servo is assigned to a particular joint—fingers, wrist, and elbow—making the prosthetic limb act in a manner similar to a real human arm.

The PCA9685 servo driver is a key component in the system. It is a 16-channel, 12-bit PWM controller that communicates with the Arduino UNO using the I2C protocol. This module enables the control of multiple servos simultaneously with minimal pin usage on the microcontroller. This not only simplifies the wiring but also allows for the future expansion of the prosthetic arm's functionalities. The Arduino UNO, acting as the central processing unit, reads input signals from various types of sensors—such as flex sensors, push buttons, or electromyography (EMG) sensors—and translates them into commands that control the servo motors via the PCA9685.

An intuitive control interface is vital for the usability of the prosthetic arm. This project explores several input methods, such as flex sensor gloves that mirror hand movements, and EMG sensors that detect muscle signals from the residual limb. These inputs allow the prosthetic arm to be controlled in a natural and user-friendly way. For instance, using a glove equipped with flex sensors, a user can move their healthy hand, and the prosthetic arm will mimic those movements in real-time, enhancing coordination and ease of use.

Another important consideration in the design is affordability and ease of fabrication. Components such as the Arduino UNO, PCA9685, and servo motors are low-cost and readily available. Moreover, using 3D printing to create the arm's structure reduces production costs and allows for customization according to the user's needs.

In summary, this prosthetic arm project is a significant step toward democratizing access to assistive technology. By combining affordable hardware, open-source programming, and user-friendly design, it offers a practical solution for individuals with upper limb disabilities. The project not only helps users regain basic hand functionality but also serves as a platform for future innovation in prosthetic development

PROBLEM STATEMENT

Most low-cost prosthetics available in the market today are either mechanical (body-powered) or offer limited motorized motion, restricting the user's ability to perform complex tasks that require finger articulation or wrist rotation. These basic prosthetics often lack adaptability, user-friendly interfaces, and the fine motor control necessary for daily activities like writing, using utensils, or operating electronic devices. Additionally, the absence of personalization and modularity in such designs reduces their effectiveness and comfort for different users.

The core problem is the lack of a cost-effective, customizable, and responsive prosthetic arm solution that can be manufactured using readily available components and controlled intuitively by users. Such a system must balance affordability with functionality, provide natural movement, and be easily maintained or upgraded. Furthermore, it should be designed in a way that even individuals without advanced technical knowledge can use, adapt, or repair it with minimal effort.

This project addresses this problem by developing a prosthetic arm that uses servo motors for movement, controlled via a PCA9685 servo driver, and managed by an Arduino UNO microcontroller. The goal is to provide a prosthetic arm capable of performing basic to moderately complex movements such as gripping, lifting, and rotating objects. By leveraging open-source hardware and software, the prosthetic design can be reproduced, modified, and improved by the global maker community, students, and researchers.

One of the major challenges in prosthetic design is the simultaneous control of multiple actuators (i.e., servos) to replicate natural joint and finger movements. The limited number of PWM (Pulse Width Modulation) outputs on most microcontrollers, including the Arduino UNO, restricts the number of servos that can be controlled directly. The use of the PCA9685 module solves this issue by allowing control of up to 16 servos over an I2C interface, thereby significantly enhancing the arm's dexterity without complicating the hardware setup.

Another issue is the intuitive control mechanism of the prosthetic. Many users find it difficult to adapt to complex control systems that require extensive training. To address this, the proposed system can incorporate flex sensors, EMG signals, or simple push buttons to create a more natural interface for the user. These options also allow for different user needs and capabilities, increasing the versatility of the design.

In summary, the primary problem lies in developing a prosthetic arm that is affordable, functional, modular, and user-friendly. This project aims to bridge the gap between high-cost commercial prosthetics and limited-functionality low-end models by providing an open-source, Arduino-based solution using servo motors and PCA9685 for efficient and scalable control.

METHODOLOGIES

The development of a cost effective and functional prosthetic arm involves a combination of mechanical design, electronics integration, programming, and user interface development. This project adopts a modular and iterative methodology, combining hardware and software components to design a prosthetic arm that mimics natural human hand and arm movements. The approach is broken down into several stages: conceptua, component selection, mechanical assembly, electronic circuitry, programming, and testing.

1. Conceptual Design and Requirements Analysis

The initial phase involves identifying the primary functions of the prosthetic arm, such as gripping, opening/closing fingers, wrist rotation, and elbow movement. Based on the requirements of the targeted users—primarily those in need of a lowcost solution—criteria like affordability, simplicity, reliability, and ease of use are prioritized. Sketches and CAD models are created to determine the dimensions, joint structure, and range of motion necessary for performing daily tasks.

2. Component Selection

The prosthetic arm's movement is powered by servo motors due to their ability to provide precise angular control. Micro servo motors (e.g., SG90 or MG996R) are selected for finger movement, while higher torque servos are used for the wrist and elbow. The PCA9685 servo driver module is chosen to control multiple servo motors simultaneously. It uses I2C communication and provides 16channel PWM outputs, freeing up Arduino UNO's limited pins and reducing circuit complexity. The Arduino UNO is selected as the central controller due to its affordability, ease of programming, and wide support for sensors and modules.

3. Mechanical Construction

The structural parts of the prosthetic arm—including fingers, palm, wrist, and forearm—are designed using CAD software and manufactured using 3D printing. Lightweight and durable materials such as PLA or ABS are used to ensure the device remains portable and comfortable. Joints are designed to house servo motors internally, allowing compact integration while minimizing exposed wiring.

4. Electronic Circuitry

Each servo motor is connected to the PCA9685, which is interfaced with the Arduino UNO via I2C communication (SCL and SDA pins). The system is powered using an external battery pack (e.g., 6V or 7.4V Liion) capable of supplying adequate current for all servos. Sensors such as flex sensors, push buttons, or EMG modules are integrated to detect user intention and send control signals to the Arduino.

5. Programming and Control Logic

The Arduino is programmed using the Arduino IDE. Libraries such as `Wire.h` and `Adafruit_PWMServoDriver.h` are used to interface with the PCA9685. A control loop is created to continuously read sensor input and generate corresponding PWM signals for servo movement. For example, if a flex sensor on the user's glove detects finger bending, the Arduino sends a signal to the respective servo to mimic the same finger movement in the prosthetic arm.

6. Testing and Calibration

After assembly, individual motor movements are tested and calibrated to ensure smooth and synchronized operation. The response of the arm to various input methods is evaluated for accuracy and delay. Adjustments are made in the software to finetune the motor angles and sensor thresholds. Iterative testing ensures that the prosthetic arm performs reliably under different conditions.

7. Future Scalability and Optimization

Provisions are made for integrating wireless control (e.g., Bluetooth or WiFi), machine learning for gesture recognition, and mobile app connectivity. The design is kept open source for future modifications by the community.

SYSTEM ARCHITECTURE

The system architecture of the prosthetic arm based on Servo Motors, PCA9685, and Arduino UNO is designed to ensure efficient communication between the user's intent (through sensors) and the actuation mechanism (servos) in a structured, reliable, and scalable manner. The architecture consists of four primary layers: Input Interface, Processing and Control Unit, Actuation Layer, and Power Supply Unit. Each of these layers is integrated to mimic natural human arm movement with costeffective and modular components.

1. Input Interface Layer (User Intent Detection)

This layer captures the user's movement or muscle activity using appropriate sensors. Multiple control input methods can be employed:

Flex Sensors: When placed on a glove worn by the healthy hand, they detect finger bending. The resistance changes are read as analog values to replicate similar motions in the prosthetic arm.

EMG (Electromyography) Sensors: Detect electrical signals from muscles in the residual limb. These are filtered and amplified before being sent to the microcontroller.

Push Buttons or Joystick: For basic control operations like opening/closing the hand or rotating the wrist.

These inputs represent the user's intention and are connected to the Arduino UNO's analog or digital input pins.

2. Processing and Control Unit (Arduino UNO)

At the heart of the architecture lies the Arduino UNO, an ATmega328Pbased microcontroller, responsible for processing the sensor inputs and generating control signals for servo motors.

Key functions of this unit include:

Reading and interpreting analog/digital signals from sensors.

Mapping sensor values to appropriate servo angles.

Communicating with the PCA9685 servo driver module via I2C (SCL and SDA) protocol.

Running programmed logic that ensures coordinated movement across multiple joints (fingers, wrist, elbow).

The Arduino uses libraries such as `Wire.h` for I2C communication and `Adafruit_PWMServoDriver.h` to control PWM output through the PCA9685.

3. Actuation Layer (Servo Motors + PCA9685)

This layer includes:

PCA9685 PWM Driver Module: A 16channel 12bit PWM controller, connected to Arduino through I2C. It allows the control of multiple servo motors with high resolution and stability, overcoming the limited PWM pins on the Arduino UNO.

Servo Motors: Each servo motor is mapped to a specific movement:

Micro Servos (SG90/MG90): For finger articulation.

High Torque Servos (MG996R): For wrist rotation and elbow bending.

The PCA9685 receives control signals from Arduino and generates the corresponding PWM signals to drive the servo motors.

4. Power Supply Unit

Servo motors require more current than the Arduino can supply. Hence, a dedicated power source (e.g., a 6V or 7.4V Liion battery pack) is used to power the servos and PCA9685. Arduino is powered via USB or the same battery (through a voltage regulator if needed). Proper grounding and current management are ensured to prevent power surges or motor stalls.

Data Flow Summary

1. User Input → Flex/EMG sensor generates signals.
2. Arduino UNO reads signals → computes angles → sends I2C command.
3. PCA9685 receives command → outputs PWM signals.
4. Servos move accordingly → Arm performs action.

CONCLUSION

The development of a prosthetic arm using servo motors, the PCA9685 driver, and the Arduino UNO microcontroller offers a promising, low-cost, and scalable solution for individuals suffering from upper limb disabilities. This project successfully demonstrates how modern open-source electronics and affordable hardware components can be combined to create a functional assistive device that replicates basic human arm movements. The overall design addresses key challenges in prosthetic technology, including affordability, ease of control, modularity, and adaptability, particularly for users in resource-constrained environments.

By leveraging servo motors for joint articulation and finger movements, the prosthetic arm is capable of performing essential tasks such as gripping, lifting, rotating, and releasing objects. These functions significantly enhance the independence of the user in performing day-to-day activities. The PCA9685 servo driver enables the simultaneous and precise control of multiple servo motors without overloading the Arduino UNO's limited PWM pins. This expands the flexibility of the system, allowing more complex movements and additional degrees of freedom, which are essential for creating realistic and effective prosthetic limbs.

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