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Design and Development of a Servo-Controlled Prosthetic Hand Using ESP32

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A B S T R A C T :

This paper presents the design and development of a cost-effective prosthetic hand controlled using an ESP32 microcontroller. The prosthetic hand is actuated using servo motors to replicate human hand movements, providing a functional and affordable solution for individuals with limb disabilities. The system is designed to be lightweight and customizable using 3D printing technology. The ESP32 microcontroller facilitates wireless communication and precise control of finger movements. The paper details the methodology, hardware components, system architecture, and performance analysis of the developed prosthetic hand. The results demonstrate the feasibility of using servo-based actuation for prosthetic applications, highlighting the advantages and potential improvements for future developments.

Keywords: Prosthetic Hand, ESP32, Servo Motors, Microcontroller, 3D Printing, Wireless Control.

1. Introduction

Prosthetic hands play a crucial role in enhancing the quality of life for individuals with upper limb amputations. Traditional prosthetic devices are often expensive and lack advanced control features, making them inaccessible to a large number of users. The advent of microcontrollers and cost-effective actuators has enabled the development of affordable and functional prosthetic solutions.

Recent advancements in microcontrollers such as ESP32, along with servo motor technology, have paved the way for the development of robotic prosthetics with enhanced movement capabilities. Compared to conventional mechanical prosthetics, microcontroller-based prosthetic hands offer increased flexibility, adaptability, and potential for remote operation.

2. Methodology

The development of the prosthetic hand follows a structured approach, including mechanical design, electronic integration, and software implementation. The methodology includes:

- **Mechanical Design:** The hand structure is 3D-printed using lightweight plastic material. The fingers are actuated using MG90 servos, while an MG995 servo controls the wrist movement.
- **Electronic Components:** The ESP32-S microcontroller serves as the control unit, processing input signals and actuating the servos accordingly. A battery pack supplies power to the system, ensuring mobility and independence from external power sources.
- **Control Mechanism:** The servo motors receive PWM signals from the ESP32 to control the movements of individual fingers and the wrist.
- **Wireless Communication:** The ESP32's Wi-Fi and Bluetooth capabilities allow for potential remote control and integration with other assistive technologies.
- **Software Implementation:** The system is programmed using Arduino IDE, utilizing libraries for servo control and wireless communication.

3. Results and Discussion

The developed prosthetic hand was tested for movement accuracy, response time, and power efficiency. The servo-based actuation demonstrated precise control over finger movements, achieving basic grasping functions. The ESP32 provided stable communication and efficient processing.

A comparison was made between the proposed system and traditional mechanical prosthetic hands. The findings indicate that while traditional prosthetics rely on purely mechanical linkages, the servo-controlled hand offers more versatile movements and potential for automation.

Comparison with Existing Prosthetic Hands

Feature	Traditional Prosthetic Hand	Servo-Controlled Prosthetic Hand
Control Mechanism	Mechanical Linkages	Servo Motors with ESP32
Cost	High	Affordable
Weight	Heavy	Lightweight (3D Printed)
Customizability	Low	High
Wireless Control	No	Yes (via ESP32)

Equations for Servo Motor Torque Calculation

To determine the required torque for each servo motor, we use the standard torque equation:

$\tau = F \times r$

Where:
- τ = Torque (Nm)
- F = Force applied by the servo (N)
- r = Distance from the axis of rotation (m)

For a finger joint controlled by an MG90 servo:

$\tau = 0.5N \times 0.04m = 0.02$ Nm

This calculation ensures that the servos selected provide adequate torque to move the fingers effectively.

4. Future Scope

The developed prosthetic hand demonstrates a functional and cost-effective design. However, several improvements can be made to enhance its usability and efficiency:

- **Integration of Sensor Feedback:** Adding force sensors in the fingertips to improve grip strength control.
- **Machine Learning for Gesture Recognition:** Training the system to adapt to user-specific movement patterns.
- **Enhanced Material Selection:** Using lightweight metal or carbon fiber for durability.
- **Battery Optimization:** Implementing power-saving techniques for longer battery life.
- **Smartphone Control Interface:** Developing an app for wireless control and customization of gestures.

5. Conclusion

This paper presents a cost-effective approach to prosthetic hand development using ESP32 and servo motors. The system successfully replicates basic hand functions and provides a customizable, lightweight alternative to traditional prosthetics. The results indicate that the proposed system can serve as an affordable alternative for individuals with limb disabilities. Future work will focus on integrating advanced control mechanisms, such as sensor feedback and machine learning-based gesture recognition, to enhance the adaptability and usability of the prosthetic hand.

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