Design and Simulation of a Low-Cost, 3D-Printed Upper Limb Prosthetic Using EMG Sensors and ML

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Abstract

Globally, over 30 million individuals require prosthetic devices, but only 10% have access due to high costs and limited availability. Upper-limb amputees face loss of autonomy and psychological distress. While myoelectric prosthetics offer sophisticated control, their cost ($3,000–$50,000) limits accessibility, especially in low and middle-income countries. Low-cost prosthetics are essential for restoring motor function, enhancing well-being, and enabling socio-economic participation.

This project focuses on the **design and virtual simulation of an affordable, 3D-printed prosthetic arm** controlled via surface EMG (sEMG) signals and enhanced with machine learning (ML) for intuitive hand movement.

Objectives

1. Develop a **mechanically strong, modular arm** using PETG and ABS materials.
2. Implement an **EMG-based control system** capable of differentiating multiple grip modes.
3. Analyze performance using **finite-element and control-system simulations**.

Approach

- The **mechanical hand** is five-fingered and anthropomorphic, with phalangeal segments connected by tendon systems driven by RC servos. PETG is used for flexible components (finger joints) and ABS for rigid components (palm base, wrist connector). The modular socket houses electronics and allows easy maintenance.

- **Signal acquisition:** sEMG sensors capture muscle activity from forearm flexor and extensor muscles. Signals are band-pass filtered (20–450 Hz), rectified, and smoothed using RMS.

- **Feature extraction:** From 200 ms signal windows, features like **Mean Absolute Value (MAV), Waveform Length (WL), and Median Frequency (MF)** are extracted.

- **Machine learning:** An **LDA classifier** maps processed EMG signals to hand movements: rest, full grasp, and pinch grip. Servo motors actuate tendons to achieve the desired grip.

- **Simulation:** The mechanical design and control system are evaluated via finite-element and control-system simulations to ensure performance and reliability.

Progress and Next Steps

- **Completed:** Mechanical design of the hand and socket, tendon-driven actuation model, sEMG signal preprocessing pipeline, and classifier setup. CAD modeling and initial simulation frameworks are in place.

- **Ongoing:** Finite-element analysis of the mechanical components, testing the ML-based control system in simulation.

- **To be done:** Finalize simulation results, refine the mechanical design, 3D-print optimized components, integrate EMG control with physical prototype, and validate performance through testing.