Design and Control of a Low‑Cost EMG‑Controlled Prosthetic Arm

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**Abstract**

This project presents the design, implementation, and evaluation of a cost‑effective prosthetic hand controlled by surface electromyography (sEMG). By leveraging an Arduino Nano, a single‑channel EMG sensor kit, five hobby‑grade servos, and a 3D‑printed mechanical hand, we achieve real‑time open/close control based on forearm muscle activity. The system emphasizes affordability, simplicity, and user‑friendliness, making it suitable for educational purposes and low‑income settings. Performance tests demonstrate reliable control (> 94% accuracy) with < 0.6 s latency and multi‑hour battery life on a 2,200 mAh pack.

**Introduction & Literature Review**

**Introduction**  
Limb loss affects millions worldwide, yet high‑end myoelectric prostheses remain prohibitively expensive (USD 5,000–50,000). This gap motivates a low‑cost alternative that translates residual‑limb EMG signals into prosthetic motion. Our design uses surface electrodes placed on the forearm to detect two primary gestures—hand open and hand close—which are interpreted by an Arduino Nano and mapped to five servo motors for synchronous finger movement. The mechanical hand is 3D‑printed from biodegradable PLA, and a buck converter ensures stable 5 V power from a 12 V source.

**Objectives:**

1. Capture and condition EMG signals reliably.
2. Implement on‑board threshold logic with latency < 200 µs.
3. Drive five‑DOF finger motion in real time with minimal hardware cost.

**Literature Review**

* **sEMG Fundamentals:** Measures muscle electrical activity (10–500 µV) non‑invasively; requires amplification and band‑pass filtering (20–500 Hz).
* **Embedded Control:** Arduino Nano offers real‑time 10‑bit ADC and PWM outputs; threshold logic avoids ML complexity while ensuring robust binary control.
* **Actuation:** Hobby servos (5 kg·cm torque) provide sufficient force; previous multi‑channel, ML‑driven systems incur higher cost and complexity.

**System Design**

1. **EMG Sensor Kit & Electrodes**
   * Integrated amplifier and band‑pass filter
   * Three Ag/AgCl electrodes: two on flexor muscles, one ground on a bony landmark
2. **Arduino Nano**
   * ADC sampling at 500 Hz
   * Moving‑average filter (128‑sample window)
   * Dual thresholds (≤ 60 → open; ≥ 80 → close)
   * PWM output at 490 Hz
3. **Servo Motors & Mechanical Hand**
   * Five 4.8–6 V servos mounted in a 3D‑printed PLA assembly
   * String linkages convert servo rotation to finger flexion/extension
4. **Power Supply**
   * 12 V Li‑ion pack stepped down via buck converter to 5 V
5. **Mechanical Housing**
   * Modular PCB and battery mounts for ease of assembly

*A Visio‑created flowchart (600 dpi, Arial Bold, color‑coded) illustrates this signal‑to‑motion loop.*

**Results & Analysis**

* **Signal Quality:** Moving‑average filter yields ~ 90% noise reduction.
* **Response Time:** 0.4–0.6 s from muscle contraction to servo actuation.
* **Accuracy:** 94% correct gesture detection; 6% false triggers due to skin impedance or motion artifacts.
* **Grip Strength:** Adequate for light objects (pens, plastic cups); limited by servo torque.
* **Battery Life:** 3–4 hours continuous operation on a 2,200 mAh pack.

**Challenges:**

* Electrode placement and skin preparation critically affect signal stability.
* Motion artifacts mitigated via re‑calibration and cable strain relief.
* String‑linkage backlash introduced minor repeatability errors (< 5° over 50 cycles).

**Discussion & Conclusion**

**Discussion**

* **Achievements:** Demonstrated a functional, affordable prosthetic hand prototype for basic open/close control.
* **Limitations:** Binary control only; no individual finger articulation or sensory feedback; manual threshold calibration required.
* **Future Work:**
  + Integrate wireless EMG modules for untethered use.
  + Employ multi‑channel EMG with machine‑learning classifiers for richer gesture sets.
  + Add haptic feedback (vibration motors/LEDs) for improved user awareness.
  + Upgrade actuators (e.g., geared DC motors) to enhance grip force and durability.

**Conclusion**  
This work validates that a simple, affordable EMG‑controlled prosthetic hand can deliver reliable, real‑time performance with minimal hardware. It opens pathways for educational kits, humanitarian solutions, and further research into advanced control strategies.

**References**

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