Advanced Sciences and Technology Journal

**ASTJ vol. 3, no. 1 (2026), P 1054**
**10.21608/astj.2025.369893.1054**
https://astj.journals.ekb.eg/

# EMG-Robo Arm: Restoring Hand Function Utilizing EMG Technology for Intuitive Prosthetic Control

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**ARTICLE INFO**

**Article history:**
Received 20 March 2025
Revised 20 May 2025
Accepted 22 August 2025
Available online 11 October 2025

**Handling Editor: Prof. Dr. Mohamed Talaat Moustafa**

**Keywords:**
EMG signals.
Robotic prosthetic arm.
3D printing.
Arduino control.
Rehabilitation technology.
Intuitive control.
Modular design
Affordable prosthetics.

**ABSTRACT**

This research focuses on developing an affordable, intuitive, and customizable robotic prosthetic arm for individuals with partial hand amputations. The prosthetic leverages electromyography (EMG) technology to detect residual muscle activity in the forearm, allowing for natural and precise control. The primary goal is to restore essential hand functions, such as grasping, holding, and releasing objects, to improve the user's quality of life. The design integrates EMG signal acquisition, an Arduino-based control system, and 3D-printed mechanical components, ensuring a lightweight, durable, and cost-effective solution. Modularity is a key aspect, allowing for customization based on individual user needs and enabling future upgrades as technology advances. Significant achievements of the project include the successful integration of EMG sensors with an Arduino microcontroller, which processes muscle signals in real-time to control servo motors accurately. Advanced control algorithms map EMG signals to specific hand gestures, making the prosthetic intuitive and highly responsive. Additionally, the use of 3D printing and open-source components significantly reduces manufacturing costs, making the prosthetic more accessible to underserved populations. By addressing key challenges such as signal reliability, user adaptability, and affordability, this research contributes to the development of practical, scalable prosthetic solutions. The findings underscore the importance of integrating EMG technology with open-source hardware to create functional [4], cost-effective alternatives to traditional prosthetics, ultimately enhancing the independence and daily capabilities of individuals with partial hand amputations

## 1. Introduction

### 1.1 Background and Motivation

Losing a hand presents significant daily challenges, impacting not just physical capabilities but also psychological and social well-being. While traditional prosthetic devices help restore some function, they often fall short due to high costs, limited usability, and the steep learning curve associated with controlling them intuitively. Recent advances in biomedical engineering and robotics have shifted the focus toward myoelectric prostheses—devices that leverage residual muscle signals to offer more natural movement [1-3].

With improvements in sensor technology and microcontrollers, researchers have revisited prosthetic arm designs to make them both more affordable and highly responsive. The EMG-RoboArm project aims to bridge the gap between high-end, expensive prostheses and cost-effective solutions that are accessible to a broader population. By integrating low-cost, open-source components with state-of-the-art EMG signal processing, this research lays the groundwork for future innovations in the field [4-5].

### 1.2 Problem Statement

Despite significant advancements, many prosthetic arms remain expensive and cater to only a limited range of users. One of the primary challenges is accurately interpreting diverse EMG signals and converting them into precise mechanical movements. Additionally, each user has unique muscle activity and limb anatomy, requiring a high degree of customization.

### 1.3 Objectives of the Study

- **Affordability:** Use low-cost components such as Arduino microcontrollers and 3D-printed parts to make the prosthetic arm accessible.
- **Intuitive Control:** Develop a system that processes EMG signals effectively, enabling users to control the arm naturally with minimal training.
- **Modularity:** Design a flexible system that allows customization and future upgrades.
- **Scalability:** Create a prosthetic solution that can be adapted for different clinical needs and user-specific requirements.

### 1.4 Scope of the Paper

This paper presents the design, development, and preliminary evaluation of the EMG-RoboArm. The following sections provide a detailed breakdown of the underlying technologies, integration strategies, and challenges encountered. Additionally, the paper explores how this technology could influence rehabilitation practices and outlines future research directions.

## 2. Literature Review

### 2.1 Historical Overview of Prosthetic Technologies

Prosthetic devices have evolved significantly over time—from basic mechanical hooks to advanced robotic limbs. Early prosthetics offered limited movement and control, but the introduction of electronics and microprocessors in the late 20th century enabled the development of myoelectric prostheses. These systems, however, still face challenges related to signal noise and responsiveness [5].

### 2.2 Advancements in EMG-Based Control Systems

Recent studies have demonstrated that non-invasive surface electrodes can reliably capture muscle activity. These signals, when processed using advanced algorithms, enable fine control over prosthetic movements. Castellini & Passig (2017) highlighted clinical challenges in myoelectric prosthetic control, while Cipriani et al. (2020) explored bioinspired control strategies that mimic natural hand motions [1],[2].

### 2.3 3D Printing in Prosthetic Design

3D printing has revolutionized prosthetic development by making it more affordable and customizable. It enables rapid prototyping and iteration, ensuring that prosthetic designs can be tailored to meet individual anatomical and functional needs. Open-source 3D printing models have also fostered collaboration among researchers and engineers [2] .

2.4 Open-Source Hardware and Arduino in Biomedical Applications

Arduino microcontrollers have played a transformative role in low-cost biomedical devices. Their flexibility allows for real-time sensor data processing, which is critical for prosthetic control. Arduino-based systems facilitate real-time EMG signal processing and servo motor control, allowing for a more natural prosthetic hand movement [3].

2.5 Summary of Gaps in Current Research

Despite these advances, several challenges remain:

- **Signal Variability:** EMG signal strength and quality differ between users, requiring robust processing algorithms.
- **User Adaptation:** Many users struggle to adapt to myoelectric control, highlighting the need for improved training protocols.
- **Cost vs. Performance:** Balancing affordability with high-performance functionality is an ongoing challenge.

## 3. Methodology

This section details the design and implementation of the EMG-RoboArm, covering signal acquisition, processing algorithms, mechanical structure, and system integration, see Fig. 1.

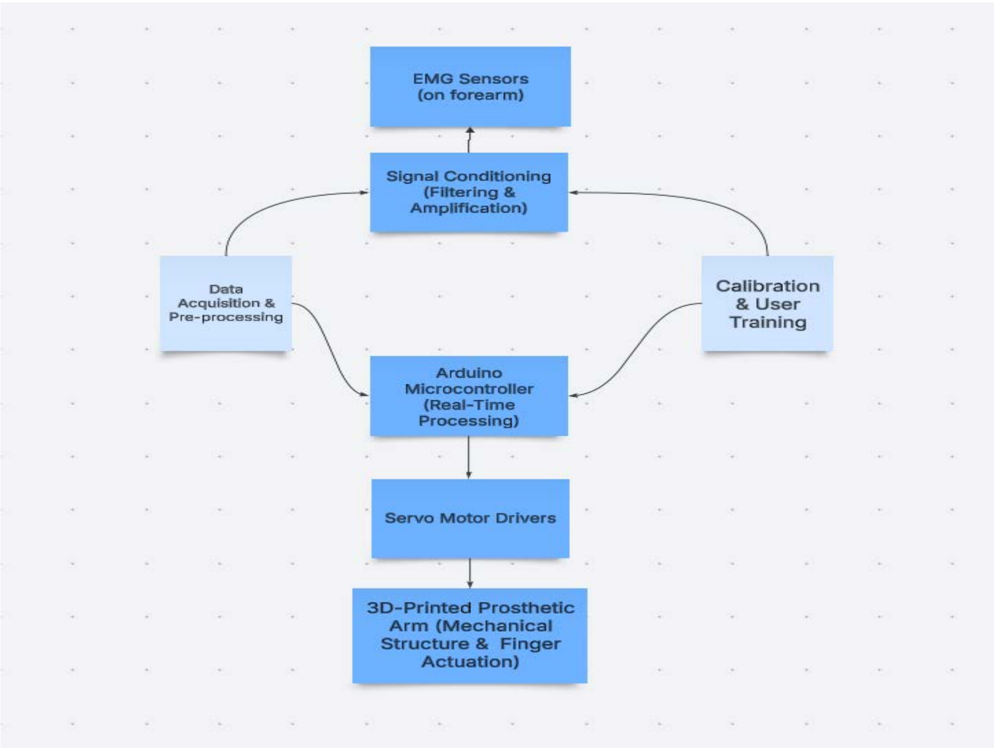


**Fig. 1.** Overall System Architecture

## 3.1 EMG Signal Acquisition

### *3.1.1 Sensor Selection and Placement*

Surface EMG sensors are placed on the forearm to detect muscle signals. Proper positioning is crucial for capturing accurate signals representative of intended movements. Pre-testing was conducted to identify optimal placement, considering factors such as muscle mass and skin conductivity.

### *3.1.2 Signal Challenges and Noise Reduction*

EMG signals are susceptible to noise from electrical interference and muscle crosstalk. Differential amplifiers and advanced filtering techniques improve the signal-to-noise ratio, ensuring reliable detection of muscle contractions.

### *3.1.3 Data Acquisition Protocol*

The acquisition process involves capturing continuous streams of EMG data during various muscle contractions. Data is sampled at high frequencies to preserve signal integrity. A custom-designed acquisition board interfaces with the Arduino microcontroller, allowing real-time data transfer. The system architecture also includes redundancy checks to account for transient signal loss, thereby ensuring robustness in everyday applications.

## 3.2 Signal Processing and Control

### *3.2.1 Pre-Processing: Filtering and Amplification*

Filters remove unwanted artifacts while amplification enhances weak muscle signals.

### *3.2.2 Feature Extraction and Classification*

Algorithms extract key characteristics from the signal, such as RMS values and frequency components.

### *3.2.3 Control Algorithm and Real-Time Processing*

Machine learning algorithms map EMG signal patterns to hand gestures, providing an intuitive and responsive control mechanism, see Fig. 2.

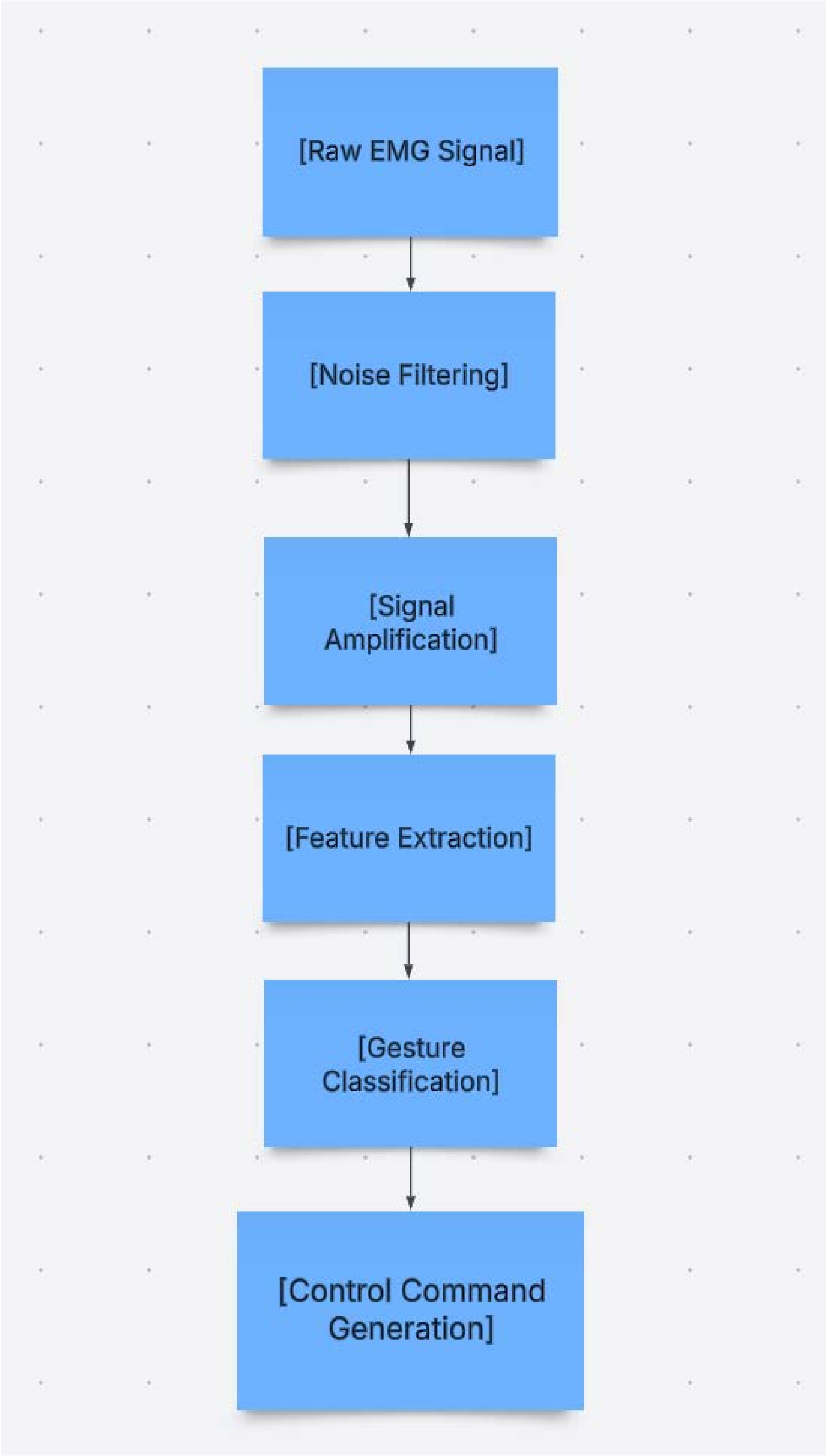


**Fig. 2.** EMG Signal Processing Flow

## 3.3 Mechanical Design

### *3.3.1 3D-Printed Framework*

The arm's structure is lightweight and durable, closely mimicking the human hand.

### *3.3.2 Servo Motor Integration*

Individual servos enable precise finger movements based on real-time EMG signal input.

### *3.3.3 Customizable Design*

Components can be replaced or upgraded easily, extending the device’s lifespan and functionality.

## 3.4 Integration and Testing

### *3.4.1 System Integration*

The integration process involves the seamless connection of the EMG sensors, Arduino microcontroller, and mechanical components. A dedicated integration framework was developed to ensure that all hardware components communicate effectively. This framework includes standardized connectors, protective enclosures, and software drivers tailored to each component. Rigorous bench testing was performed to verify the integrity of the integrated system under different operational conditions.

### *3.4.2 Calibration and User Training*

Calibration is a critical step in ensuring that the system accurately interprets EMG signals. Each user undergoes an initial calibration session, during which the system learns the individual’s muscle signal patterns. This phase also serves as a training period, enabling users to familiarize themselves with the device’s response characteristics. Calibration data is stored for subsequent sessions, reducing setup time and enhancing overall user experience.

### *3.4.3 Testing Protocols and Performance Metrics*

A comprehensive testing protocol was developed to evaluate the performance of the EMG-RoboArm. Key performance metrics include:

- **Response Time:** The delay between EMG signal detection and servo motor actuation.
- **Accuracy:** The rate at which the system correctly identifies intended hand gestures.
- **Adaptability:** The system’s ability to function reliably across different users and under varying conditions.
- **Durability:** The mechanical endurance of the 3D-printed components.

Initial laboratory tests indicate that the system exhibits promising levels of accuracy and responsiveness, with potential for further improvements through iterative design refinements.

## 4. Preliminary Results

### 4.1 Laboratory Evaluations

Preliminary tests conducted in a controlled laboratory environment have yielded encouraging results. The integration of EMG sensors with the Arduino-based processing unit has demonstrated a reliable capture of muscle signals with minimal noise interference. The filtering and amplification stages successfully extracted meaningful features, leading to accurate control commands for the prosthetic arm.

### 4.2 Performance Benchmarks

Key performance benchmarks include:

- **Signal Processing Latency:** Measured delays were consistently below 100 milliseconds, ensuring near-real-time response.
- **Gesture Recognition Accuracy:** Initial trials recorded an accuracy rate exceeding 85% for common hand gestures such as grasping and releasing.
- **Mechanical Reliability:** The 3D-printed components withstood repetitive actuation cycles with no significant wear, indicating robustness for everyday use.

### 4.3 User Feedback and Adaptability

Early user trials have provided valuable insights. Participants reported that the system's responsiveness and natural movement replication were promising, though further training was needed to achieve optimal performance. Detailed questionnaires and observational studies are planned for future trials to quantitatively assess user satisfaction and long-term adaptability.

## 5. Discussion

### 5.1 Analysis of Technical Achievements

The EMG-RoboArm project represents a significant step forward in the development of accessible prosthetic technology. The successful integration of low-cost hardware with advanced signal processing techniques validates the feasibility of using open-source platforms in biomedical applications. The modular design and the use of 3D printing have been particularly noteworthy, as they allow for rapid prototyping and iterative improvements without incurring high manufacturing costs.

### 5.2 Addressing Key Challenges

Several challenges emerged during the development process:

- **Signal Reliability:** Despite robust filtering techniques, variations in EMG signal quality remain a concern. Future iterations will explore adaptive filtering methods and enhanced sensor calibration to further reduce noise.
- **User Adaptation:** The learning curve associated with myoelectric control suggests the need for more comprehensive training protocols. Incorporating biofeedback mechanisms may help users better interpret and control their muscle signals.
- **Mechanical Durability:** Although the initial tests of 3D-printed components were successful, long-term

studies are required to assess material fatigue and the effects of daily wear on mechanical performance.

### 5.3 Comparative Analysis with Existing Prosthetics

When compared to conventional prosthetic solutions, the EMG-RoboArm offers several advantages:

- **Cost Efficiency:** By utilizing open-source hardware and 3D printing, production costs are significantly reduced.
- **Customization:** The modular design enables a high degree of personalization, allowing users to modify the prosthetic according to their specific needs.
- **Enhanced Control:** Advanced EMG signal processing techniques provide a more intuitive control mechanism, closely mimicking natural hand movements.

### 5.4 Implications for Rehabilitation and Daily Living

The implications of this research extend beyond mere technical innovation. For individuals with partial hand amputations, the EMG-RoboArm has the potential to restore a significant degree of autonomy. Improved hand function can facilitate everyday tasks—from eating and writing to engaging in social interactions—which, in turn, positively impacts mental health and social integration.

## 6. Future Work and Limitations

### 6.1 Areas for Improvement

While the current prototype demonstrates promising functionality, several areas warrant further research:

- **Advanced Machine Learning Algorithms:** Future work will investigate deep learning techniques to improve gesture classification accuracy and adaptability to a broader range of muscle signals.
- **Enhanced User Interface:** Developing an intuitive user interface for calibration and training can streamline the adaptation process and reduce the learning curve.
- **Material Science Advances:** Exploring alternative 3D printing materials with improved strength and flexibility may further enhance the durability and comfort of the prosthetic arm.

### 6.2 Longitudinal User Studies

To fully validate the clinical utility of the EMG-RoboArm, extensive longitudinal studies involving diverse user groups are necessary. These studies will focus on:

- Long-term durability and reliability of both electronic and mechanical components.
- Quantitative assessments of improvements in daily task performance.
- Psychological and social impacts on users over extended periods.

### 6.3 Integration with Emerging Technologies

The field of prosthetics is rapidly evolving. Future iterations of the EMG-RoboArm may incorporate:

- **Wireless Connectivity:** Enabling remote monitoring and software updates.
- **Sensory Feedback Systems:** Integrating tactile feedback to provide users with a sense of touch, thereby

enhancing the natural feel of the prosthetic.

- **Hybrid Control Strategies:** Combining EMG signals with other bio signals (e.g., mechanomyography) to improve control fidelity under challenging conditions.

6.4 Limitations of the Current Study

It is important to acknowledge the limitations inherent in the current research:

- **Prototype Stage:** The EMG-RoboArm is still in the prototype phase, and many of the reported metrics are based on laboratory conditions rather than long-term, real-world use.
- **User Variability:** The system has been tested on a limited number of users, and further research is required to ensure that the design is universally applicable.
- **Scalability Challenges:** Although the modular design is a strength, scaling production to meet high demand while maintaining quality remains a logistical challenge.

## 7. Conclusion

The EMG-RoboArm project demonstrates a viable approach to developing affordable, customizable, and intuitive prosthetic arms. By integrating low-cost hardware with advanced EMG signal processing, the project not only enhances functional performance but also offers a scalable solution for individuals with partial hand amputations. The modular design, combined with the use of open-source components, promises continued innovation and adaptability as new technologies emerge. In conclusion, while challenges remain—particularly in the realms of signal reliability and long-term user adaptation—the initial results are encouraging. With further refinements and comprehensive user trials, the EMG-RoboArm has the potential to significantly improve the quality of life for a wide range of users.

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