Bionic Arm Controlled by EMG Signals

Shikha Mishra[1], Anshul Ambastha[2], Anurag Kaushik[3]
[1]Dept. of Electronics and Communication, Galgotias College of Engineering and Technology, Greater Noida, India
[2,3] Dept. of Electronics and Communication, GCET, Greater Noida, India

***Abstract*—This paper introduces an affordable bionic arm that uses electromyography (EMG) signals to mimic basic hand movements, such as opening and closing a fist. Intended for individuals with upper limb impairments, the system employs EMG sensors to capture muscle activity, an Arduino Uno for signal processing, and servo motors to execute the intended gestures. Essential components include the L298N for voltage conversion, multiple batteries to ensure stable power, and a 3D-printed structure for the mechanical arm. The prototype showcases the feasibility of engineering applications in prosthetics and holds promise for further advancements in biomedical development and real-world implementation.**

***Index Terms*— Bionic Arm, EMG, Arduino, Prosthetics, Servo Motors, Biomedical Engineering**

I. INTRODUCTION

The integration of biomedical signal processing with embedded electronics has significantly advanced the field of prosthetic technology, enabling the development of more responsive and intelligent assistive devices. One notable innovation is the bionic arm—a robotic limb designed to replicate natural hand movements by interpreting biological signals. Unlike traditional prosthetics, which are often purely cosmetic or rely on basic mechanical functionality, bionic arms offer greater adaptability and user control. By utilizing electromyography (EMG) sensors, these systems can detect and analyze muscle activity from residual limbs, providing a more intuitive and seamless interface between the user and the device. This natural interaction enhances the user's ability to perform everyday tasks with greater ease and precision. This paper explores the design and implementation of a cost-effective bionic arm, focusing on the use of EMG signals processed by a microcontroller to control movement. The aim is to demonstrate a practical approach to bio-interfacing for educational and research purposes.

II. RELATED WORK

Multiple projects and research studies have demonstrated the feasibility and effectiveness of using electromyography (EMG) signals for controlling prosthetic limbs. For instance, Open Bionics has pioneered the development of affordable, lightweight 3D-printed prosthetic hands that utilize EMG sensors to detect muscle activity, enabling intuitive and responsive control. In a significant academic contribution, researchers Englehart and Hudgins introduced real-time, multifunctional control of prosthetics using machine learning techniques such as support vector machines (SVM), showcasing the potential for advanced signal processing in prosthetic applications. Additional efforts in the field have focused on improving gesture recognition through sophisticated approaches including signal classification, adaptive filtering, and the integration of various machine learning algorithms. These advancements aim to enhance the precision, reliability, and adaptability of EMG-controlled prosthetics. This project, while inspired by such innovations, adopts a more simplified and cost-effective approach tailored for educational settings, demonstrating core concepts without compromising on functional performance or user interaction.

III. METHODOLOGY

The proposed system consists of several core stages: capturing EMG signals, conditioning the data, processing it through a microcontroller, and driving servo motors for movement. EMG electrodes placed on the user's forearm detect muscle activity during contraction. The raw signals undergo amplification and noise filtering before being sent to an Arduino Uno, which analyzes the input based on predefined thresholds to identify intended actions. Pulse-width modulation (PWM) signals are then generated to control the motion of 3D-printed finger components. A voltage regulator module (L298N) steps down the 12V battery input to a stable 5V required to operate the servos efficiently.

Hardware Components

- EMG Sensor: Captures electrical activity from muscle contractions to serve as input signals.
- Arduino Uno: Acts as the core processing unit. Receives EMG input and controls the servo motors based on signal thresholds.
- Servo Motors: Used to actuate finger joints of the prosthetic arm.
  Compact and lightweight with sufficient torque for finger movements.
- L298N Motor Driver: Regulates power supply. Converts 12V input to a 5V output compatible with servo motors.
- Batteries: Two 9V batteries power the EMG sensors.
  One 12V battery powers the servo motors. Power is isolated between signal processing and actuation to reduce interference.
- 3D-Printed Frame: Designed using CAD software.
  Printed with PLA material for a lightweight yet durable structure.
  Forms the body and mechanical support for the prosthetic arm.

Communication Architecture

1. Hardware Setup:
   a. EMG electrodes placed on user's forearm
   b. Arduino Uno processes EMG input and controls servos
   c. L298N used for voltage regulation
   d. Powered by dedicated battery units for stable operation
2. Processing Flow:
   a. EMG signal captured →

Amplified
→ Threshold logic on Arduino
→ Actuation command sent to servos

Circuit Prototype

The circuit setup includes linking the EMG sensor's output to one of the Arduino Uno's analog input pins. Servo motors are connected to the digital PWM pins for control. To maintain stable sensor readings and ensure sufficient torque for the motors, the power supply is divided—two 9V batteries power the EMG sensors, while a separate 12V battery, regulated through an L298N module, supplies the servos.

Figure 1 illustrates the servo connection schematic: This circuit shows how two servo motors are controlled by an Arduino Uno using PWM signals. A 9V battery supplies power, which is regulated by an L298N module to ensure that the servo motors receive a stable 5V. The signal pins from the Arduino are connected to the servo motor control lines, allowing them to actuate based on the EMG signal interpreted by the microcontroller

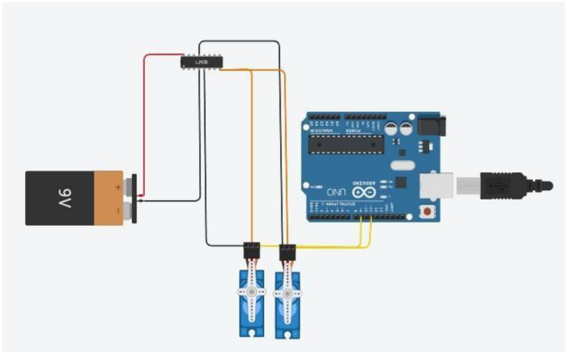


Figure 2 shows the EMG sensor module wiring:

This diagram illustrates how the EMG sensor module is connected to an Arduino Uno. Two 9V batteries are used in series to provide dual-polarity power (+9V and -9V), which is required by the EMG sensor. The sensor captures muscle signals from electrodes placed on the user's forearm.

These signals are then passed to the Arduino's analog input pin for threshold detection and processing, enabling gesture recognition.

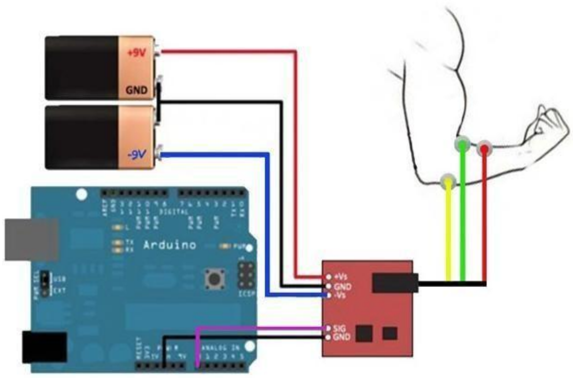
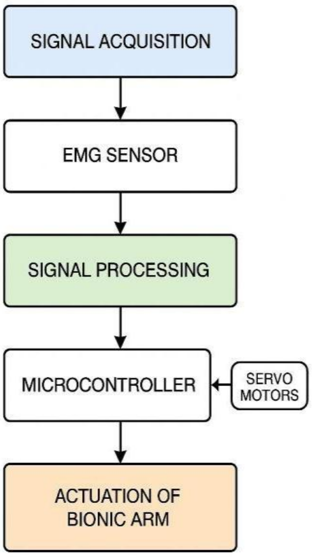


Figure 3 presents the flowchart of the signal-to-actuation process:



IV. DISCUSSION

The project successfully validates the feasibility of using electromyography (EMG) signals for basic prosthetic control, demonstrating that muscle activity can be effectively translated into robotic movement. Despite inherent challenges such as signal noise, muscle fatigue, and variability in sensor placement, the system performs reliably under controlled conditions. EMG signals, captured through surface electrodes, are processed and interpreted by a microcontroller to control the movement of a 3D- printed prosthetic arm. The arm itself is designed to be lightweight, cost-effective, and easily adaptable, making it suitable for experimentation, education, and low-cost prosthetic development.

Currently, the system is configured to support a single motion, serving as a proof of concept for EMG-based control. However, the underlying hardware and software architecture are designed to be modular and scalable. This flexibility allows for future enhancements, including the integration of multiple gesture recognition capabilities and more advanced machine learning algorithms for improved classification accuracy. With additional development, the system can be extended to support complex hand gestures, dynamic grip control, and real- time adaptability to user inputs. Overall, the project highlights the potential of combining biomedical signal processing, embedded systems, and 3D printing in creating functional, affordable, and expandable prosthetic solutions.

V. CONCLUSION AND FUTURE WORK

The creation of this EMG-controlled bionic arm prototype presents a practical and efficient method for translating human muscle signals into mechanical movement. It effectively illustrates how biological signals, processed through microcontroller logic, can enable intuitive operation of prosthetic systems. The design prioritizes low cost, modular construction, and simplicity, making it more accessible to users with upper limb disabilities. By thoughtfully combining signal detection components, servo-based actuation, and power management, the system accurately converts muscle intent into motion. This hands-on project also serves as a valuable educational tool for exploring biomedical technologies.

Looking ahead, the system can be enhanced by integrating machine learning algorithms to support recognition of a wider range of gestures. Adding wireless communication could improve mobility and convenience, while haptic feedback and flexible, ergonomic designs could make the prosthetic more lifelike and user-friendly. Future progress will also depend on clinical evaluation and adapting the device for real-world prosthetic use.

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