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Real Time Robotic Prosthetic Arm Using Arduino

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Abstract: In our society, some people suffer from paralytic diseases that cause them several disabilities like damage to the brain or spinal cord, that can happen in a car accident, fall, or sports injury. An EMG (electromyography) signal is a biomedical signal that measures the electrical activity of muscles. EMG signals are used to study neuromuscular activities and muscle force. Prostheses are artificial replacements that a person can wear instead of a missing body part. Here we are using a robotic arm for a handicapped person. The project is working under the principle of EMG. EMG signals are generated when muscles contract, which creates charged particles in the muscle membrane, and these signals are measured using electrodes placed on the skin. Different types of upper limb exoskeletons are deployed for robotic-based rehabilitation purposes according to the functionality of the robotic devices.

Index Terms - EMG, Arduino, Prosthetic Arm, Servo Motors, PWM.

I. INTRODUCTION

According to the World Health Organization (WHO), a significant portion of the global population lives with physical disabilities, many of whom require prosthetic devices to regain mobility and independence. The loss of an upper limb severely impacts an individual's ability to perform everyday tasks, reducing their quality of life. Traditional prosthetic arms, though mechanically functional, often lack real-time adaptability and intuitive control, making them less practical for many users.

Advancements in bioelectrical signal processing and embedded systems have paved the way for more responsive and user friendly prosthetic solutions. By utilizing electromyographic (EMG) signals electrical signals generated by muscle activity prosthetic arms can be controlled in real-time, allowing for more natural and seamless movement. This project focuses on developing an affordable and efficient robotic prosthetic arm that responds to real-time EMG signals, enabling intuitive hand motions.

The proposed system integrates an EMG muscle sensor with an Arduino microcontroller to control five servo motors that replicate natural hand gestures. This design prioritizes accessibility and customization, ensuring ease of use for individuals with upper limb disabilities. By leveraging open-source hardware, the project offers a cost-effective and adaptable alternative to conventional prosthetic technologies. Furthermore, the modular nature of the robotic arm allows for future enhancements and personalization, making it a scalable solution for diverse user needs.

II. REVIEW OF LITERATURE

J. Wang et al. [1] offers a comprehensive overview of electromyography (EMG)-based motor brain-computer interfaces (BCIs) specifically designed for upper limb movement. It highlights the potential of motor BCIs to decode voluntary movement intentions from brain signals, providing critical applications in neurorehabilitation and daily life assistance for individuals with motor impairments.
Fu et al. [2] compare the effectiveness of wrist and forearm EMG signals for multi-day biometric authentication, addressing challenges related to signal stability, user variability, and long-term reliability. Previous research in this field has explored various
physiological signals, such as EEG, ECG, and EMG, for authentication, with EMG showing promise due to its uniqueness and difficulty in replication.
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A. Schwarz et al. [4], the authors focus on decoding natural reach-and-grasp actions using human EEG signals. This study explores how brain activity related to complex motor tasks, such as reaching and grasping, can be decoded to control external devices in real-time.
Karen Lemmel-V´elez et al. [5] ,the paper presents the design of a robotic hand controlled by electromyography (EMG) signals, aimed at providing a functional and cost-effective prosthetic solution for people with disabilities.
Raju Ahmed et al. [6] ,discusses the design and implementation of a prosthetic arm control system utilizing electromyography (EMG) signals. The authors focus on the use of EMG signals, which are generated by muscle contractions, to control the movement of a prosthetic arm.

Collectively, these reviews underscore the promising potential of EEG-based motor BCIs for assisting individuals with motor impairments, particularly through neurorehabilitation and prosthetic control. The studies reveal that BCIs can decode complex, voluntary motor intentions by harnessing neural signals related to motor imagery, motor execution, and specific hand movements.

III. METHODOLOGY

The system is designed to control a robotic arm in real time through EMG Signals, with Arduino as the central microcontroller. The block diagram for this system includes key components such as the Arduino microcontroller, EMG Sensors, and Servo motors. The Arduino receives input signals, processes them, and sends control commands to the motors, which then control the servo motors to move the robotic arm.

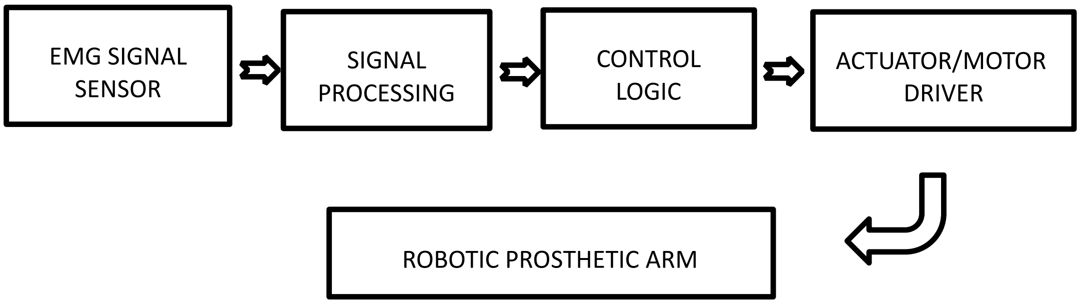

Figure 3.1: Block Diagram of Real-Time Robotic Prosthetic Arm Using Arduino.

The block diagram of the 'Real-Time Robotic Prosthetic Arm Using Arduino' shown in Figure 3.1 provides a visual representation of the system's key components and their interactions. It illustrates how signals from an EMG Sensor are processed by the Arduino microcontroller, which then sends control commands to the servo motors. These motors actuate the fingers of the prosthetic arm, allowing it to perform real-time movements based on input.

This project is divided into two main sections: signal acquisition and processing, and robotic arm control. The EMG signals are collected from the upper arm using an EMG muscle sensor with three electrodes. These signals are sent to an Arduino UNO, which processes the data to identify the muscle activity patterns. The Arduino determines the maximum and minimum signal values that correspond to hand movements. Once the signals are analysed, the microcontroller generates pulse width modulation (PWM) signals that control five servo motors, each corresponding to a finger in the prosthetic hand. The servos manipulate a 3D-printed hand structure, enabling open and closed movements. The power supply for the servos is regulated using a buck converter to ensure stable operation. This system effectively translates muscle activity into hand movements, making it an intuitive and efficient solution for individuals with limb impairments.

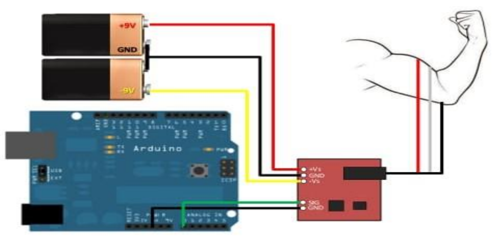

Fig..3.2: Sensor connection with Arduino

Fig. 3.2 illustrates the setup for interfacing a biomedical sensor (such as an EMG sensor) with an Arduino microcontroller using two 9V batteries. The batteries are connected in series to provide +9V, GND, and -9V for powering the sensor. The sensor's output signal (SIG) is fed into the Arduino for processing, enabling muscle activity detection. Proper electrode placement on the muscle ensures accurate signal acquisition.

The Fig..3.3 illustrates the transformation of a raw EMG signal into a rectified and smoothed form for better processing. The raw EMG signal consists of alternating positive and negative oscillations, making direct analysis difficult. Full-wave rectification inverts the negative portion, ensuring all values are positive while preserving frequency components. Finally, smoothing applies a low-pass filter to create a stable signal suitable for microcontroller processing. This refined signal is essential for applications in prosthetics, robotics, and biomedical diagnostics, enabling accurate muscle activity monitoring.

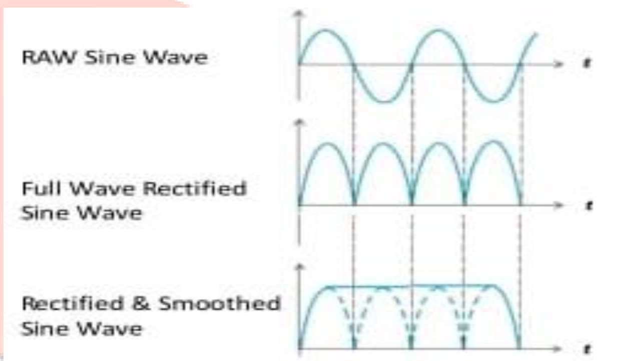

Fig.3.3: Raw EMG Signal

IV. WORKING AND SIMULATION

The project focuses on designing and implementing a real time robotic prosthetic arm controlled using electromyography (EMG) signals. The system captures muscle activity through EMG sensors placed on the user's arm muscles. These signals are then processed and interpreted by an Arduino microcontroller, which sends control commands to servo motors that drive the movements of the prosthetic arm.

Signal Acquisition – EMG sensors detect electrical activity generated by muscle contractions and transmit it to the Arduino for processing. The system begins by detecting electrical signals generated by muscle contractions using EMG sensors. These sensors consist of electrodes placed on the skin over specific muscles in the forearm. When the user thinks about moving their hand (for example, making a fist or opening their fingers), the muscles generate bioelectric signals that are captured by the EMG sensor. The raw signals are very weak (in microvolts), so they must be amplified and filtered to remove noise before further processing.
Signal Processing – The Arduino filters and interprets the signals to determine the user's intended movement. The processed EMG signals are sent to the Arduino microcontroller, which acts as the brain of the system. The Arduino reads these signals through analog-to-digital conversion (ADC) and determines what action the user intends to perform.
Real Time Control – Seamless User Interaction the entire system operates in real time, meaning the prosthetic arm moves almost instantly in response to the user's muscle activity by comparing with the preset values already taken.
Motor Actuation – Based on the processed signals, the Arduino generates Pulse Width Modulation (PWM) signals to control servo motors, enabling hand and finger movements. Real-Time Control – The prosthetic arm responds dynamically to user inputs, allowing for natural and intuitive movement.

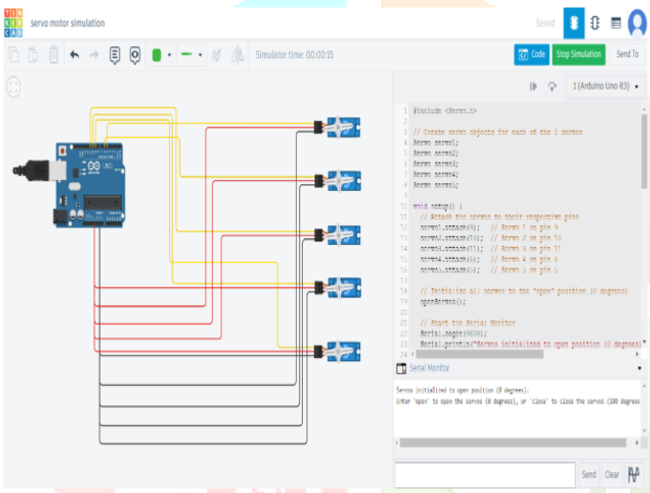

Fig. 4.1: Open position of servo motors

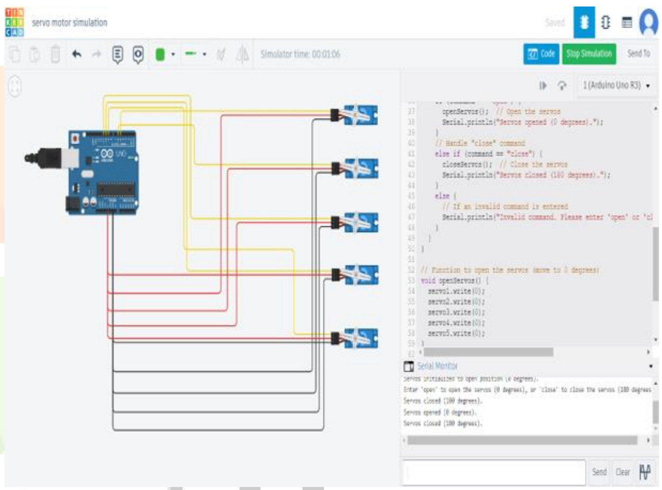

Fig 4.2: Close position of servo motors

During the simulation, Figure 4.1 and Figure 4.2 shows the Arduino sends Pulse Width Modulation (PWM) signals to the servos, commanding them to execute the programmed movements. For example, one servo motor moves the elbow joint from 0 to 90 degrees to simulate raising the arm, while another motor controls the hand, opening and closing it by adjusting between 0 and 90 degrees. The Tinker cad simulation successfully demonstrates the real-time interaction between the Arduino and the servo motors, validating the control logic and ensuring the feasibility of the system for practical application in prosthetic arm prototypes. This model allows for easy modifications and testing of the movements before moving forward with physical implementation

V. RESULTS AND DISCUSSION

The developed robotic prosthetic arm successfully responded to real-time EMG signals, demonstrating effective signal acquisition and movement control. The system was able to differentiate between muscle contractions and translate them into corresponding hand movements with minimal latency. The Arduino-based control system efficiently managed power distribution using the XL4015 buck converter, ensuring stable operation of the servo motors. The customizable nature of the Arduino platform allowed for easy calibration and adaptation for different users. However, some challenges were noted, such as variations in signal strength across users and potential interference from environmental noise. Future improvements will focus on enhancing signal processing through advanced filtering techniques and integrating machine learning models for better movement prediction and accuracy. Overall, the project demonstrates a cost-effective and practical approach to robotic prosthetics, providing individuals with limb impairments an intuitive and accessible solution for regaining hand functionality.

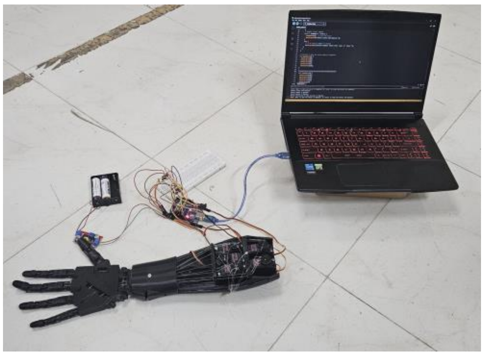

Fig. 5.1 : Hardware implementation

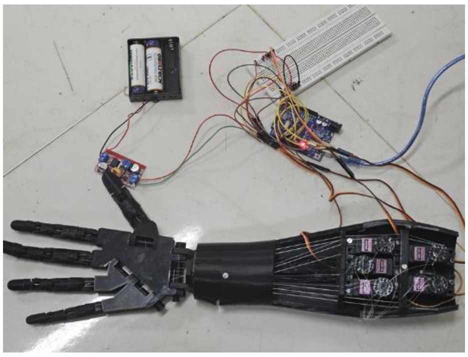

Fig. 5.2 : Open position of hand

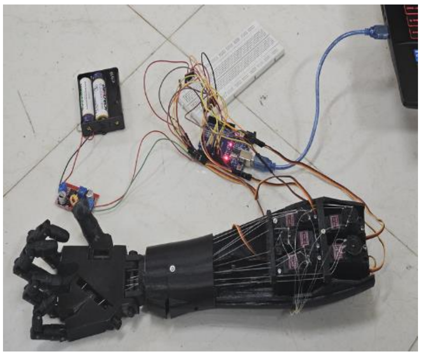

Fig. 5.3 : Close position of hand

Fig. 3, 4, and 5 illustrate the hardware implementation of the project. One shows the open position and the other shows the close position.

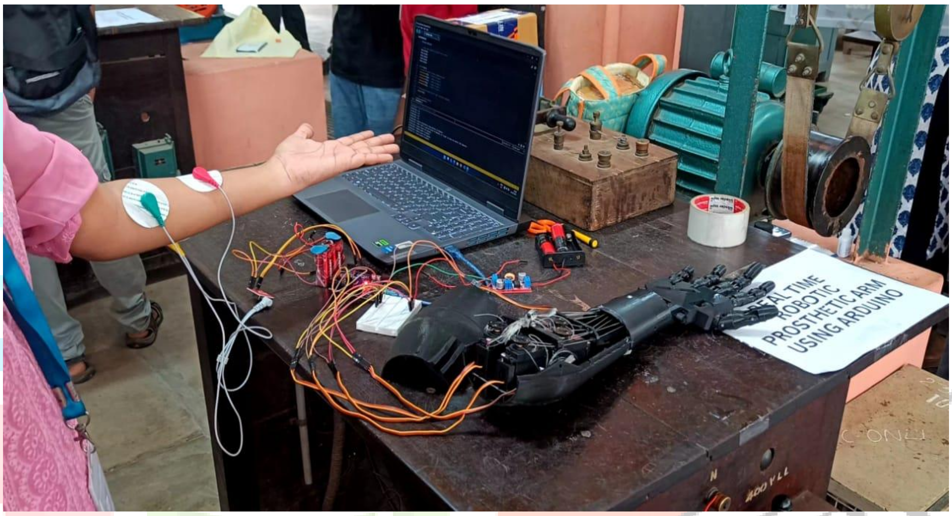

Fig. 5.4 Prototype of the project

The above figure 5.4 shows the overall hardware implementation of the project. The real time signal from the muscles are compared with the preset values within the Arduino and generates PWM signals for the servo motor actuation

VI. CONCLUSION

The project demonstrates the feasibility of a cost-effective, real-time controlled robotic prosthetic arm using EMG signals and Arduino-based control. By integrating bioelectrical signal processing with servo-driven actuation, the system provides a functional and intuitive solution for individuals with upper limb disabilities. The prosthetic arm successfully translates muscle activity into precise hand movements, enhancing usability and accessibility.

The modular and open-source nature of the design allows for future improvements, such as enhanced signal processing algorithms, wireless connectivity, and the integration of machine learning for adaptive control. With further development, this technology has the potential to significantly improve the quality of life for amputees by offering a more natural and responsive prosthetic solution.

Future work will focus on refining the accuracy of EMG signal interpretation, optimizing power efficiency, and expanding the range of hand gestures. The ultimate goal is to create an advanced yet affordable prosthetic arm that closely mimics human hand functionality, empowering users with greater independence and mobility.

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