

Design and Development of Robotic Arm using EMG Sensor

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Abstract—Designing and implementing a robotic hand utilizing electromyography (EMG) is associated with developing a prosthetic device which can be controlled via muscle electrical signals. The aim of this project is to obtain EMG signals from residual limbs using surface electrodes placed on functional muscle groups. Such signals undergo amplification, filtration, and further processing to yield distinct features indicative of muscle activity. A control algorithm is designed to interpret these features and subsequently translate them into commands meant for the robotic hand. Machine learning and pattern recognition approaches are used to associate defined sets of EMG signals to predetermined movements of the hand. The fingers, joints, and tendons of the robotic hand are constructed in such a way that allows for dexterous motion and gripping capability which enable it to mimic the structure and functionality of a human hand. Usually, the prototype is made through 3D printing as it is the most cost-effective method. Users EMG signals calibration is performed to ensure optimum mapping with the specific movements of the hand they wish to control. Continuous testing of the system is done to improve precision, responsiveness, comfort, and general user experience. This technology is incredibly useful in regions where economic resources limit access to commercial prosthetics. For instance, Ecuador is one of those countries where a considerable part of the population suffers from amputation of limbs. They truly lack the financial resources to afford even prosthetic limbs that are sold on the market. This project aims to aid these people with upper limb loss by restoring their mobility and independence through low-cost hardware, 3D printing, EMG technology, and affordable, ultrasound-based control devices.

Index Terms—EMG, prosthetics, robotic hand, Arduino, pattern recognition, motor control.

I. INTRODUCTION

The advancements in robotics to assistive technologies and in prosthetic limbs are at a new height. One of the specially robotic hands that is controlled using EMG signals is considered a

milestone in assistive robotic technologies to attain milestones on the controller with the upper limb robotics. EMG systems are an innovation for those amputees suffering from forearm amputation and partial hand amputation. The methods dealing with application of electric impulses to muscles offer means for augmenting the ability to recover movement, manual dexterity, and fingertip movements in people with limb absence using flexible robotic devices.

Physical disability and loss of upper limbs often hinders mobility and other important division of labor save 39 work especially for men. Its is estimated around 220,000 people are suffering with the issue in India. The use of robotic limbs can give them back the independence and the self-care many people take for granted towards a much more efficient life. Recent motivating works have been reported for handicapped people due to development in finance and control becomes via EMG signal which is relatively new for robotic prosthesis foundation. Start with the recognition or objective of the automated general virtual devices to multitask people with a with a robotic hand functions for performing various tasks. EMG electrodes enable micrometric head transducers to achieve higher sculpturing and manufacturing needed limbs.

Electromyography (EMG) signals obtained from the fore-arm muscles are utilized to operate servo motors integrated within the prosthetic hand. These signals, derived from the contractions and relaxations of muscles, provide critical information regarding the desired movements of the hand. This initiative aims to leverage EMG signals from the human forearm to facilitate the motion of a robotic hand through servo motors. Specifically, three electrodes are strategically positioned over selected forearm muscles that govern finger movements, allowing the robotic hand to replicate natural hand gestures. Since EMG signals are generated by the neuromuscular system, they yield vital insights into

a person’s intended actions. When accurately processed, these signals enable robotic hands to execute movements that closely resemble natural hand actions, thereby significantly improving the quality of life for users by allowing them to perform tasks that were previously challenging or unfeasible. The fundamental principle of EMG-based control involves placing electrodes on the skin’s surface to detect electrical variations caused by muscle activity. These signals are subsequently processed and converted into control commands through signal processing and machine learning techniques, which interpret the user’s intentions with remarkable accuracy. A key benefit of EMG control is its non-invasive characteristic. In contrast to invasive systems that necessitate surgical implantation, surface EMG electrodes are simple to apply and remove, rendering them practical and user-friendly. Additionally, EMG control systems can handle multiple degrees of freedom, facilitating more accurate and fluid movements of the robotic hand. Education refers to the process through which an individual either learns or imparts knowledge to someone else. It also serves as a platform for individuals to cultivate vital skills necessary for understanding social norms. Nevertheless, the primary objective of education is to enable individuals to lead a fulfilling life and make meaningful contributions to society as they mature. Various forms of education exist, but conventional schooling significantly influences how we assess an individual’s success. In addition to this, education plays a crucial role in alleviating poverty and offering individuals the opportunity to achieve improved lifestyles. It’s important to recognize that this is one of the main reasons parents endeavor to provide their children with prolonged educational opportunities. Education is essential for everyone as it facilitates a more enriched life with numerous advantages. It enhances one’s communication abilities by teaching reading, writing, speaking, and listening skills. Furthermore, it equips individuals to meet basic job qualifications, allowing them to attain better employment with greater ease. An educated populace is also instrumental in fostering a nation’s economic development. Nations boasting the highest levels of literacy tend to experience favorable advancements in both human and economic growth. Thus, acquiring education is vital for all individuals to maintain a healthy and harmonious existence.

II. METHODOLOGY

The proposed prosthetic hand system integrates an Arduino UNO microcontroller, a regulated power supply, four MG995 servo motors, and one SG90 servo motor. The Arduino UNO is selected for its versatility in reading various inputs, such as sensor data, button presses, and controlling outputs like motors and LEDs, making it suitable for this application. The MG995 servo motors are chosen for their low-speed, high-precision positioning capabilities, essential for replicating human hand movements accurately. Each servo motor features three wires: one for power, one for ground, and one for control signals.

The system employs electromyography (EMG) sensors to detect electrical signals generated by muscle contractions in the user’s forearm. These signals are amplified, filtered to remove noise, and then processed by the Arduino UNO. Based on the processed EMG signals, the Arduino generates pulse-width modulation (PWM) signals to control the servo motors, enabling the prosthetic hand to perform actions such as opening, closing, and grasping objects.

The design aims to create a cost-effective, lightweight, and user-friendly prosthetic hand that closely mimics the functionality of a natural human hand. The use of 3D-printed components contributes to the lightweight nature of the device, enhancing user comfort and mobility. Additionally,

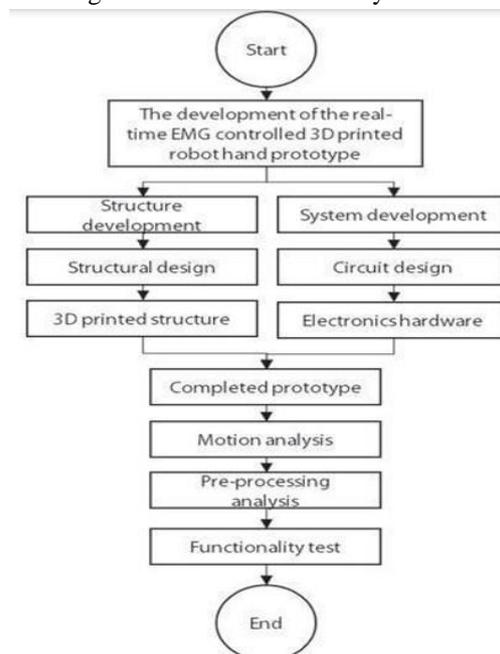


Fig. 1. Work flow

the system's modular design allows for customization and potential future enhancements, such as wireless control via cloud or Wi-Fi connectivity. By focusing on affordability and functionality, this prosthetic hand design seeks to provide an accessible solution for individuals who have lost a hand or have a paralyzed hand, improving their ability to perform daily tasks with greater ease and independence.

A. Hardware Component

Arduino UNO: The Arduino Uno is a foundational micro- controller board renowned for its versatility in DIY electron- ics and prototyping. Developed in 2005 as an open-source platform, it simplifies interactive project creation for users of all skill levels. Based on the ATmega328P microcontroller, it features a user-friendly interface and robust community support.

MG90S Servomotor: The MG90S servomotor is a com- pact, high-performance actuator designed for applications re- quiring precise angular motion and reliable torque output. Featuring durable metal gears and a stall torque of up to 11 kg/cm at 6V, it ensures accurate and stable control of joint movement in robotic and prosthetic devices. The motor operates within a voltage range of 4.8V to 6.6V and responds to pulse-width

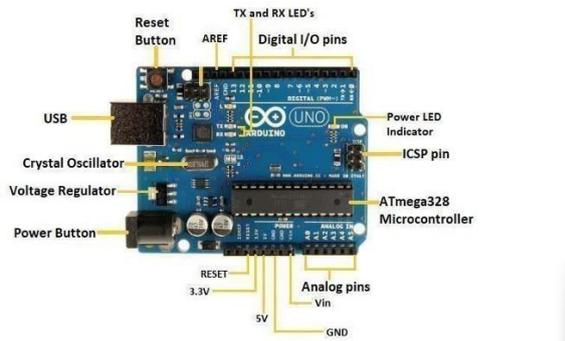


Fig. 2. Arduino UNO

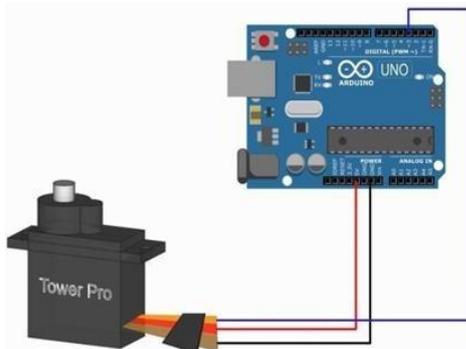


Fig. 3. MG90S Servomotor

modulation (PWM) signals for positioning. With three wire terminals for ground, power, and signal control, the MG90S integrates seamlessly with microcontroller platforms such as the Arduino Uno, making it well-suited for replicating human hand gestures in prosthetic applications.

LCD display module: The 16×2 character LCD display module provides a practical interface for visual feedback and user interaction in embedded systems. Operating within a voltage range of 4.7V to 5.3V, the module supports both 4-bit and 8-bit parallel communication modes. It includes configurable pins for control and data input, including RS (Register Select), RW (Read/Write), E (Enable), and data lines D4–D7 when used in 4-bit mode. A variable resistor connected to the V0 pin allows for contrast adjustment. The LCD enables real-time display of system status, sensor readings, or user prompts, which is particularly useful in prosthetic systems for monitoring EMG signal strength, battery levels, or calibration messages.

EMG sensor: The EMG sensor is a biomedical device engineered to measure electrical signals generated by skeletal muscle contractions. Utilizing surface electrodes placed on the skin, the sensor captures analog voltages that reflect muscle activation levels. With a high-resolution 16-bit output and a bandwidth of 20–500 Hz, the sensor ensures precise detection of neuromuscular activity. The captured signals are amplified and filtered to remove noise, making them suitable for real- time interpretation by microcontrollers such as the Arduino Uno. The EMG sensor serves as the core input mechanism

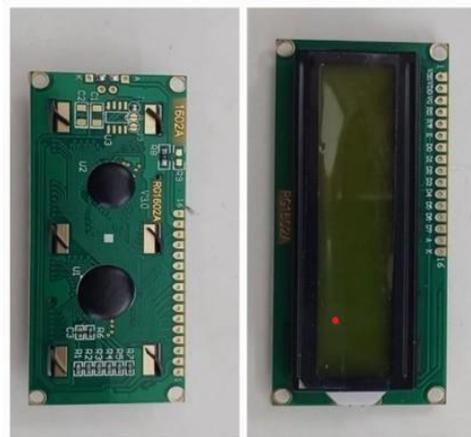


Fig. 4. LCD Display Module



Fig. 5. Emg Sensor

in myoelectric prosthetic systems, enabling intuitive, muscle-driven control of robotic limbs based on the user's intent.

Prosthetic Arm: The prosthetic arm is a 3D-printed, lightweight mechanical structure designed to replicate the form and function of a natural human hand. Engineered for ergonomic comfort and modularity, it incorporates multiple joints and linkages actuated by servomotors to enable realistic finger and thumb movements. The arm responds to EMG signals processed by the control system, translating muscle activity into coordinated actions such as grasping, pinching, and releasing. Its bionic design may also integrate myoelectric feedback mechanisms to adjust grip strength dynamically. By combining affordability, adaptability, and functionality, the prosthetic arm offers a viable solution for individuals seeking enhanced mobility and independence following upper limb loss, which can be processed using microcontrollers like Arduino, Raspberry Pi, or ESP32, among others. As shown in Fig. 6.

B. System Performance and Real-Time Control

Electromyography (EMG) signals obtained from the forearm muscles are utilized to operate servo motors integrated within the prosthetic hand. These signals, derived from the contractions and relaxations of muscles, provide critical information regarding the desired movements of the hand. This initiative aims to leverage EMG signals from the human forearm to facilitate the motion of a robotic hand through

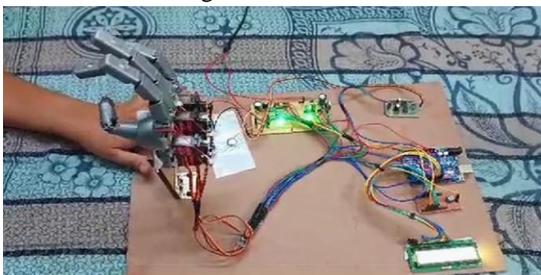


Fig. 6. Arm

servo motors. Specifically, three electrodes are strategically positioned over selected forearm muscles that govern finger movements, allowing the robotic hand to replicate natural hand gestures. Since EMG signals are generated by the neuromuscular system, they yield vital insights into a person's intended actions. When accurately processed, these signals enable robotic hands to execute movements that closely resemble natural hand actions, thereby significantly improving the quality of life for users by allowing them to perform tasks that were previously challenging or unfeasible. The fundamental principle of EMG-based control involves placing electrodes on the skin's surface to detect electrical variations caused by muscle activity. These signals are subsequently processed and converted into control commands through signal processing and machine learning techniques, which interpret the user's intentions with remarkable accuracy. A key benefit of EMG control is its non-invasive characteristic. In contrast to invasive systems that necessitate surgical implantation, surface EMG electrodes are simple to apply and remove, rendering them practical and user-friendly. Additionally, EMG control systems can handle multiple degrees of freedom, facilitating more accurate and fluid movements of the robotic hand.

C. Data Acquisition and Signal Mapping

A novel data-glove was employed to capture forearm muscle stimuli and precise 3D hand postures, with EMG sensors strategically placed at key anatomical locations. The system reliably recorded two-channel EMG signals and complete hand postures, storing the data in a text file for analysis. Hardware and software components for data acquisition performed consistently during testing, validating their efficacy. To translate EMG signals into corresponding hand shapes, a pattern recognition approach was proposed and preliminarily evaluated. Analysis of both raw EMG data and the EMG spectrum revealed encouraging results, though further refinement is necessary to enhance mapping accuracy and reliability for consistent prosthetic control.

D. Prosthetic Hand Design and Actuation

The prosthetic hand's innovative design and actuation system successfully replicated the three primary human hand grips: power, squeeze, and lateral. By spanning a two-region strength space, the

actuation structure demonstrated versatility, effectively balancing underactuated and nearly fully actuated

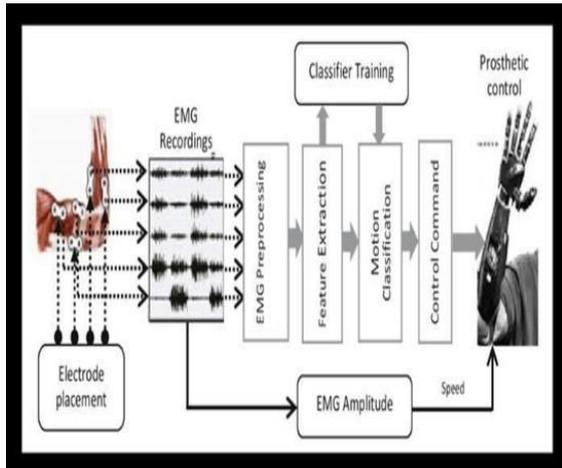


Fig. 7. Working

kinematic configurations within a single system. This design maintained the prosthetic hand's critical size and weight constraints, even when incorporating diverse actuator types. The parallel actuation structure proved to be an effective starting point for prosthetic design, offering flexibility and performance without compromising practicality. These findings highlight the potential of the proposed actuation system as a scalable and adaptable solution for prosthetic applications.

E. System Validation and EMG-Driven Control

Testing confirmed that the prosthetic hand could be effectively driven by EMG signals, with the system accurately translating muscle stimuli into grip configurations. The parallel actuation structure performed reliably across tested scenarios, demonstrating its capacity to execute the intended grips. However, to fully realize the system's potential, expansion of EMG inputs is required to support a wider range of grasps and manipulations. Preliminary tests provided valuable insights into the system's capabilities, but comprehensive evaluation of the actuation system's performance across diverse tasks remains a critical next step.

III. RESULT AND DISCUSSION

The results obtained from testing the IoT-based smart pacifier indicate a high level of accuracy in tracking infant temperature, movement, and breathing rate. The MPU6050 sensor effectively captures positional changes, ensuring that infants remain in safe sleeping postures. As shown in Fig.

12. The microphone condenser successfully differentiates between normal and irregular breathing patterns, allowing for timely alerts in cases.

Since they do not directly measure hand shape, other researchers utilising pattern classifiers for prosthetic hand control have access to a significantly smaller collection of training examples. However, they have documented some degree of success with multichannel EMG data. Multichannel electroencephalographic (EEG, brain wave) analysis has been used in other studies. All of the techniques fall under the category of single-sensing model-based methods. The new aspect of the method described here is the use of a multi-sensing strategy that combines EMG signals and location data to record a precise, real-time hand model. Our method avoids these drawbacks of existing systems and, in theory, can infer a larger range of hand forms using a more straightforward classifier architecture. Uncertainty surrounds this method, of course. Since no amputees have been involved thus far, for instance, the researcher's own experience suggests that it is challenging to regulate the forearm muscle without the coordinated feedback offered by the hand and fingers. These problems will need to be studied further. The multi sensing algorithm, in general, seems to be quite promising. In the worst case, a similar algorithm may be used to integrate the 3-D positioning system with EEG measurements if the EMG control of the prosthetic hand does not prove to be practical. We anticipate that this strategy will have drawbacks related to categorization issues, hence research in the near future will concentrate on the "3-D posture + EMG" approach described in this study. A variety of applications could potentially use the multi sensing system. For instance, the success of the 3-D positioning system in teleoperation research could be improved by combining prototype recordings and EMG data to more precisely operate a robot arm. The system may also be used to help other amputees, e.g., requiring leg prosthesis. Such work may also benefit from the multi sensing approach we have described.

Limitations and Future Enhancements While the system exhibited strong performance, several areas warrant further development. The pattern recognition model for EMG signal mapping

requires additional optimization to improve precision and robustness. Similarly, the actuation system would benefit from the integration of stronger, carefully selected actuators to enhance force generation and scale space, aligning with the strength capabilities observed in the rapid prototype. The current prototype, while functional, would be improved by constructing a more durable version with the same form factor, enabling rigorous testing under real-world conditions. Additionally, the development of advanced controllers and the incorporation of the hand's dynamical model for manipulation tasks are essential to achieving more complex and precise movements.

Future Directions Future work will focus on addressing the identified limitations through targeted improvements. Re-refinement of the pattern recognition algorithms will prioritize enhanced EMG signal mapping for diverse grip configurations. Comprehensive testing of the parallel actuation system will be conducted to validate its performance across a broader range of tasks. The development of a robust prototype, equipped with optimized actuators, will facilitate real-world evaluations. Furthermore, leveraging the dynamical model of the hand will enable more sophisticated manipulation capabilities, while advanced controller development will ensure precise and reliable operation. These advancements aim to elevate the system's functionality, making it a viable solution for amputee users seeking intuitive and versatile prosthetic control.

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