Design and Implementation of an EMG-Based 3D-Printed Prosthetic Hand

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Abstract - The loss of an upper limb significantly affects an individual's daily functioning, independence, and overall quality of life. Modern prosthetic hands aim to restore these capabilities, yet conventional solutions remain expensive, complex, and inaccessible for many users. This project presents the development of a low-cost, customizable 3D Printed EMG-Controlled Prosthetic Hand that utilizes surface electromyography (sEMG) signals to interpret user intent and generate intuitive hand movements. By integrating affordable 3D printing materials, Arduino-based control electronics, servo actuation, and EMG signal processing, the proposed system enables responsive and natural hand functionality such as grasping and releasing. The prosthetic is lightweight, modular, and easy to fabricate, offering significant advantages for rehabilitation, research, and resource-limited environments. This work demonstrates a practical approach to bridging mechanical design and biomedical signal interpretation, providing a scalable and accessible prosthetic solution that enhances user comfort.

Key Words: Electromyography(EMG), sEMG signal processing, Servo actuation, Arduino microcontroller, Biomedical Engineering, Myoelectric control

1.INTRODUCTION

The loss of a limb particularly a hand has a profound impact on an individual's quality of life, independence, and ability to perform essential daily activities. Hands play a crucial role in human interaction, manipulation, and communication. Over the decades, prosthetic hands have been developed to support individuals with upper-limb amputations, providing varying degrees of functionality and cosmetic appeal. However, traditional prosthetic solutions are often mechanical in nature, bulky, and prohibitively expensive. Their limited adaptability and high fabrication costs restrict accessibility, especially in developing regions where affordability is a major concern.

Recent technological advancements have opened new possibilities in prosthetic design, particularly through the convergence of low-cost 3D printing, electromyography (EMG) signal acquisition, embedded control electronics, and open-source hardware platforms. Electromyography (EMG) serves as a powerful bridge between human physiology and machine control. EMG technology measures the electrical activity generated by skeletal muscles during contraction.

The integration of Arduino-based microcontrollers and compact servo motors further enhances the practicality of EMG-controlled prosthetics. Microcontrollers enable real-time signal processing, noise filtering, and precise movement control, while servo motors translate these signals into accurate mechanical motion of the prosthetic fingers. This synergy of hardware and software establishes a functional mechatronic system that is both robust and user-friendly.

The present project focuses on developing a 3D Printed EMG-Controlled Prosthetic Hand capable of responding to muscle contractions in real time. By converting EMG inputs into proportional motor commands, the device aims to provide a lifelike and intuitive user experience. The research emphasizes affordability, modularity, and adaptability, making the prosthetic accessible for clinical applications, rehabilitation, and future biomedical research. Furthermore, this approach supports the growing movement toward personalized healthcare, leveraging open-source technologies to create customizable solutions for upper-limb amputees

2. Body of Paper

The implementation of the 3D Printed EMG Prosthetic Hand is based on the integration of bio signal acquisition, embedded control, 3D-printed mechanical actuation, and servo-based tendon movement. The control hardware and circuit layout for the prosthetic system is illustrated in Figure, showing the interconnection between the Arduino Uno microcontroller, EMG sensor module, servo motors, power supply, and breadboard distribution network.

The system employs a MyoWare or equivalent EMG sensor that captures muscle activity from the user's forearm. When the user contracts specific muscle groups, the sensor detects electrical activity from the muscle fibers and converts it into an analog voltage signal. This processed signal is then transmitted to the Arduino Uno through one of the analog input pins (A0), as seen in Figure, where the purple wire represents the signal line connection from the EMG sensor to the microcontroller. Power distribution for the servo motors is handled separately through the breadboard using two 9V battery supplies connected in parallel for sufficient current output, ensuring that servo load does not interfere with Arduino operation.

During operation, the EMG sensor reads muscle contraction intensity and transmits it to the Arduino, which processes the values through an analog-to-digital conversion routine. A threshold-based decision algorithm implemented in Embedded C determines specific hand gestures. If the sensed value crosses the predefined threshold, the Arduino triggers the necessary PWM adjustments to contract or relax the servo-linked tendons of the prosthetic fingers. Mechanically, the tendon-based motion pulls the joints of the 3D-printed fingers to mimic natural hand curling and releasing actions. The 3D-printed structure was fabricated using PLA material due to its durability, lightweight properties, and suitability for complex structural printing. The assembled servos are mounted inside the palm section, with tendons routed through each finger to replicate natural biomechanics.

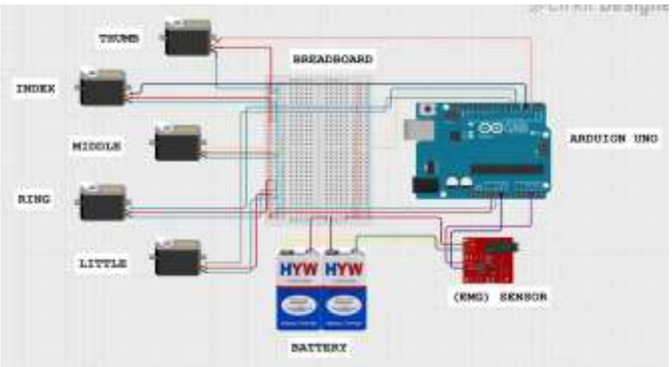

Fig -1: Implementation of Prosthetic hand in Cirkit Designer

Fig -2: Working Model

Fig -3: Working Model with components including tendons

3. CONCLUSIONS

The EMG-Based 3D-Printed Prosthetic hand demonstrates a practical and affordable approach to improving prosthetic technology. By using lightweight 3D-printed materials, the device reduces fatigue and increases comfort during prolonged use compared to traditional heavy prosthetics. The integration of flex and force sensors allows the prosthetic hand to accurately translate user intent into smooth and coordinated finger movements, enabling effective grasping and object handling.

A key feature of the project is the sensor-based feedback system, which provides basic tactile feedback through vibration or visual indicators. This helps users control grip force, reduces dependence on constant visual monitoring, and improves overall confidence and usability.

The project also emphasizes cost-effectiveness and scalability by using low-cost components, open-source platforms, and a modular design. This makes the prosthetic hand accessible and suitable for widespread use, especially in developing regions.

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