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PROSTHETIC ARM

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ABSTRACT: The accessibility of prosthetic limbs remains a significant challenge in the global healthcare landscape, particularly in developing nations where high costs prohibit widespread adoption. This paper presents the design, fabrication, and control of a low-cost, 3D-printed prosthetic arm actuated by servo motors and controlled via an Arduino UNO microcontroller. The primary objective is to replicate the essential grasping function of the human hand—specifically the flexion and extension of fingers—using a simplified Human-Machine Interface (HMI) consisting of a tactile push-button switch.

The mechanical structure was fabricated using Fused Deposition Modeling (FDM) technology with Polylactic Acid (PLA) filament, significantly reducing the weight and material cost compared to traditional manufacturing methods. The control system employs an Arduino UNO to process digital input signals and modulate Pulse Width Modulation (PWM) signals to drive high-torque servo motors. The system successfully demonstrates a reliable open-close mechanism with a response time suitable for basic object manipulation. This research validates the feasibility of combining additive manufacturing with open-source electronics to create functional, affordable assistive devices, laying the groundwork for future integration with advanced myoelectric sensors.

I.INTRODUCTION

The loss of an upper limb is a life-altering event that drastically affects an individual's physical capabilities and psychological well-being. According to the World Health Organization (WHO), a vast majority of amputees in low-to-middle-income countries lack access to proper prosthetic care due to the prohibitive costs of commercial devices, which can range from $10,000 to over $100,000. Traditional manufacturing involves complex molding and casting processes that are labor-intensive, difficult to customize, and often result in heavy, uncomfortable devices. Consequently, there is a critical need for alternative manufacturing methods that can produce functional prosthetics at a fraction of the cost.

The convergence of 3D printing, also known as Additive Manufacturing, and accessible microcontrollers like the Arduino platform offers a disruptive solution to this problem. 3D printing allows for rapid prototyping and the creation of complex geometries—such as articulated finger joints—without the need for expensive tooling. Simultaneously, the Arduino ecosystem provides a flexible, low-cost platform for controlling electromechanical actuators, making it possible to replace expensive proprietary control systems with affordable off-the-shelf components. While advanced multi-degree-of-freedom (DOF) bionic hands exist, they often require complex control inputs, such as EMG signals, and expensive processing units. Thus, a gap remains for a robust, "entry-level" electronic prosthetic that serves as a middle ground between purely cosmetic passive hands and high-end bionic hands.

The primary objective of this project is to design and implement a prosthetic hand that addresses these economic and technical barriers. Specifically, the device is manufactured using low-cost 3D printing materials to ensure affordability and ease of repair. It is designed to provide active grasping capabilities, allowing the user to perform essential open and close functions. The system utilizes a robust Arduino-based control architecture driven by high-torque servos to ensure reliability. Furthermore, the device is operated via a simple, reliable switch mechanism, which minimizes the learning curve for the user and reduces the complexity associated with signal processing in more advanced myoelectric systems.

II.LITERATURE REVIEW

The research field surrounding prosthetic technology has undergone significant evolution, moving from passive and body-powered devices to complex external-powered systems. Historically, prosthetic hands were either purely cosmetic or required cable harnesses actuated by shoulder and chest movements. The introduction of myoelectric hands in the mid-20th century marked a critical shift toward external power, utilizing the user's residual muscle signals to control motors. However, these early commercial units were typically heavy, fragile, and prohibitively expensive.

Zuniga et al.; demonstrated the significant potential of 3D-printed hands, such as the open-source "Cyborg Beast," which drastically improved the quality of life for children with upper-limb differences. While many initial 3D-printed designs were body-powered, recent literature explores motorizing these designs (active prosthetics) to assist users with limited residual joint strength. The "e-NABLE" community has been pivotal in standardizing these open-source 3D-printed prosthetics, providing a global framework for collaboration and design iteration.[1]

Giergiel et al.; highlighted the efficiency of servo motors in robotic manipulators for precise angular positioning without the need for complex feedback loops, as the position control is inherent to the servo's internal electronics. This project directly leverages these findings, applying standard robotics control theory to a wearable biomedical application for reliable, low-cost actuation.[2]

Biddiss and Chau; focused on the critical issue of prosthetic abandonment rates of upper-limb prosthetics. Their survey of over 200 amputees revealed that a significant percentage reject their devices due to excessive weight, discomfort, and lack of sensory feedback. Their findings underscore the critical importance of keeping the prosthetic device lightweight and minimizing the "harnessing" complexity. These insights directly support the design philosophy of this project, which prioritizes lightweight PLA material and a simple, battery-operated control system to reduce physical and cognitive load on the user.[3]

Dollar and Howe; have published influential work on underactuated grasping, where a single actuator drives multiple degrees of freedom. Their research highlights that compliant joints and tendon-driven systems allow for adaptive grasping—where the fingers conform to the shape of the object naturally—without complex individual motor control for each finger. This principle is central to the design of this project, utilizing a single high-torque servo to actuate multiple fingers simultaneously via tendons, achieving a compliant grip similar to the mechanisms analyzed in their study.[4]

Antfolk et al.; Their comprehensive review of sensory feedback in prosthetics indicates that while visual feedback is dominant, simple tactile feedback can significantly reduce the mental effort required to operate the device. Although this specific project utilizes a simple switch for actuation, understanding the requirements laid out by Antfolk is crucial. It provides a roadmap for future iterations of this device, suggesting that adding simple vibration motors to the switch mechanism could vastly improve the user's confidence and overall system usability.[5]

IV. Material Selection

When doing a project, it is important to pay attention to the selection of materials. To prevent waste, the items selection process must be carefully welcomed. A precise selection of items is necessary to ensure that they are long-lasting and safe for usage.

4.1 Arduino UNO

Fig. 1 Arduino UNO

This microprocessor is used because open-source nature, ease of programming for rapid iteration, and sufficient Pulse Width Modulation (PWM) pins for precise control of the servo actuators.

4.2 Prosthetic arm

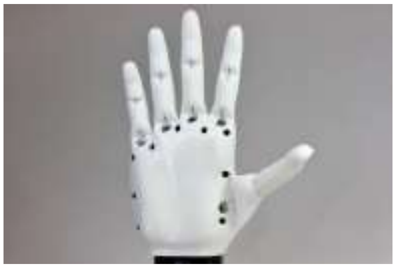

Fig.2 3D printed prosthetic arm

It best alternative to depict real hand.

4.3 Servo Motor

Fig. 3 Motor

It is best for moving fingers as we can control it according to our need.

4.4 Push button switch

Fig 4 Push Button Switch

It used to open and close arm whenever we want.

V. RESULTS AND DISCUSSION

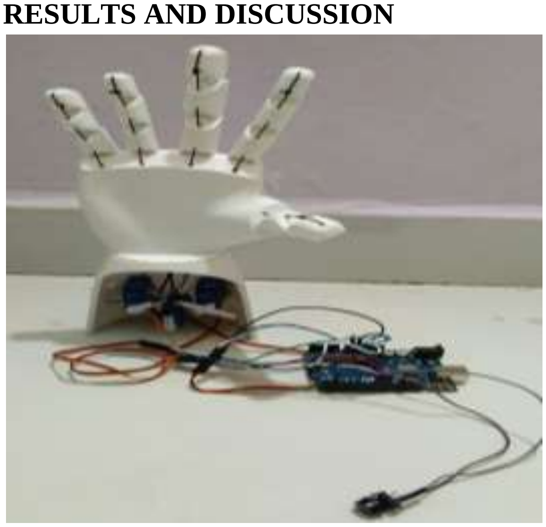

Fig 5 Working Model

Working principle

The prosthetic hand works by using servo motors to control the movement of each finger or a group of fingers, while an Arduino Uno functions as the main controller. A push-button is connected to one of the Arduino's digital input pins. When the system powers on, the Arduino sets the servos in the finger-open position. When the user presses the switch, the Arduino detects the change in the input signal and decides whether the fingers should open or close. It then sends PWM control signals to the servos, which rotate their horns to pull tendons or move linkages that bend the mechanical fingers. A second press of the switch causes the Arduino to reverse the command, sending new PWM angles to open the fingers again. The servos rotate back, releasing the fingers to their relaxed position. Smooth and gradual angle changes ensure safe and controlled finger movement. The servos are powered by an external 5–6V supply, and all grounds are shared for stable operation. The Arduino continuously monitors the switch so that the hand can open and close whenever needed.

VI. CONCLUSION AND FUTURE SCOPE

This prosthetic hand prototype successfully demonstrates a practical and affordable approach to assistive technology using an Arduino Uno, servo motors, and a simple switch mechanism. The system provides basic yet reliable finger actuation, enabling the hand to open and close smoothly with controlled motion. This project highlights how commonly available electronic components and straightforward programming can replicate essential hand functions and support individuals with partial hand disabilities. It proves that even a beginner-level robotic prosthetic can help restore simple gripping actions needed for daily tasks. Additionally, the project serves as a strong foundation for further research and development in biomedical robotics, allowing students and engineers to understand the working principles behind real prosthetic devices.

There is significant potential to enhance this prosthetic hand model for more advanced and practical use. One major improvement involves replacing the switch with EMG sensors, enabling the user to control the hand using natural muscle signals for intuitive movement. Force or pressure sensors can be added to detect how tightly the hand grips an object, preventing accidental slipping or damage. The mechanical structure can be redesigned using lightweight materials, flexible joints, and ergonomic shapes to improve comfort and durability. Incorporating machine learning algorithms can enable adaptive grip patterns based on object type and user behavior. Additionally, wireless communication modules like Bluetooth or Wi-Fi can allow remote control, data monitoring, and smartphone integration. With these advancements, this project can evolve into a highly functional prosthetic device capable of providing a more realistic and user-friendly experience in real-world applications.

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