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Development of a prosthetic arm with gesture recognition for enhanced social interaction

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Abstract: This paper presents the design and development of an affordable prosthetic arm capable of performing finger movements, such as opening and closing, in various patterns. The prosthetic arm utilizes an Arduino microcontroller and servo motors, aiming to create a user-friendly assistive device for individuals with upper limb disabilities through a Brain-Computer Interface (BCI). The device is intended for individuals with below-elbow (transradial) amputations, which may result from causes like trauma, cancer, or vascular diseases. Constructed with PLA+ materials, the prosthetic is designed for both comfort and durability, with 3D printing enabling cost-effective and customizable production. The prototype is tested for three movement patterns: default option 1: opening and closing all fingers starting from the pinky, option 2: opening and closing all fingers simultaneously, and option 3: opening and closing all fingers starting from the thumb. Test results are analyzed to evaluate the functionality and performance of the device. This innovative approach demonstrates the potential of a low-cost, highly functional prosthetic arm that can enhance mobility and independence for users, demonstrating the power of accessible, affordable technology for assistive applications.
Keywords: *3D printing, Amputees, Gesture recognition, Brain-Computer Interface (BCI), Prosthetic arm.*

1. Introduction

Modern developments have led to significant improvements in the design and functionality of prosthetic devices. This paper introduces an innovative prosthetic arm equipped with gesture recognition technology, capable of mimicking hand gestures that correspond to popular emojis familiar to users. The primary objective of this development is to address a major limitation of traditional prosthetics: their inability to express gestures and body language, which are crucial in social interactions.

Most conventional prosthetic devices fail to enable users to communicate non-verbally, a critical aspect of interpersonal relationships that fosters emotional support and human connection [1]. This limitation underscores the need for a prosthetic arm that not only restores hand functionality but also allows users to convey messages and emotions through gestures.

The prosthetic arm is designed for a variety of social settings, including homes, public spaces, and social events, where gestures are an essential form of communication [2]. With its gesture recognition

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capability, this device aims to enhance users' ability to communicate socially, positively impacting their quality of life and helping to alleviate feelings of loneliness.

The development of this prosthetic arm stems from the need to address the communication gap created by conventional prosthetics. Furthermore, the gesture-based system could increase digital platform usage among individuals with disabilities, improving their access to technology and overall quality of life.

This paper will explore the design and functionality of a prosthetic arm with gesture recognition technology, highlighting how this innovation can overcome the shortcomings of traditional prosthetics, facilitate social and emotional communication, and provide additional utility in terms of digital integration.

2. Literature Review

The prospects of hand gesture recognition are clearly seen as a major advancement in different areas of human life [3, 4]. In smart home integration, it can be used to highly transform the way occupants and homes interface with each other by controlling home appliances using hand gestures [5-7]. This innovation could result in a better qualified living environment that is aware of the users' needs. Gesture recognition could improve experience with assistive technologies for people with disabilities within the frame of the concept. Especially, in virtual and augmented reality, it may enhance the interactivity by means of the natural hand gestures. In the healthcare domain, gesture recognition has a potential for patient surveillance and tele-healthcare; gesture is a natural way to introduce healthcare solutions [8-10]. Furthermore, it can be used in the process of rehabilitation since exercises prescribed by doctors can be more enjoyable. It also true that the gesture-based controls can be very useful in education and training as dynamic gestures are always useful for learning and practicing.

3D printing technology offers a promising opportunity for creating affordable, functional, and personalized prosthetic limbs. 3D printing enables prosthetics that are not only practical but also aesthetically appealing, with participatory design allowing users, particularly children, to contribute to the design process, fostering a sense of control and positive psychological impact [11, 12].

The catalogue of 3D-printed upper limb prostheses consists of a wide variety of devices intended for different levels of amputation. A review was conducted to find out that there are 58 diverse prosthetic devices that are produced using 3D printing technology [13]. One of the major concerns is the pediatric population since their sizes change due to growth and the ability of 3D printing to quickly produce new devices [14]. It is also noteworthy that the formation and distribution of these prostheses are also carried out with the help of community initiatives, using open-source designs to increase accessibility.

SolidWorks used for designing and XYZ slicing software to get the G-code for 3D printing for slicing the model [15-17]. The prosthetic was designed to be printed in sections and then joined once it was printed. The patient was able to grasp simple objects using the prosthetic and the features added to the prosthetic included finger grips. Some measures were observed to enhance the prosthetic durability, for example no contact with heat since the prosthetic was printed using PLA material. Currently, 3D-printed prosthetics are revolutionizing the field by offering affordable solutions. Programs like e-NABLE provide low-cost, fully adjustable prosthetic limbs for children, ensuring families don't have to bear the financial burden and have access to support as children grow [18, 19]. 3D printing allows prosthetics to be produced quickly, often within a day, which is particularly beneficial for children who frequently require new prosthetics. The common materials used are ABS and Bridge nylon.

The Association Dominicana de Rehabilitation (ADR) is involved in the fabrication of lower-limb prosthetics, which are mostly produced by conventional techniques [20, 21]. However, the thesis reveals possibilities of adopting 3D printing to their operations and making prosthetics cheaper to amputees. Thus, the ADR is in the process of seeking ways of adopting a hybrid model where some parts are printed while others are fabricated in the conventional manner. This hybrid method can help reduce overall costs by quite a margin and thus increase the availability and accessibility of prosthetics to the people who need them [18, 22].

The core component of the hand gesture-controlled robot system is a camera or webcam, which captures images of hand gestures for image processing. The robot utilizes wireless communication with a range of 50-80 meters, facilitated by an RF module operating at 315 MHz. This configuration seamlessly connects the gesture recognition system to the robot. Movement commands such as forward, backward, left, right, and stop are generated using Java programming on the computer and transmitted to the robot's receiver via ZigBee technology [23, 24]. The real-time control mechanism allows users to control the robot's movements naturally, using only their hands.

The hand gesture recognition involves a basic hand motion control system with reference to Arduino technology. The hand gesture recognition system uses ultrasonic sensors for sensing the hand gestures as well as their positions [25]. This system entails the use of an Arduino board, which interfaces with these sensors placed on either side of a laptop screen to detect movement of hand. For this purpose, a Python script is used with the help of the PyAutoGUI library to map the identified gestures to computer operations like changing the volume or switching between tabs. The current use of the hand gesture recognition system involves the use of additional supporting hardware and software parts [26]. Motor working is controlled through an Arduino Uno microcontroller, power supply is an L298N motor driver, wireless communication through HC-05 Bluetooth module is used and the ESP32 camera provides real-time video streaming feed. From the software aspect, the system is designed on the Arduino Integrated Development Environment (IDE) and the Python Integrated Development Environment (IDE) known as PyCharm; alongside the libraries OpenCV and MediaPipe for image and gesture detection respectively [27]. The process of gesture recognition involves several steps: using a webcam to capture hand gesture images, extracting features on the captured images and finally developing a classifier to categorize the images and control the robot's movements via wireless connection. An interface is developed using PyQt5, which provides a graphical user interface through which users can see the movement of the robot and control it [28].

At the core of this system is the Arduino, which is the system's master controller; other components include the motion sensor, RF Transmitter-Receiver Pair, and Motor Driver. All these components together help in the interpretation of hand movements and converting them into signals that control different gadgets. Gesture recognition process mainly targets specific hand gestures to perform the tasks such as scrolling down the web pages, moving between the tabs, and controlling the media [29]. This is made possible using the computer vision and image processing algorithms that help the system to identify the various gestures made by the user. This implementation also benefits the users who can use the computers without having to use a keyboard and mouse which makes the experience less stressful on their wrists.

This system is rather inexpensive, being based on only two ultrasonic sensors as well as the Arduino board, which makes it less expensive than some other gesture recognition systems. It allows the user to do different computer activities like playing or pausing media, moving to the next slide or even paging down, by just using gestures. Some of the sensors are designed to follow the movement of hands and convert those movements into instructions for the computer [30]. This approach also helps in implementing practical interaction between the users and the technology and shows how this gesture recognition can be adopted in other aspects of life.

3. Material and Methods

3.1. MakerBuying 4DOF Potentiometer extension board for Arduino SNA161

The MakerBuying 4DOF Potentiometer Extension Board for Arduino SNA161 identified as an essential step toward revolutionizing prosthetic limbs, especially prosthetic arms. This extension board is a very important component of the control as well as feedback systems required in the proper functioning of such apparatuses. Four DOF on the board is used to accomplish a variety of movements of a prosthetic arm and considerably imitates the human arm muscular movements. The board has several potentiometers, and each regulates one joint or movement, so it allows performing a number of gestures and actions that make the use much more interesting.

Three significant benefits of the SNA161 extension board include an adjustable control feature [31]. The resistance of each potentiometer is adjustable, which makes this product have flexibility of use, thus users can set it according to their requirements. This customization is especially beneficial to users, for instance those who need some certain settings so that they can use the devices comfortably. The board is very suitable for Arduino microcontrollers hence making it easier for the board to be implemented in the control of a prosthetic arm. The use of Arduino also makes it easy to program and control the movement of the arm as developers can easily write code that translates the readings from the potentiometer and commands movements of motors or servos contained in the prosthetic arm.

The incorporation of potentiometers enhances the actions of the prosthetic arm to be smooth and flexible thus enabling the user to carry out tasks. The real-time response given by the potentiometers allow users to change certain aspects of the interface such as the strength of grip or speed of movement based on the task, which is valuable for tasks that must be completed with a great deal of accuracy. The MakerBuying 4DOF Potentiometer Extension Board for Arduino SNA161 holds the key position to the improved prosthetic arms with the added features.

3.2. Maker Uno

The Maker Uno is a vital microcontroller board that sequentially commands different electronic projects like controlling a prosthetic arm [32]. It is not for the novice user only but even for the professional developers who want to experiment with the environment. Basically, with many input or output interfaces consisting of 26 pins, the Maker Uno can easily connect to various sensors, motors and any other electrical and mechanical devices.

As for the prosthetic arm, the Maker Uno is used to determine the inputs from the user and regulate the motion of the arm. It operates based on signals coming from sensors like potentiometers or even motion sensors, which interpret the user's intentions. For example, if the user shifts the residual limb or changes a control device in any manner, the sensors then send related signals to the Maker Uno. The board interprets these signals and turns them into commands to control the functioning of the prosthetic arm like in performing hand gestures.

The Makerbuying component usually relates to other peripherals which are complementary to the Maker Uno. This may include different sensors, motor drivers, as well as communication modules which are integrated with the Maker Uno to form a complete prosthetic control system. For instance, the motor driver can be employed to manage the servos or motors which allow the prosthetic arm to function. These components work coherently to perform more elaborate movements and enhanced flexibility in the prosthetic arm.

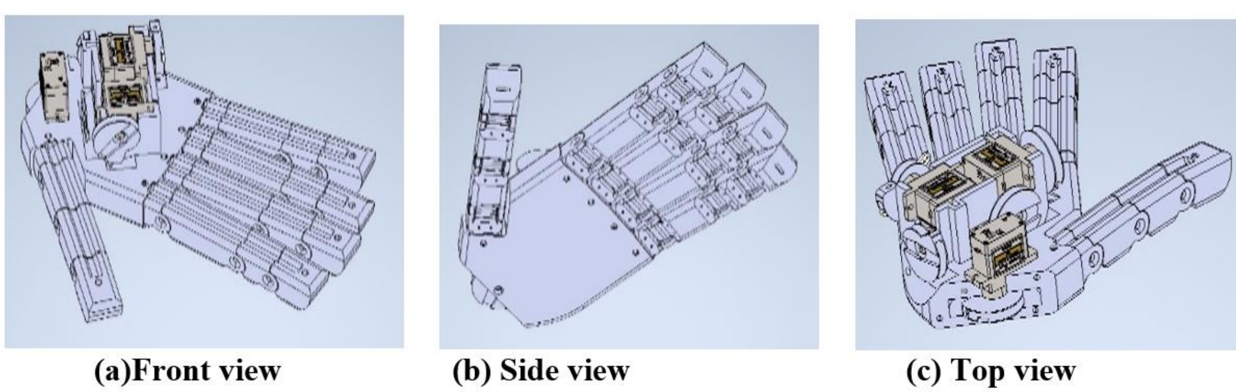

Figure 1.
3D Printed Prosthetic Arm.

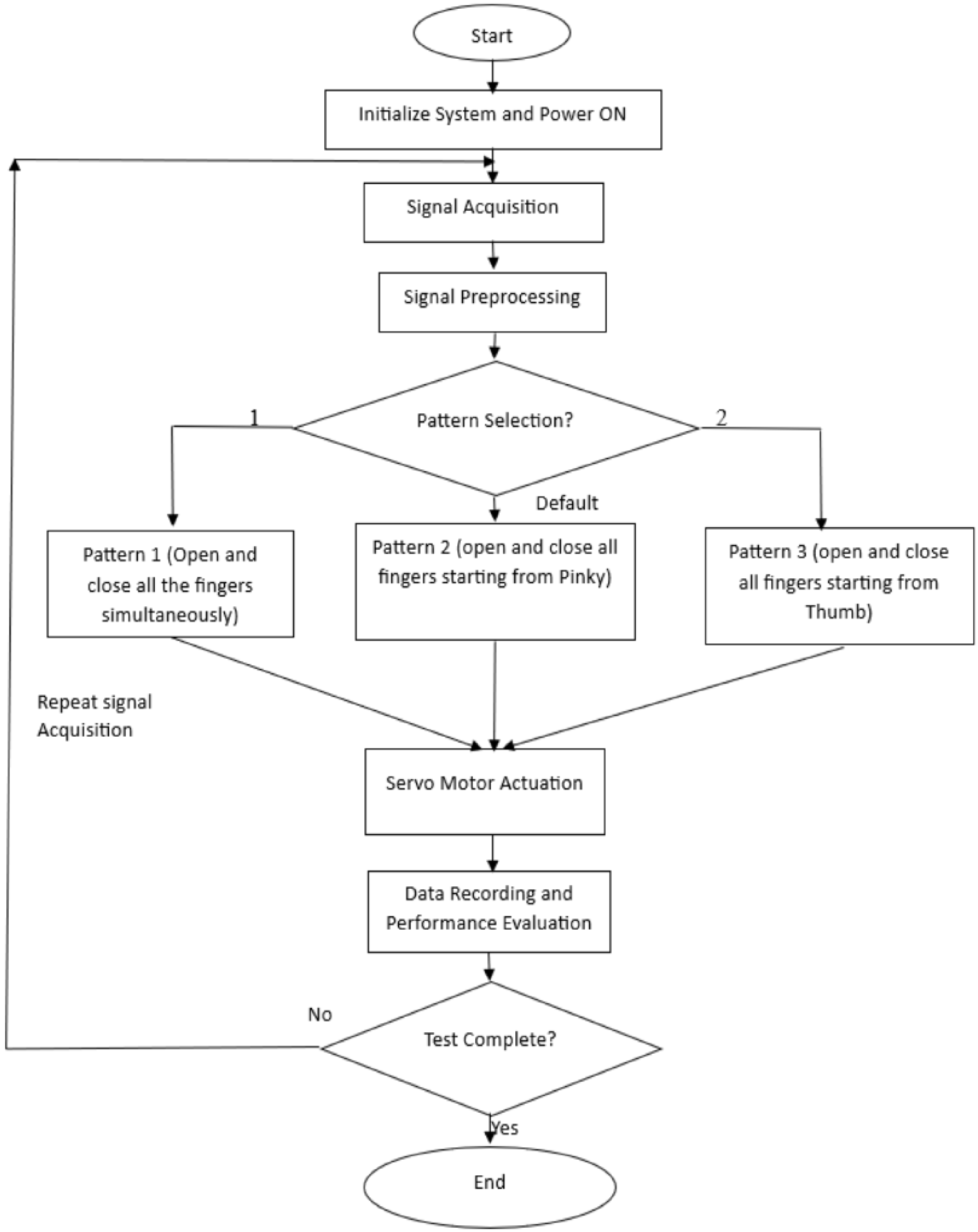

Figure 2.
Flowchart.

The flowchart, as shown in Figure 2, presents the sequential working of a prosthetic arm and the hand movements performed by the prosthetic arm at each step. The flow starts with the system and servo motors' initialization, which is essential for the prosthetic arm to perform precise and timely movements. This initialization makes all the components to be in a state that is ready for operation, and this makes it possible to control the arm perfectly. The BCI EEG signals are captured based on the user's choice (default option1, or Pattern 1, or Pattern 2) imagination and preprocessing the raw data is essential to remove the unwanted frequencies and artifacts. According to the selected pattern the servo motors are ON in sequence. The sequence can be repeated for various patterns or end. This approach enhances the reliability and precision of the prosthetic arm's movements, allowing it to execute a wide range of gestures effectively.

The functionality of the developed prosthetic arm is tested for the sequence of pattern (default option, pattern 1, or pattern 2,) for 10 times, it is working. At this point of time, the 3D printed prosthetic arm is tested with the Arduino microcontroller coding. BCI integration is under progress.

4. Result and Discussion

Default option 1

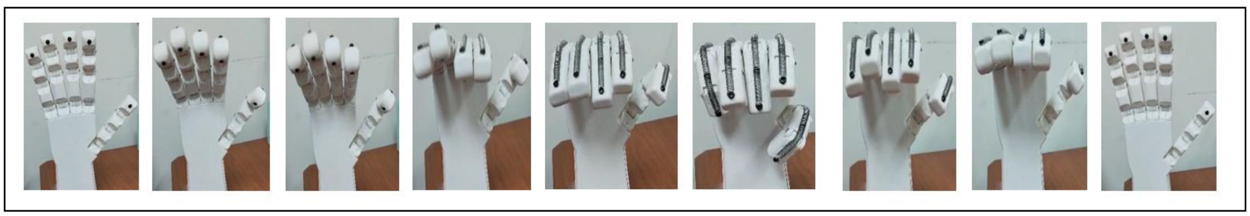

Figure 3.
All the fingers Open and close Simultaneously.

Option 2

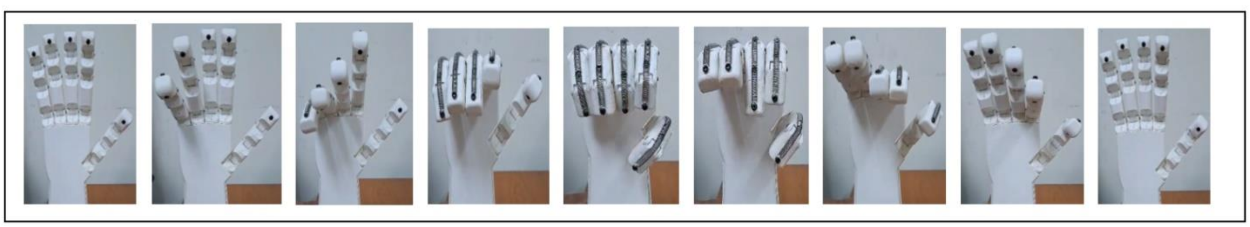

Figure 4.
All the fingers Open from Pinky finger and close from Pinky finger.

Option 3

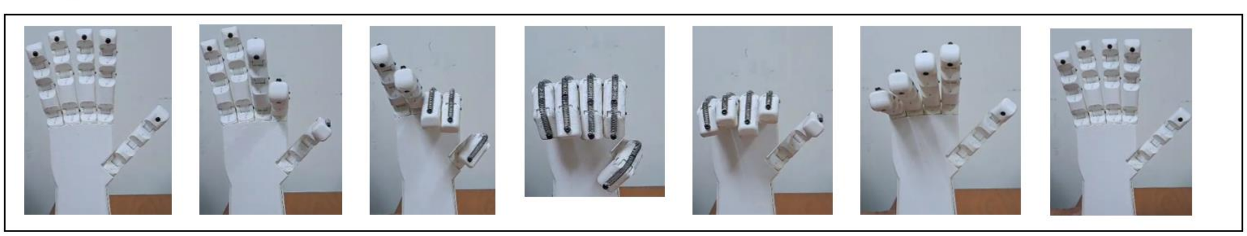

Figure 5.
All the fingers Open from Thumb and close from Thumb.

By Selecting the default option1, the sequence of all the fingers Open Simultaneously and all the fingers close Simultaneously are shown in Figures 3. The sequence of all the fingers Open from Pinky

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finger and all the fingers close from Pinky finger are shown in Figures 4 by selecting option 2. By Selecting the option 3, the sequence of all the fingers Open from Thumb and all the fingers close from Thumb are shown in Figures 5.

5. Conclusion and Recommendation

This paper present on designing and developing an affordable prosthetic arm that can perform finger movements, such as opening and closing, in different patterns. It utilizes an Arduino microcontroller and servo motors, with the aim of creating a user-friendly assistive device for individuals with upper limb disabilities through a Brain-Computer Interface (BCI). The prosthetic arm is intended for individuals with below-elbow (transradial) amputations, which can result from causes like trauma, cancer, or vascular diseases. Constructed with PLA+ materials, the prosthetic is designed for comfort and durability, and it is 3D printed to allow for cost-effective and customizable production. The prototype is tested in three movement patterns: default option1: opening and closing all fingers starting simultaneously, option 2: opening and closing all fingers from the Pinky, and option 3: opening and closing all fingers starting from the thumb. Test results are analysed to evaluate the functionality and performance of the device. This innovative approach demonstrates the potential of a low-cost, highly functional prosthetic device that can enhance mobility and independence for users, showcasing the power of accessible, affordable technology for assistive applications. The future recommendations include the EEG signal bridge with Arduino is under development. The complete integration and testing are in the pipeline.

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Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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