Design and Implementation of Smart Prosthetic Hand Using Artificial Intelligence

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Abstract
This research paper presents a comprehensive examination of a computational approach for controlling a robotic arm through brain, gesture, and voice signals. The human brain, consisting of numerous neurons, forms the basis for an Electroencephalogram (EEG) based Brain-Computer Interface (BCI) prosthetic arm. This non-invasive technique holds great potential in assisting individuals with severe disabilities in their daily lives, particularly by facilitating voluntary arm movement. The Brainsense headset captures EEG signals from the brain, which are then processed by a microcontroller to control servo motors and manipulate the prosthetic hand accordingly. Additionally, the system incorporates a glove controller that emulates natural gestures, utilizing flex sensors to facilitate precise arm motion control. To further expand the system's capabilities, a voice control system has been developed, enabling individuals to command the prosthetic arm through voice signals transmitted via Bluetooth. A user interface, supported by a microcontroller, facilitates real-time monitoring and oversight of all operations. This innovative prosthetic arm design offers significant benefits to individuals with below-elbow amputations, empowering them to regain independence in their daily lives. The primary objective of this research paper is to enhance the quality of life for physically disabled individuals, enabling them to reduce their reliance on others. This model holds tremendous practical value, particularly for individuals with hand disabilities who are unable to perform manual tasks. Furthermore, it serves as a valuable tool in academic settings, allowing undergraduate students pursuing robotics studies to gain hands-on experience in their curriculum. The work done & presented in this paper is the result of the final year one year project work that has been done by the final year engineering students of the college and as such there is little novelty in it and the references are being taken from various sources from the internet, the paper is being written by the students to test their writing skills in the final stages of their engineering career and also to test the presentation skills during their final year project presentation and the work done & presented in this paper is the report of the undergraduate project work done by the students.

Keywords Robotic arm, Electroencephalogram, Brain-Computer Interface, Brainsense headset, Bluetooth, Voice control, flex sensors

1. Introduction

This project draws inspiration from individuals with motor deficits caused by stroke, soldiers who have lost their arms in war, and those who have limited control over their arms and hands. According to recent studies conducted by the World Health Organization (WHO), approximately 15% of the global population experiences some form of disability, with half lacking access to adequate healthcare [1]. In India alone, there are approximately 5 million people living with disabilities. Worldwide, there are over 10 million amputees, with 30% of them having undergone arm amputations [2]. Causes of limb loss can range from traumatic injuries and birth defects to various diseases, including those acquired during military conflicts or vehicular accidents [3]. Replicating the intricate functionality of the human hand has long been a coveted achievement in the fields of robotics and prosthesis, but it also represents one of the most formidable engineering challenges [4]. Hand gestures are a ubiquitous form of human interaction and can be effectively utilized in human-computer interaction (HCI) [5].

The prevalence of amputees and individuals with limb dysfunction is on the rise due to political, economic, scientific, and demographic factors. Although prosthetic limbs have been available for decades, they often lack natural operation and seamless interaction with the environment. Additionally, their usage typically necessitates invasive surgical procedures [6]. Complex procedures aim to reassign nerves, enabling amputees to control their prosthetic devices through neural signals associated with intended actions [7]. Robots are not limited to industrial applications; they also play a significant role in enhancing human life. Robotic arms, available in various sizes and configurations, are programmable mechanical arms designed to perform a wide range of tasks [8]. The primary objective of this project is to assist individuals with physical challenges in their daily lives, providing them with the ability to independently manipulate and transport objects. To enhance the efficiency of assistive robots, innovative approaches are required to empower users, fostering independence, self-fulfillment, and social inclusion [9].

The history of brain-computer interfaces (BCI) can be traced back to Hans Berger's groundbreaking discovery of the electrical activity of the human brain and the subsequent development of electroencephalography (EEG) in 1924 [10]. A BCI serves as a non-muscular communication channel, enabling individuals to transmit commands and messages to automated systems such as robots or prostheses through their brain activity. BCI systems find applications in various domains, including spellers, wheelchair control, cursor manipulation, multimedia, and virtual reality [11]. Acquisition, a critical aspect of BCI systems, often relies on EEG as a widely adopted, cost-effective, and portable solution. EEG involves the recording of brainwaves through electrodes attached to the subject's scalp. These brainwave signals exhibit low amplitudes in the microvolt range and frequencies ranging from 1 Hz to 100 Hz. Specific features are extracted from the EEG signals, which correspond to different states of the user's brain activity and can be associated with commands for various applications [12] (see Fig. 1 for illustration).

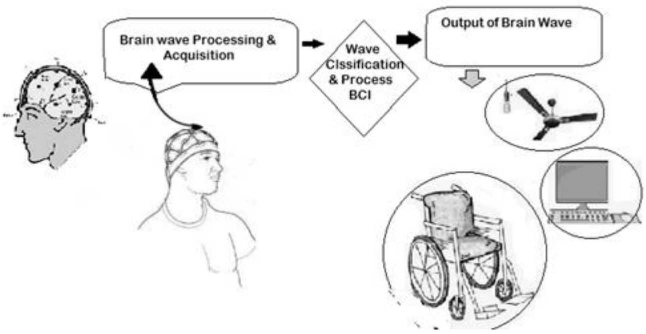

Fig. 1: Applications of BCI interface

Speech recognition algorithms have undergone extensive development over the years and have gained significant popularity due to advancements in voice recognition performance and the robustness of machine learning algorithms. Many elderly assistance robots can be controlled using devices such as joysticks, tablets, or PCs [13]. However, some individuals may encounter difficulties in using these traditional input methods. To address this, voice-controlled robots offer a potential solution. Nonetheless, most current speech control services, including smartphones and home automation systems, rely on internet connectivity to process user voice commands through remote servers. This reliance on internet connection poses limitations for certain use cases, and for assistive technologies, operating without internet connectivity is preferable to ensure autonomy and safety [14]. In this project, we propose using voice instructions as input via Bluetooth to a preprogrammed controller, which in turn generates the desired output using a robotic arm [15]. Among the various techniques available, one popular approach is the glove-based technique, which measures hand and arm joint angles as well as spatial position [16]. Gesture recognition technology has witnessed rapid growth in popularity, primarily due to the relatively low cost and compact size of flex sensors, making them ideal for detecting and recognizing human body motions [17]. The primary objective of gesture recognition in this paper is to detect specific hand gestures and correspondingly send commands to the robotic system for the execution of desired actions [18].

2. Literature Reviews

Numerous studies have explored the development of smart prosthetic arms utilizing various technologies. This section aims to provide an overview of existing technologies and their contributions. In a notable work [1], the authors focused on brain-controlled robots to enhance mobility for individuals with degenerative muscular diseases. Their approach involved a comprehensive methodology for acquiring EEG signals using simple electrodes. Another study [3] addressed a medically-oriented challenge by proposing an intricate mechanical design for the prosthetic arm along with electronic control. The researchers successfully developed a cost-effective yet functional prosthetic arm capable of accepting vocal commands from users. Additionally, a paper [5] delved into the design of a hand gesture recognition module for analyzing and classifying hand gestures in the context of human-computer interaction (HCI), particularly glove-based techniques. This research aimed to establish mappings between angular measurements obtained from a data glove and predefined hand gestures. These examples highlight the diverse range of research endeavors focused on implementing prosthetic hands. Considering these advancements, we have developed a Smart Prosthetic Hand that can be intuitively controlled through voice, gesture, and EEG signals.

3. Scope & Objectives

The scope of our project is to help people with disability to live and lead a normal life and to do their daily activity without any aid of others in an efficient and better way. It mainly helps people who have lost their hands due to war, paralysis and people who have lost the control over their limbs. BCIs used to transmits the subject thoughts, decoded by brain electrical activity into control signal, for external This technology offers a non-invasive solution without the need for brain surgery, providing valuable assistance to individuals in need. By enabling greater independence, it contributes to both physical and mental well-being. The main objective of the project was to enhance the control of assistive robots, making it more intuitive and efficient through voice commands.

The design of the prosthetic hand focused on accurately replicating a limited set of hand motions rather than attempting to mimic the full range of gestures. This approach recognizes the complexity involved in emulating all possible hand movements. However, for the chosen articulations, it was crucial to ensure that the prosthesis appears as natural as possible. Considering the practicality of everyday use, the design prioritized robustness, stability of motion, and durability of parts. Simplicity in machining was also considered, avoiding overly complex manufacturing processes while ensuring functionality.

4. Objectives of the project work

The main objective is to design and develop a reliable low - cost prosthetic arm control circuit. Also, to design a smart prosthetic arm, which uses captured signals from the brain and processes it to control the arm and to accomplish complex navigational tasks (pick and place objects) in realistic environment for people with disability in hand. The prosthetic hand design that mimics the gestures and act accordingly. To control the hand by giving voice commands. Also, to achieve home automation based on the signals processed and to send an alarming message to the family members in case of any emergency situations along with GPS location of the person using the Prosthetic hand.

5. Proposed Methodology

In this section of the paper, the process of approaching the project is explained in brief. As discussed in the previous sections, the project is about building a Smart Prosthetic Hand which can be operated using three methods such as EEG signals, Voice commands and gestures. To realize this project, we bring many contributions. One of our inputs is voice. The user can control the prosthetic arm in the form of human voice commands. The commands given to the Bluetooth module and the Arduino voice control app in the phone acts as an interface. For this, we give our voice commands. The speech recognizer takes input voice commands and converts them to text format and is fed to the Arduino in string format [24]. Here it will parse the string format and check if the given input is present in the built-in library and the pre-coded instructions for example ‘open all fingers, ‘close’ etc,.

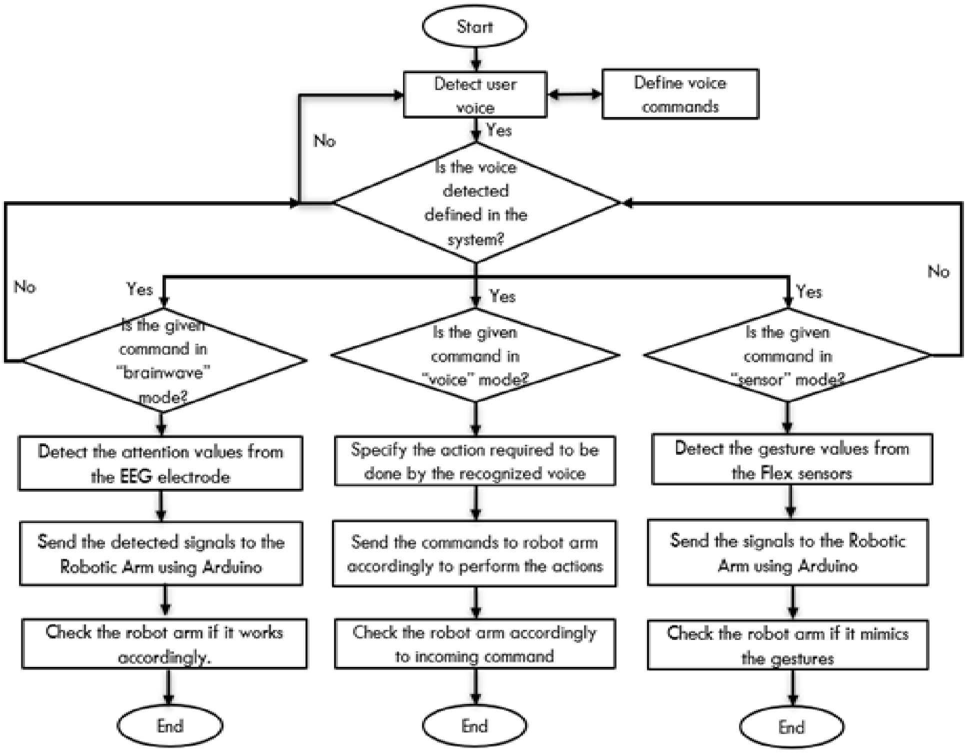

Fig. 2: Flow Chart

Finally, it is inserted into the Prosthetic Hand and it obeys the instructions and in return gives the respective output. As part of the training phase, Hand is trained with user specific voice so that it cannot be misused by any other individual as shown in the Fig. 2 [25]. The robotic hand replicates the gestures performed by the controlling arm, making it a straightforward project that can be recreated by individuals with basic knowledge in electronics and programming [26]. Each finger of the hand is operated by an individual servo motor, receiving signals from an Arduino board that determines their positions [26]. To detect the bending of fingers, flex sensors are utilized as input for the Arduino [25]. These flex sensors are integrated into gloves worn by the user. When the user desires to interact with home appliances, they simply use their hands to control them. When the flex sensors bend and the resistance values change, the Arduino converts the resulting current changes into digital signals, which are then transmitted to a Bluetooth module [27]. The Arduino code uploaded to the board verifies and compares the received data. If the data indicates a value of 1, the bulb is turned on. Conversely, when the received data is 0, the bulb is switched off. This approach allows for the control of various appliances throughout the home. Furthermore, this technology can be applied to perform additional actions such as object manipulation, as depicted in Figure 3 [28].

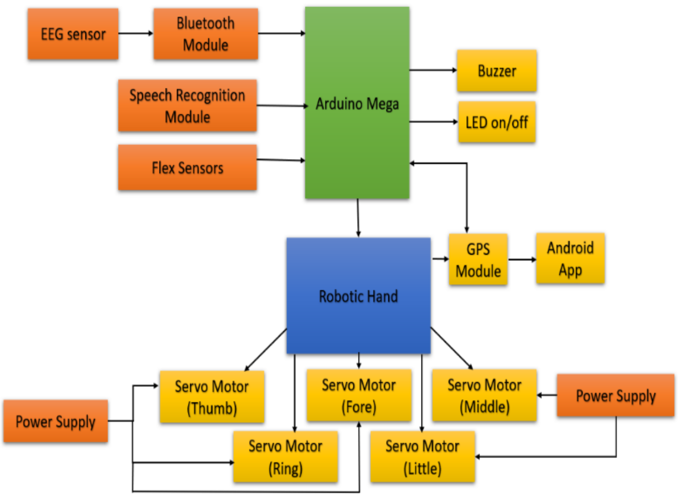

Fig. 3: Block Diagram for the proposed model

The system at hand can be classified as a Brain-Computer Interface (BCI) System [27]. A BCI system allows individuals to communicate with automated systems, such as robotic arms or prosthetic arms, by utilizing their brain activity, rather than muscular control. The fundamental concept behind a BCI is to translate patterns of brain activity produced by the user into corresponding commands [29]. A typical BCI system consists of signal acquisition and signal processing stages, which include pre-processing, feature extraction, and classification. Among the crucial components of a BCI system is the signal acquisition technique. The most commonly used and widely adopted method is electroencephalography (EEG), which offers a cost-effective and portable solution [28]. EEG involves recording brainwaves through electrodes attached to the subject's scalp, capturing signals with low-level amplitudes in the microvolt range and frequencies ranging from 1 Hz to 100 Hz. Specific features are extracted from the EEG signals and associated with different states of brain activity, allowing for the generation of commands for various applications [30]. The EEG headset or brainwave sensor detects the electrical signals from the brain and transmits them to a PC or laptop via Bluetooth in the form of data packets. The received data is then processed using the Arduino Integrated Development Environment (IDE), and the control commands are sent to the robotic arm through serial transmission. Based on the data received by the microcontroller from the PC or laptop, the system performs predefined actions determined by the level of concentration. These actions are outlined in Table 1 [31]..

Commands	Extracted Signal
One	Attention: Above 70
Two	Attention: Above 60
Three	Attention: Above 50
Close	Attention: Above 45
Four	Attention: Above 40
Five	Attention: Below 40

Table 1 : Data received based on concentration

The proposed multimethod controlled system is by default operated via voice commands due to its user-friendly interface and can be changed to any of the remaining modes of operation. In case if there are any emergency situations or if any of the control techniques is not working as desired, buzzer is equipped to send a message describing the issue to the family members of the user. The proposed block diagram is shown below [29].

6. Software & Hardware

The model comprises three modules: a software module, a mechanical module, and an electrical module. This architecture provides a flexible framework that can be customized to suit specific use cases. In a typical BCI system, two fundamental components are involved: signal acquisition and signal processing. Signal acquisition involves capturing brain signals, while signal processing encompasses pre-processing, feature extraction, and classification, as depicted in Figure 4 [30]. The software module plays a pivotal role in implementing signal processing algorithms and facilitating system integration. The mechanical module focuses on the physical design and construction, including components necessary for interaction or manipulation. The electrical module encompasses electronic components and circuitry for signal transmission, amplification, and interfacing with external devices. This modular design can be adjusted as per the requirements of the desired application.

Fig. 4: Brainsense Headset

Signal acquisition - Signal Acquisition is first step in signal processing. Here one is brainwave headset provided by Neurosky, is used to sense the brainwave signal. This EEG signal is passed to the signal pre-processing step [32].

Signal Pre-Processing: In the initial stage, the acquired signals undergo pre-processing to eliminate artifacts such as power line noise, electromyogram (EMG), electrocardiogram (ECG), electrooculogram (EOG), and body movement [31]. Following pre-processing, features are extracted from the signals, which serve as inputs for the classifier. The classifier then translates these extracted features into desired output commands. Filtering techniques, including lowpass, high-pass, band-pass, and notch filtering, are commonly employed to remove artifacts and frequency-specific noise, such as body movement and line noise [32].

Feature Extraction: Feature extraction involves deriving informative and non-redundant values (features) from the measured data to facilitate subsequent learning and generalization steps, leading to improved human interpretations. It is closely related to dimensionality reduction [33]. When input data is large and potentially redundant, feature extraction aims to transform it into a reduced set of features (feature vector) [34]. This process, known as feature selection, aims to retain relevant information for the desired task while reducing data dimensionality [35]. In the context of BCI systems for brain-controlled robots, features can be categorized into time domain features, such as amplitudes of event-evoked potentials, and frequency domain features, such as frequency power spectra of EEG signals [36].

EEG Module: The EEG module consists of a BCI headset responsible for detecting P300 waves and transmitting serial data to the processing unit. Any suitable open-source headset can be utilized, provided it meets latency and accuracy requirements. The construction of an EEG machine involves various raw materials, including flat, resin-coated printed circuit boards and electronic components such as resistors, capacitors, and integrated circuits composed of different metals, plastic, and silicon [37].

Control Module: The control module, implemented in software, serves as the processing unit responsible for translating raw EEG serial data related to specific thoughts into physical actions, such as arm lifting or object gripping. In our implementation, a Long Short-Term Memory Neural Network has been trained using a custom dataset [38].

Bluetooth Module: The Bluetooth technology manages the wireless communication channel, and Bluetooth modules facilitate wireless data transmission and reception between two devices. The Bluetooth module interacts with the host system through the host controller interface (HCI) [39].

Flex Sensors: The flex sensor is a crucial input sensor that plays a major role. It detects bending angles, and as the angle increases, the resistance of the flex sensor also increases. A potential divider circuit is employed to convert the change in resistance to voltage change. Flex sensors are typically attached to gloves using needle and thread. They require a 5-volt input and provide an output voltage ranging from 0 to 5V [41]. The resistance of the flex sensor changes unidirectionally, with a resistance of approximately 10K when unflexed and increasing to 30K-40K when flexed. The voltage divider, formed by the flex sensor and a resistor, divides the input voltage to produce the output voltage based on the ratio determined by the variable (R1) and fixed resistors (R2) [43].

HC-05 Bluetooth Module: The HC-05 module operates in two modes: Data mode, enabling data exchange with other Bluetooth devices, and AT Command mode, allowing changes to the default device settings [44]. The module can be easily paired with microcontrollers using the Serial Port Protocol (SPP). It requires a +5V power supply and connects the module's Rx pin to the microcontroller's Tx pin and vice versa for communication [45].

7. Conclusion & Future Directions

Human-Robot Interaction (HRI) encompasses various domains, and one notable application is in the field of prosthetics. The present project introduces a comprehensive approach to capture EEG signals directly from the brain using specialized electrodes, enabling the execution of corresponding actions based on these signals. By leveraging this methodology, the project aims to enhance the interaction between humans and robotic systems in the context of prosthetics. The speech recognition module will collect the data through vocal command and will perform efficiently. A hand gesture recognition system is built using Flex Sensors. The transmitted data will be mapped onto the arm to perform various actions. The Smart Prosthetic Hand will be integrated with signals from brain, voice commands and hand gestures. Also, a buzzer is included in case of any emergency. Thus, the Smart arm can effectively perform the essential tasks on daily-basis. Future work includes evaluation of the performance of this approach in hand-gesture understanding using both a larger vocabulary and a larger knowledge- base. In this paper, we present a 3-D hand motion tracking and gesture recognition via the wireless data glove using accelerometer. Instead of flex sensors and gloves, an AI algorithm or AI chip with high computational mathematics and programming can be implemented to make the hand respond to the thoughts of the user and head movements.

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