BRAIN-CONTROLLED ROBOTIC PROSTHETIC HAND

Sam Maddaloni, Grace Davis, and Raiyan Mohammed, Atif Said and Mohammed Benalla
Vaughn College of Aeronautics and Technology, Flushing, NY, USA
Corresponding Author: Mohammed Benalla <mohammed.benalla@vaughn.edu>

ABSTRACT

Today, there are many prosthetic options for amputees ranging from purely aesthetic to fully functioning myoelectric limbs. However, these options are not always viable due to high cost, invasive surgery, and long rehabilitation time. This paper describes a proposal for the design and development of a robotic arm that is controlled using electroencephalography (EEG) signals from the user's brain. This project aims to prove that a brain controlled 3D-printed prosthetic is more affordable and non-invasive. Additionally, calibration of the arm defers learning to the mechatronic system with the goal of minimizing rehabilitation required on the amputee's part. The robotic arm prototype is intended to aid upper limb amputees with a range of short below elbow (BE) to wrist disarticulation (WD) with their regular everyday functions. This project's research stems into the fields of biomedical, mechanical, and mechatronic engineering. During preliminary research and testing, brain signals were successfully measured using an Emotiv Insight EEG headset. The Emotiv BCI software enabled a user to command virtual movement using thoughts. This ongoing project will result in a brain-controlled prosthetic hand prototype.

Keywords: Upper Limb, Brain Computer Interface, 3D-printing, Robotic Hand

INTRODUCTION

One in every two hundred people are amputees in America [1]. There are many prosthetics available today with a range of advantages and limitations. Cosmetic prosthetics are primarily for aesthetic purposes but can also be used for balance. The cost and rehabilitation time associated with this option are comparatively low as seen in Table 1. During the American Civil War, over 70,000 soldiers had a limb amputated [2]. As a result in the 1860s, mechanical functions were added to prosthetics by using straps attached to the amputee's body [3]. Mechanical arms today offer limited functionality but require extensive rehabilitation time. Mechanical options require little to no invasive surgeries and are often detachable.

In order to offer more functionality to upper limb amputees, myoelectric technology was integrated into prosthetics in 1948 by a Munich University physics student, Reinhold Reiter. Electromyography (EMG) sensors were used to measure the electrical signals of muscles in the residual limb, and the signals were used to control motors on the prosthetic [4]. The Bebionic myoelectric hand is the most sophisticated myoelectric hand available today. It features different hand sizes and wrists, fourteen grip patterns, opposed and unopposed thumb positions, and grip-enhancing soft finger pads. The Bebionic hook grip can carry up to a 45 kg load, and each finger can hold up to 25 kg. The price of a Bebionic hand starts at about $11,000, but this does not include the additional costs of an arm if needed, surgery, and rehabilitation [5].

In order to successfully use a myoelectric prosthetic, muscles in the residual limb must be able to produce the minimum microvolt threshold required to receive the electric signal from the muscle [6]. Further, the amputee must also be able to control the amplitude of the signal in order to proportionally control the speed and grip force of the machine [7]. For full arm, bilateral, or paralyzed amputees, the ability to control a myoelectric prosthetic significantly lessens or may not be possible at all.

Table 1. Comparison of Available Prosthetic Devices

	Cosmetic	**Mechanical**	**Myoelectric**
Cost	< \$5,000	< \$10,000	\$10,000 - \$20,000
Invasiveness	None	Minimal	Minimal
Rehabilitation	6-12 months	12+ months	12+ months
Functionality	Passive	Basic movements	Many grip patterns

New research into brain-controlled prosthetics aims to provide an option for these amputees and to significantly decrease rehabilitation time. The Johns Hopkins University Applied Physics Lab has developed the Modular Prosthetic Limb (MPL), a high-fidelity brain-controlled closed-loop anthropomorphic device. Using targeted muscle reinnervation surgery, a procedure that reassigns the nerves in the residual limb, in conjunction with the MPL, scientists were able to offer sensory feedback to the amputee. With more than 100 sensors, the MPL enables amputees to regain a sense of touch resulting in a closed-loop prosthetic. Brain-controlled prosthetics are still considered experimental. They currently require very invasive surgery and cost around \$500,000 [8].

Neurons throughout the human body use electrical signals to transmit and receive information amongst one another using synapses [9]. The brain contains about 100 billion neurons [10] which emit a synapse 0.1 - 2 times per second [11]. Measuring differences in electrical charges between electrodes is called electroencephalography (EEG). These signals are very small, measuring in tens of millivolts; therefore the signal must be amplified [9].

The brain is made up of four main lobes: frontal, temporal, parietal, and occipital. The frontal lobe is responsible for planning and decision making. The parietal lobe processes sensory information such as touch and speech. Information processing for vision occurs in the occipital lobe. The temporal lobe is responsible for sensory information processing such as hearing [12].

The International Federation of Clinical Neurophysiology developed the International 10-20 electrode placement standard for EEG testing (Figure 1). It is called the 10-20 system because each electrode is placed either 10% or 20% apart. The first letter of the electrode represents the brain lobe that it is located. The numbers indicate which hemisphere of the brain the electrode is located- odd numbers for the left and even numbers for the right hemispheres [13].

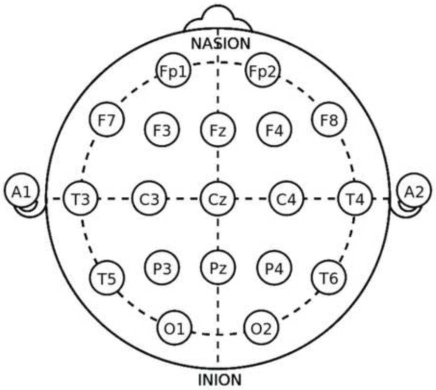

Figure 1: The International 10-20 Electrode Placement Standard

The objective of this project is to address the major limitations of current prosthetics by processing electrical signals from the brain using an EEG headset to control a robotic arm.

METHODS

The 3D printed Arm

Stereolithography (SLA) is a method of 3D printing that converts liquid materials into solid parts, layer by layer, through UV light. This material is under consideration as it is already widely used in the prosthetic field, it creates very fine details with a smooth finish, and it easily scales which is very beneficial to adapt to many different arm sizes, or growing children. The same design would be able to be printed in different sizes as they grow. However, the con of this material is that it is one of the more expensive ones, and this prosthetic needs to be affordable to the everyday consumer.

Servo motors and Tendons

The servos used for this project are the Hitec HS485HB servo motors. This project requires seven motors to be used. Five are used for movement of the fingers and thumb and two used for movement in the wrist; one for rotation of the wrist and the other for gliding movement. These motors produce a torque of 72.6 oz-in and a motion speed of 0.2 seconds at 4.8 V. According to the definition of torque, $\tau = \perp$ □ × □ × □□□□, using a 1 inch arm on the servo produces 0.28 N in the fingers. The average human grip strength is 20 N grip force. The tendons are made of an 80 lb nylon line which transfers the tension between the servos and the fingers to produce the gripping force.

The microcontrollers and servo shield

The microcontroller used for this project is the Arduino Uno interfaced with a Raspberry Pi Zero. Both work together because of their different uses. Raspberry Pi is integrated with low energy bluetooth capability (BLE). This type of bluetooth is recommended to communicate with the Emotiv Insight headset. The Raspberry Pi will receive the signals, and then it will filter and process them. This microcomputer has a 1.0 GHz CPU and 512 MB RAM. The power consumption will be approximately 5 V and 160 mA. The Raspberry Pi communicates with the Arduino Uno which is capable of controlling the motors. The Arduino Uno has a 16 MHz processing time and is easily programmable. It also runs at around 5 V of power. The servo shield used is an Adafruit PWM/servo shield. The shield provides an easy way to prototype with sensors and servos. Also, the servo shield minimizes space usage because it does not need extra wires to power the servo and sensors. Both signal and power are supplied from this part.

Power supply and power booster

The power supply being used is Adafruit. The battery used is the Adafruit Li Ion 3.7 V 2000 mAh. This results in about 7 hours of battery life, considering the whole system uses 293.33 mA. The power booster is the Adafruit PowerBoost 500 Shield - Rechargeable 5 V Power Shield. This is used to boost the battery power from 3.7 V to the 5 V required to power the microcontroller, the microcomputer, the shield and the Bluetooth receiver. Also, this the required voltage to obtain the torque needed in the servo motors being used.

Communication

The Emotiv Insight headset is compatible with Bluetooth Low Energy for wireless communication. Bluetooth is a low-energy and automatic wireless connection that transmits information through radio waves [14]. Bluetooth Low Energy (BLE) uses seventy-five percent less energy than popular Bluetooth 4.0 [15]. It is important for the prosthetic to minimize power requirements because the arm has limited space for a large battery. Additionally, it is necessary for the arm to be wireless to maximize comfortability and convenience.

The Emotiv Insight sends signals to the Raspberry Pi via Bluetooth LE. The Raspberry Pi processes those signals and sends them to the Arduino Uno via Bluetooth. The Arduino Uno receives input from the Raspberry Pi, pressure sensors, and temperature sensors. The Arduino Uno interfaced with the Adafruit Motor Shield controls the servo motors (Figure 2).

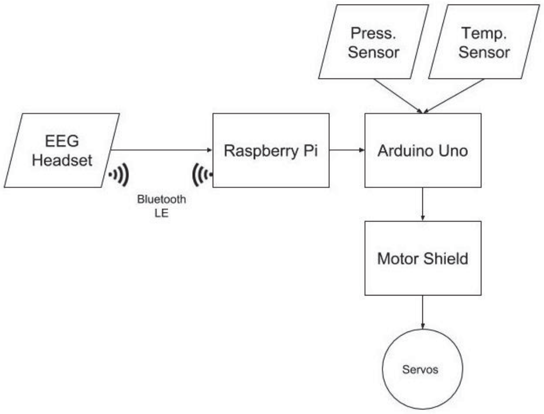

Figure 2: Communication and Hardware

Signal Processing and Programming

The EEG technology used for this project is the Emotiv 5-channel headset. The Emotiv Insight interfaces with Emotiv BCI software to filter out noise from amplified signals. Additionally, Emotiv BCI allows users to train resting and various mental commands. In other words, the software learns the state of the brain during different actions in order to calibrate the EEG headset.

When the robotic arm is turned on, the user will be prompted to choose calibration or live mode. During calibration mode, the Emotiv BCI software will prompt the user to focus on a specific hand motion. The signals received from the headset will be recorded on the Raspberry Pi. The Raspberry Pi will be programmed to compare signals received from the EEG headset during live mode to those prerecorded during calibration mode. During live mode, when the Raspberry Pi recognizes a set of signals from the headset, it will send the necessary commands to the Arduino Uno and Motor Shield to actuate the appropriate servos on the prosthetic arm.

RESULTS AND DISCUSSION

Preliminary trials with the Emotiv Insight headset have been conducted to test its accuracy and reliability. Through trials, participants have found that the five sensors of the headset must be in the correct position and have good contact with the skin to provide efficient signals. A saline solution has been applied to increase conductivity, and as a result better signals from all the electrodes were obtained. During calibration, The Emotiv BCI software displayed a 3D cube on the screen. First a baseline sample was taken of the cube sitting in a resting position, then using various training exercises such as push, pull, lift, and rotate, the user was able to train the cube to respond to his or her thoughts. For each motion the program required two baseline tests during which the user watched the cube on the screen move under its own volition while the headset recorded the signals received. Any future training on the same motion was compared to the two initial baseline tests. If the signals received were not close enough to the baseline tests, the user was able to choose to store or erase the results of that session. Possible causes of poor training sessions included a loss of concentration, getting distracted, or simply losing connection to the electrodes or headset. Through trials with various participants, it was found that a minimum of four training sessions were required for accurate control during live sessions. The ability to accurately control the cube during live sessions directly increased as the number of completed training sessions increased. A few different strategies to consistently train the headset were developed. Many people found that actually performing the motion by mimicking the pushing motion or lifting their arm had helped with consistency in training trials. Another way to train was visual imagery association. Instead of watching the cube lift or push one can think of things flying or getting smaller. The most effective training method is being analyzed from these trials.

FUTURE WORK

During the first phase, the movements intended to be achieved are basic opening and closing the fingers, turning the wrist, and gripping an object. The second phase includes completing some additional everyday household tasks such as eating and drinking, brushing teeth, turning on and off light switches, and turning keys. Once these are completed, the purpose of the third phase is protect the prosthetic by implementing sensors. Temperature sensors will provide feedback not only for the user's safety, but also to let the user know this temperature is dangerous to the device. Additionally, the arm will be waterproof to protect the electronics. Wet and dry sensitive skin covering the arm will notify the user how wet or dry something is.

CONCLUSION

Through our research, it is evident that currently available prosthetics have serious limitations due to their expensive costs, invasiveness, and long rehabilitation times. Additionally, those afflicted by paralysis or shoulder disarticulation require an option that does not rely on EMG signals. By harnessing brain waves in the form of EEG signals and integrating them into a brain computer interface, the ability to control a robotic arm will become available to amputees and other patients. Throughout the length of this project, major focus will be allocated to completing all three phases while maintaining a low cost and high fidelity prosthetic arm. The proposed brain-controlled prosthetic arm costs less than $700, which is affordable for quickly growing pediatric and low-income patients. In addition, the robotic arm is environment-friendly, food safe, and energy-efficient.

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