AFFORDABLE EEG-CONTROLLED PROSTHETIC ARM USING AI AND ML WITH HAPTIC FEEDBACK

Rithinteja Aechan, Mehdi Hussain

1/4/24

Table of Contents

Abstract

Being an amputee can have a considerable impact on the lives of individuals. A study on the Global prevalence of traumatic non-fatal limb amputation found that worldwide, over 57.7 million people suffer from some sort of limb amputation caused by traumatic causes such as falls, road injuries, and other transportation injuries (McDonald CL, Westcott-McCoy S, Weaver MR, Haagsma J, Kartin D., 2021). Furthermore, a study conducted on the Mental Health of Individuals With Post-Traumatic Lower Limb Amputation concluded that many amputees often find themselves having severe mental health issues later on in life including a feeling of helplessness and lower self-esteem, and have a much more negative outlook on the future (Şimsek, N., Öztürk, G. K., & Nahya, Z. N., 2020).

What if there was a device that could alleviate these problems and enhance the lives of amputees? This engineering project aims to create a device for amputees that utilizes a Raspberry Pi 3, Nuerosky Mindwave Mobile 2 Headset, and InMoov Hand and Forearm in order to assist users to be able to control a 3D printed prosthetic arm using variations in brain activity, including attention, meditation, and blinking. The goal of this project is to enhance the lives of amputees and create a more affordable, non-invasive solution that offers amputees an enhanced quality of life through a prosthetic arm equipped to reduce the physical, emotional, and financial burdens associated with traditional prosthetic options.

Introduction

A study on the Global prevalence of traumatic non-fatal limb amputation found that worldwide, over 57.7 million people suffer from some sort of limb amputation caused by traumatic causes such as falls, road injuries, and other transportation injuries (McDonald CL, Westcott-McCoy S, Weaver MR, Haagsma J, Kartin D., 2021). Furthermore, a study conducted on the Mental Health of Individuals With Post-Traumatic Lower Limb Amputation concluded that many amputees often find themselves having severe mental health issues later on in life, including a feeling of helplessness and lower self-esteem, and have a much more negative outlook on the future (Şimsek, N., Öztürk, G. K., & Nahya, Z. N., 2020).

Many current prosthetic arms on the market suffer from a high cost of entry, a lack of sensory and haptic feedback for the user, and being generally uncomfortable and heavy for the user over longer periods, especially when it's the user's primary use of mobility. Current models of prosthetic arms that are available to users suffering from a wide range of disabilities cost upwards of $50,000, making them unattainable for most Americans, and nearly impossible to obtain in developing countries.

Information on parts used

Raspberry Pi 3 Model B+

The Raspberry Pi is a board that acts as a computer. The Raspberry Pi can be used for a variety of purposes. It can run a variety of operating systems, including the official Raspberry Pi operating system, Raspberry Pi OS, as well as other popular systems such as Linux and Windows

10 IoT Core. Despite its small size, the Raspberry Pi has numerous USB ports, an Ethernet connector, an HDMI port, and a microSD card slot, making it extremely adaptable and accessible for a wide range of projects. In this research project, the Raspberry Pi was used to compute AI/ML models and to operate the servos for the prosthetic arm.

InMoov Hand and Forearm

Built by French sculptor and designer Gael Langevin, the InMoov robot parts are an open-source set of 3D prints used to build parts of fully assembled life-size robots. In this research project, we made use of the InMoov Hand and Forearm, which includes 3D prints that allow us to use servos operated by the Raspberry Pi to open and close the hand and move around the forearm.

Neurosky MindWave Mobile 2 Headset

The Neurosky MindWave Mobile 2 Headset is an EEG-enabled headset that allows for the tracking of brain activity through alpha, beta, gamma, and delta waves. Each of these wave types is associated with different states, such as the level of attention, meditation, and whether or not one is blinking. Within this research project, the Neurosky MindWave Mobile 2 Headset is used to gather brain activity from the user in order to identify key mental states and operate the prosthetic arm without the need for manual input.

Neurosky Mindwave (EEG) Device Dataset

In order to most effectively make use of the data provided by the Neurosky Mindwave Mobile 2 Headset, the Neurosky Mindwave (EEG) Device Dataset provides over 300+ sample pieces of data in order to correlate and provide accurate values for attention, meditation, and blinking by offering hundreds of past accurate values of alpha, beta, gamma, and theta waves. Within this research project, we make use of the Neurosky Mindwave (EEG) Device Dataset to provide accurate results for the user when they interact with the Neurosky Mindwave Mobile 2 Headset to operate the prosthetic arm.

Engineering Problem

How can we improve the quality of life for individuals who are amputees through a more affordable, non-invasive solution that offers amputees an enhanced quality of life through a prosthetic arm equipped with haptic feedback to reduce the physical, emotional, and financial burdens associated with traditional prosthetic options.

Engineering Goal + Outcome

Using a Raspberry Pi 3, EEG brain sensors, open-source InMoov prosthetic parts, and trained AI models, we want to create a non-invasive inexpensive prosthetic arm that can be easily trained and worn for the user that provides haptic feedback. We expect a device that is compact, portable, and comfortable to wear.

Methods

Equipment:

- Raspberry Pi 3
- Jumper Wiring
- Gyroscope Module
- Bluetooth Module
- 3 x Mini Vibration Motors DC 3V 12000rpm Flat Coin Button
- NeuroSky MindWave Mobile 2: Brainwave Starter Kit
- 3D print Robotic Prosthetic Arm
- 6 x Treedix Servo Motors

Simplified Procedure:

1. 3D print prosthetic arm components using available open-source libraries
2. Assemble basic skeleton of prosthetic arm by assembling 3D printed parts
3. Establish connection between servos and fingers through attaching fishing line
4. Program connection between NeuroSky Mindwave & Arduino, and return servos to standard position (0 degrees)
5. Write a simple program to test connectivity between NeuroSky Mindwave, Servo Motor, and any other required materials.
6. Develop an algorithm to allow movement with a robotic arm, using trained models from EEG Sensor values (e.g., opening/closing the prosthetic hand, moving the arm).

7. Evaluate results from the prosthetic arm with EEG-Headset on the head and make necessary adjustments.

Information

Our final product should be able to accurately obtain EEG data from brain activity from the Neurosky Mindwave Mobile 2 Headset and use that data in order to operate the prosthetic arm and maintain both an appropriate grip strength and accurately operate based on user input.

Designs/Circuit

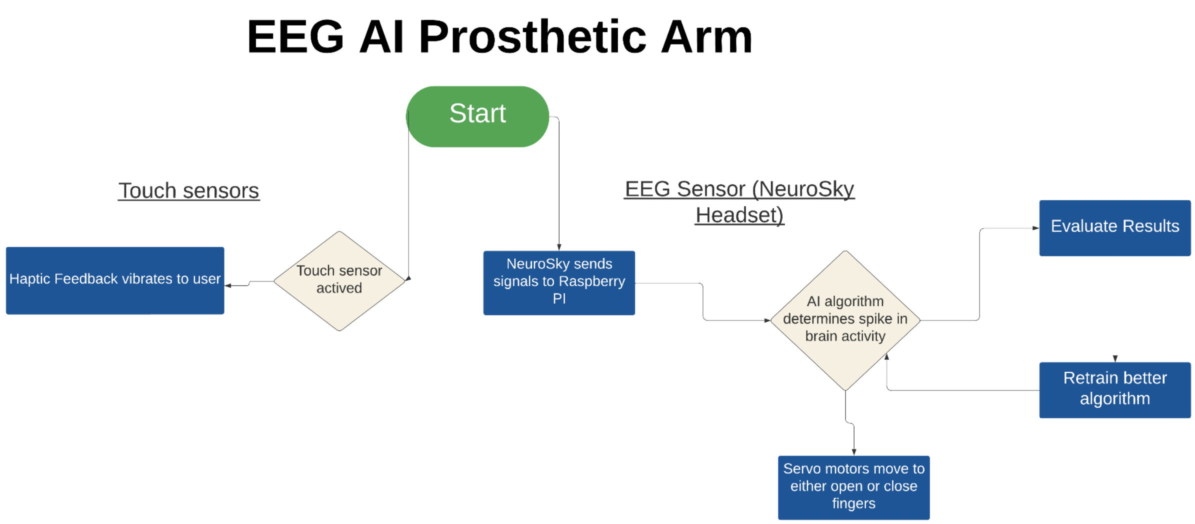


Figure 1: Above is a flowchart of how the prosthetic arm will work.

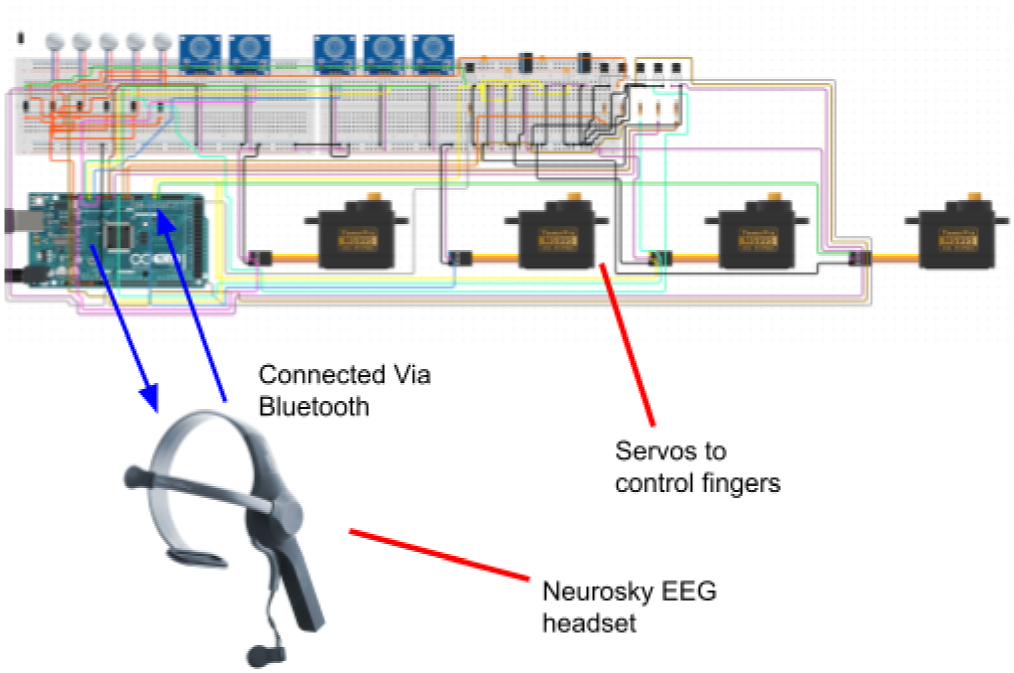
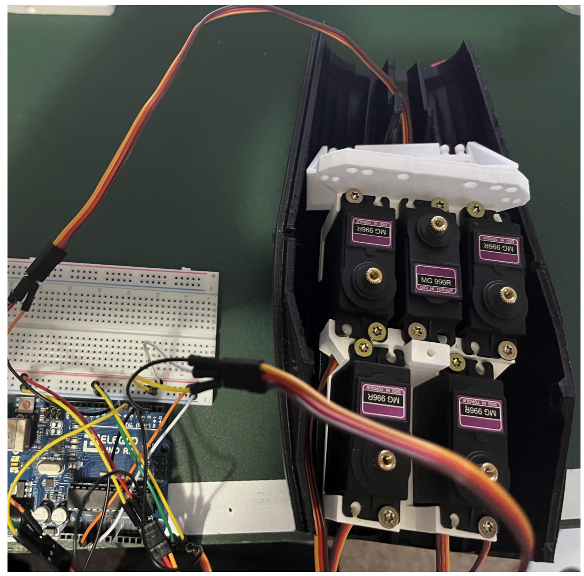


Figure 2: Above is a circuit diagram of the Neurosky EEG headset that is connected to a Raspberry Pi via Bluetooth that controls the fingers of the prosthetic arm.

Prototype

The building of the base of the forearm of the Inmoov prosthetic arm was done first, and the servos were tested to ensure they were in the correct position.

Photo on right by Rithinteja Aechan



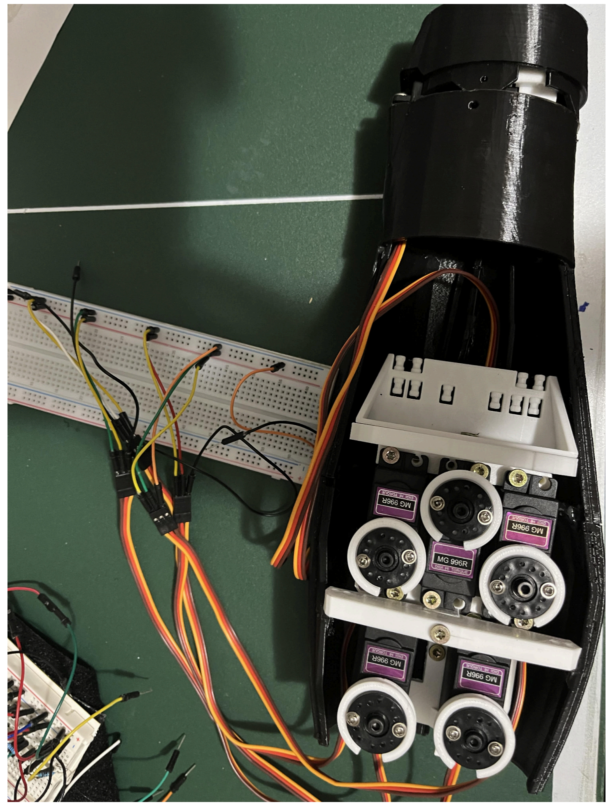
In order to ensure that our EEG-Prosthetic Arm would function properly according to Neurosky user input, we made use of the Naive Bayes Model and Linear Regression models in order to obtain threshold values of attention & meditation that would be used to identify whether the hand should be opened or closed at any given time.

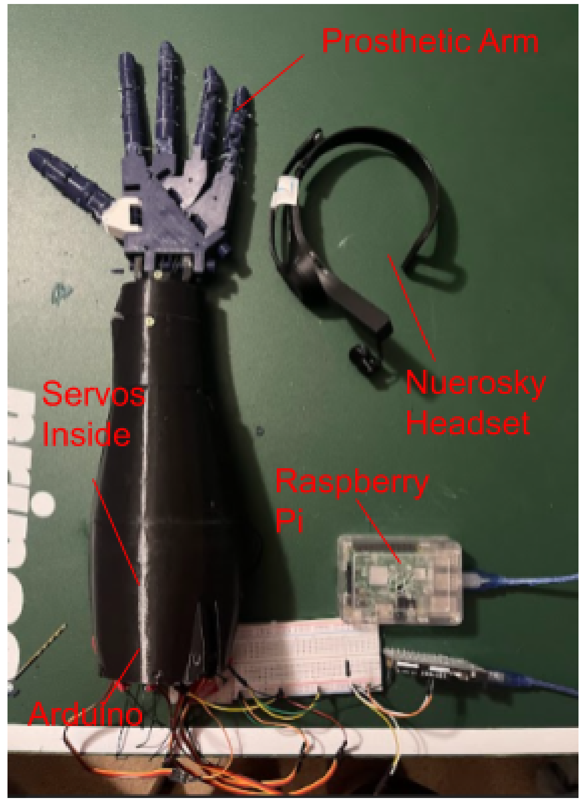
Affordable EEG-Prosthetic Neurosky ML Model Data Points

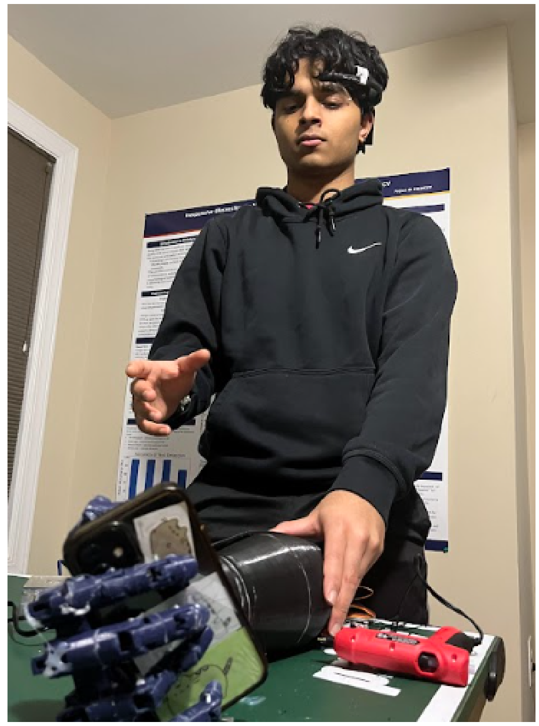
	Attention	Meditation	Delta	Theta	lowGamma	highGamma
0	13	87	530285	91823	2315	6432
1	18	82	290384	38992	6433	1345
2	73	27	182933	43293	7345	4355
3	29	61	985432	23418	3124	4234
4	8	92	643911	68132	1242	8234
5	15	85	518234	12533	6433	8432
6	12	88	132955	61923	5546	2345

```
Accuracy Array Model based on ML model:
 [[5 9 8 2]
 [8 1 2 6]
 [7 3 1 5]
 [3 6 7 3]]

Accuracy Score based on predictive model: 33.999999999999986
```

The wrist section, as well as the gears, were added to the Inmoov prosthetic arm. Photo on right by Rithinteja Aechan	

All components for the prosthetic arm were connected, which included the Camera module, the Raspberry Pi, and Neurosky. The diagram on top right by Rithinteja Aechan Photo on the bottom right of student researcher (Rithinteja Aechan) by Mehdi Hussain	



Analysis

To analyze the accuracy of our project, we tested the response time of how the Prothetic Arm would close with concentration or blinking, and the response time for opening with meditation and opening values.

Response Time of Prosthetic Arm in Seconds

Trials	Concentration (Closing)	Meditation (Opening)	Blinking (Closing)	Blinking (Opening)
1	1.54	2.3	0.55	0.67
2	1.78	2.8	0.47	0.54
3	2.52	1.87	0.76	0.78
4	1.34	3.3	0.43	0.89
5	3.75	2.53	0.97	0.34
6	4.36	4.32	0.58	0.59
7	3.22	3.54	1.3	0.89
8	4.54	2.32	0.76	0.96
9	2.3	1.24	0.96	1.12
10	2.8	5.43	1.4	0.89
Median	2.66	2.665	0.76	0.835
Mean	2.815	2.965	0.818	0.767
St.Dev	1.136556691	1.22947369	0.3368415387	0.2314231334

Figure 3: Above is a chart showcasing the different response times according to the setting of the Neurosky headset. The setting is for concentration to close the fingers, the next is meditation to open the fingers, blinking to close the fingers, and blinking again to open the fingers.

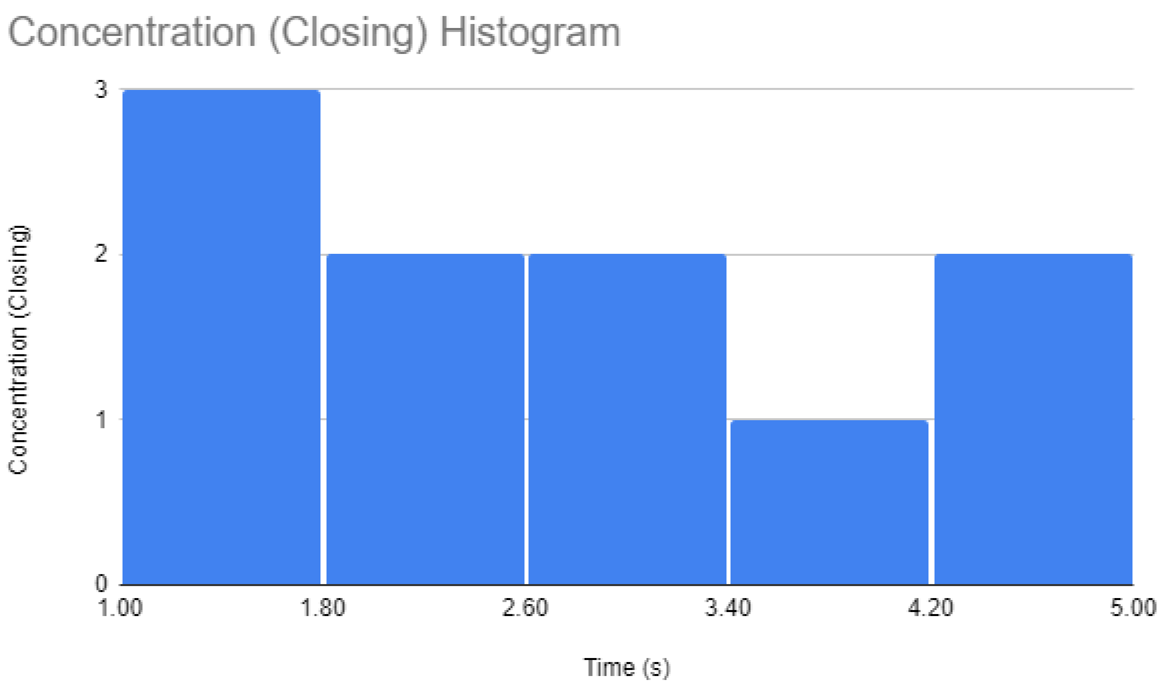


Figure 4: Above is a histogram of the response times of the fingers closing according to concentration values sent by the Neurosky headset.

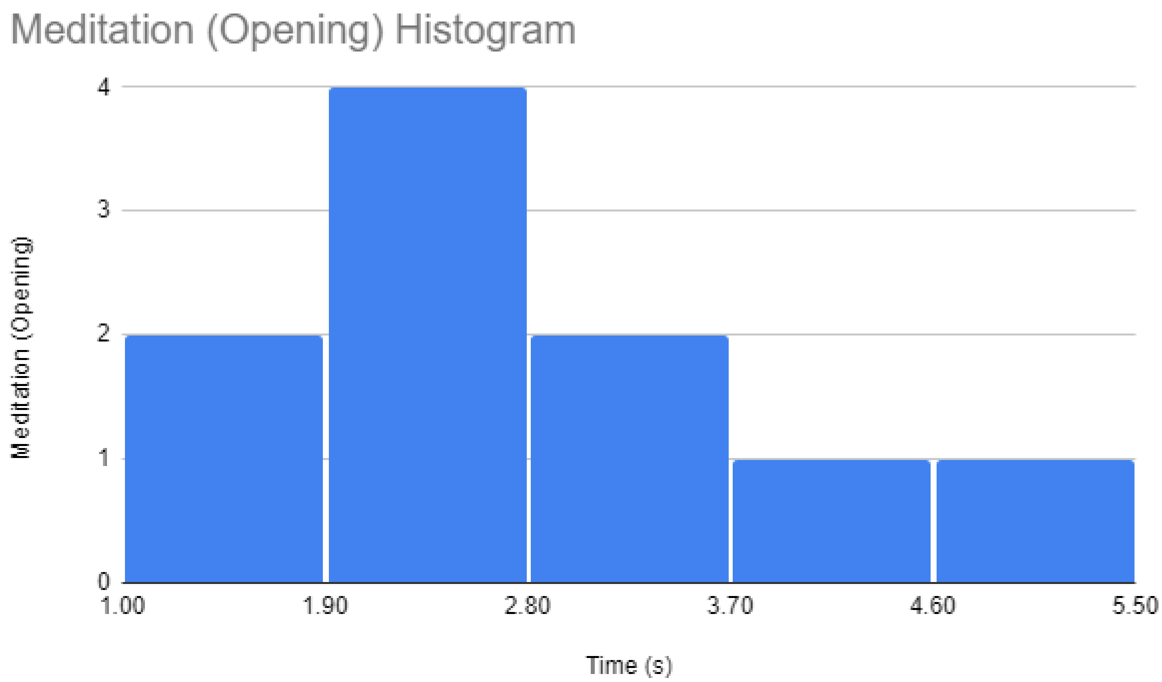


Figure 5: Above is a histogram of the response times of the fingers opening according to meditation values sent by the Neurosky headset.

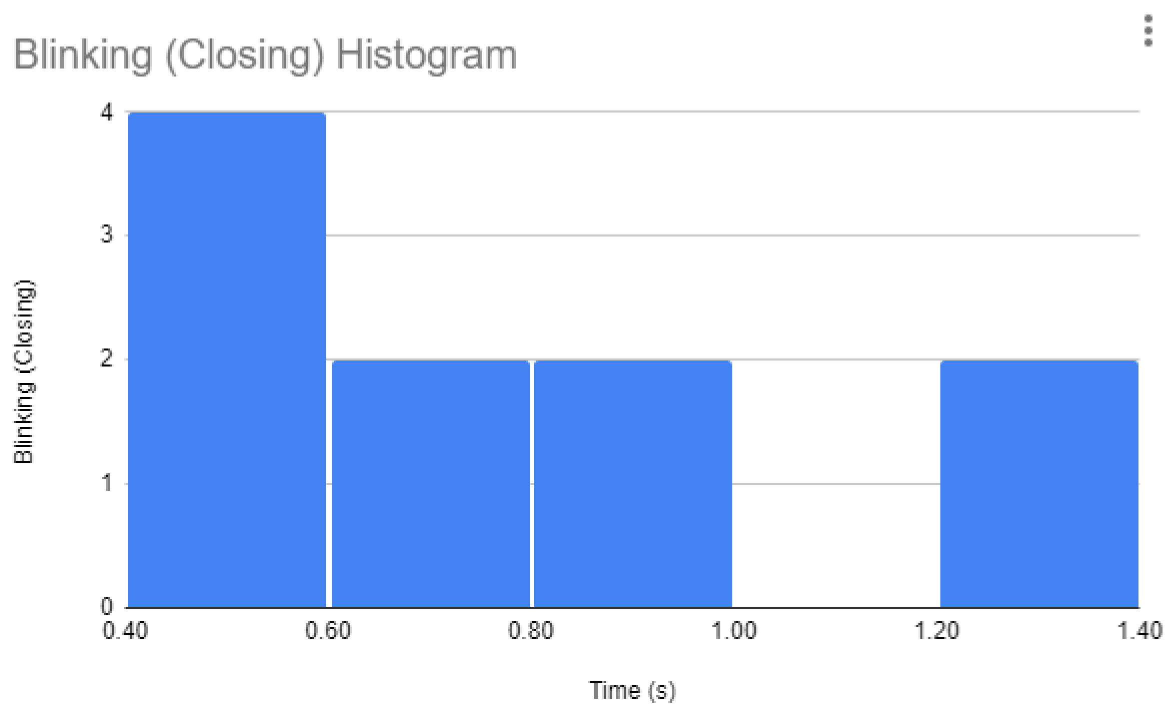


Figure 6: Above is a histogram of the response times of the fingers closing according to blinking values sent by the Neurosky headset.

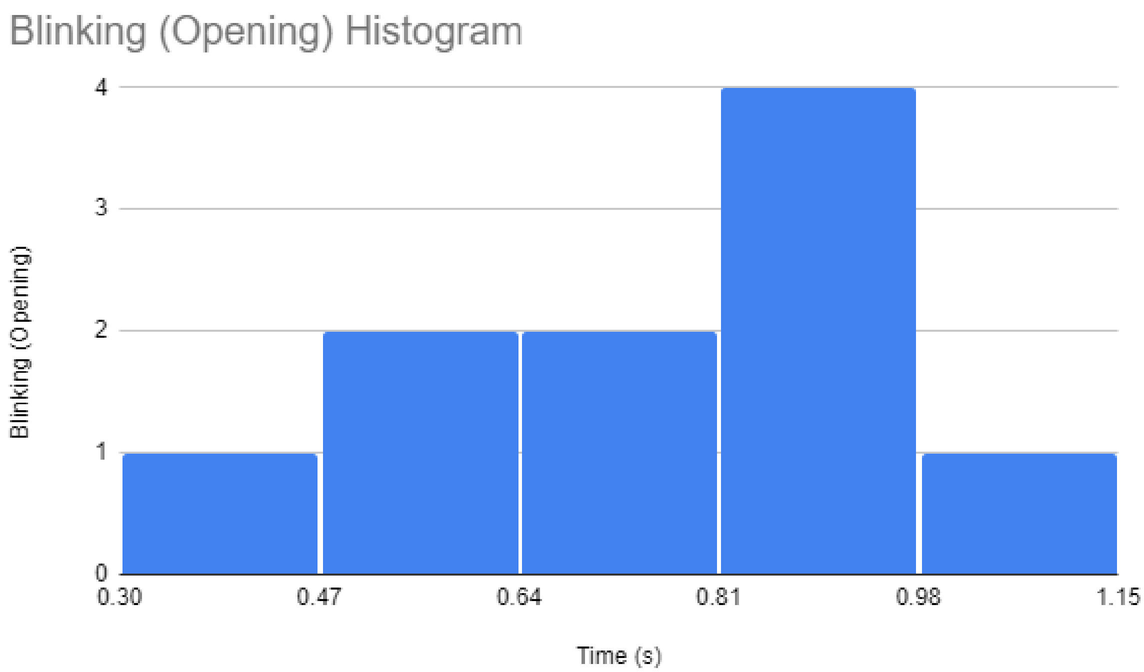


Figure 7: Above is a histogram of the response times of the fingers opening according to blinking values sent by the Neurosky headset.

Figure 8: Above is the arm being tested for a common object such as the phone.

Figure 9: Above is the arm being tested for a common object such as a Minifigure.

Figure 10: Above is the arm tested for a common object such as a water bottle.

Conclusion

Based on the results shown during the grip strength test and the accuracy of the opening/closing of the EEG prosthetic arm, our EEG-controlled robotic arm is able to perform at a highly accurate and competent level. From Figure 10 of the different response times, we were able to find out that having the EEG detect the blinks would be a faster approach in closing and opening the claw as the Nuerosky headset accurately records the data for when the situation happens. However, this may cause discomfort to the user as every time they need to open and close the hand, they need to blink. The other approach, with concentration and meditation to open and close the hand, respectively, is still a viable option as there is a median of 2.6 seconds and a mean of 2.9 seconds for both opening and closing the arm.

Upon both reviewing and testing our first iteration of the EEG Controlled Robotic Arm, we have concluded that several key improvements can be made to enhance the user experience and better aid amputees. We identified that our arm weighs much more than a typical arm weighs, sitting at 10.4 pounds compared to 2.41 pounds for the average human. In a second iteration of our design, we would make use of lighter servos such as the Wishiot Mini Super Light 3.7g Digital Servo or other nano-servos that could provide the same grip capability while reducing weight. In order to solve the problem of not having haptic feedback, we plan on using a touch sensor and haptic feedback buzzers to give back the sensation of touch when the fingers touch an object. We also plan on having a gyroscope sensor added to the device to allow for forearm rotation. In addition, we found that our AI model, while extensive, fails to carry certain situations, especially when the attention and meditative states sit in close proximity to each other. Our future iterations will make use of an ML model that consists of more individuals and a variety of situations in order to fine-tune and better obtain values for the alpha, beta, gamma, and theta waves and make sure the prosthetic arm operates efficiently and correctly based on user input. Lastly, we plan on creating our own EEG headset and creating our own arm rather than making use of the Nuerosky Mindwave Mobile 2 and the InMoov Hand and Forearm in order to create a more sleek and less bulky solution for those with amputees.

The EEG Controlled Robotic Arm was created with the intention of aiding those amputees. However, the applications of our product are much more large and extensive in scale. One example of this is the application of our product for paralyzed individuals, who require a similar set of tools and devices as those who are amputees, and our product could help aid the lives of the paralyzed as well. Our robotic arm can also be applied in industrial applications, in hazardous environments which forbid humans from being able to work or perform tasks. This includes many industries, such as car manufacturing, construction, and mining.

References

Kawashita, T., Dunnsiri, T., Shu, S., Tran, P., & Agustines, D. (2019). Losing Legs to Losing Everything: How Neglecting Holistic Health Devastated a Lower-limb Amputee. Cureus, 11(12), e6275. https://doi.org/10.7759/cureus.6275

McDonald CL, Westcott-McCoy S, Weaver MR, Haagsma J, Kartin D. Global prevalence of traumatic non-fatal limb amputation. Prosthet Orthot Int. 2021 Apr 1;45(2):105-114. doi: 10.1177/0309364620972258. PMID: 33274665.

Pezzin, L. E., Padalik, S. E., & Dillingham, T. R. (2013). Effect of postacute rehabilitation setting on mental and emotional health among persons with dysvascular amputations. PM & R : the journal of injury, function, and rehabilitation, 5(7), 583–590. https://doi.org/10.1016/j.pmrj.2013.01.009

Şimsek, N., Öztürk, G. K., & Nahya, Z. N. (2020). The Mental Health of Individuals With Post-Traumatic Lower Limb Amputation: A Qualitative Study. Journal of patient experience, 7(6), 1665–1670. https://doi.org/10.1177/2374373520932451

Amputee Coalition. (n.d.). Limb Loss in the U.S. ACL Administration for Community Living. Retrieved July 31, 2023, from https://acl.gov/sites/default/files/programs/2021-04/llam-infographic-2021.pdf