Developing Low-Cost BCI-Based Brain-Limb Interaction Device with Prosthetic Hand

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Abstract

Inventions that are designed to heal the body and/or mind should always be sought. Currently, too many people are lacking access to cheap prosthetic devices, especially those that allow neural connections to be gained with such devices. This is the reason why this study intends to propose a low-cost invention that is able to enable people to gain back concentration with limb use using Python Programming language, an EEG Neurosky headset, an Arduino, and a 3D-printed prosthetic hand. With our implementation, the proposed method can explore the boundaries of improving attention and continue to develop higher-level BCIs for the mind-limb connection, improving on current-day prosthetics and concentration/limb connection rehabilitation

Keywords: Low-cost prosthetic, BCI, Brain-limp, Interaction, 3D-printed prosthetic

1. Introduction

Technology to help is the greatest form of technology. And the biggest help that can be done is for the medical industry. Prosthetics will always be in demand. It is always good to develop solutions for human augmentation because there will always be people who need that technology. The technology surrounding the Brain-Computer Interface is still quite new. Thus, it is still very much an emerging field that should be actively pursued. Prosthetics are quite the engineering marvel. Prosthetics often require having multiple systems to work, especially precise prosthetics where the brain acts as the controller for the prosthetic. These kinds of robots must require handling data transmission, and building robot mechanisms, and must include the use of integrated circuits. Through the development of the prototype, it also was quite clear that the prosthetic could be used as some sort of attention rehabilitation. Because the prosthetic movement is based on the user's attention, it was apparent that this robot could be used as an interactive game to improve the attention of the user.

In this present study, a low-cost BCI-based interactive device is proposed to be used for attention rehabilitation for the user. This proposal is meant to be a prototype for further BCI prosthetic development.

2. Background

2.1. *Prosthetics and their Cost*

The cost of prosthetic limbs is quite steep. Osseointegrated prosthesis are prosthetics that are attached to the bone instead of the traditional socket-suspended prosthesis, which uses a socket on the amputated limb. Furthermore, socket prosthetics have introduced more microprocessor implementation, which leads to much easier use and better quality of life for the user [1].

But in the case of both types of prosthetics, the process of getting a prosthetic is quite expensive. In the case of prosthetics, the average healthcare cost in a 12-month post-amputation is 99,409 USD. An earlier recipient would have approximately 25% lower total direct healthcare cost compared to people to get their prosthetics later. This shows that not only are prosthetics causing a lot of cost in total healthcare costs (rehabilitation, etc.), but also that earlier access can reduce cost and help the patient [2].

This shows that a major goal in the rehabilitation field should be to improve the cost for better accessibility and work on solutions that make prosthetics faster to make and easier to use. Making prosthetics faster to make also reduces wait time, allowing for the patient to quickly recover and decrease the cost through faster access.

2.2. *Attention at a Decline*

As technology advances, it affects our psychological limits. The idea of shrinking attention spans is gaining a lot of traction in the media and in research. But one thing is certain: digital distractions can cause our attention spans to shorten. Companies have also started to investigate improving the attention spans of their employees [3].

Children are also extremely affected by the digital age, and so there is documented an increase in attention problems from 1983 to 2017. A possible cause for this effect is that children usually spend more time on the screen multitasking which can really affect their attention regulation skills [4].

Either way, the idea of increasing attention spans is a highly researched topic. This is definitely something that has a demand in our society, as more and more people give importance to their attention spans.

2.3. *Neurosky Mindwave Mobile*

Fig.1 The Neurosky Mindwave Mobile 2, the Headset used in this paper [5].

The Neurosky Mindwave Mobile 2, as seen in Fig. 1, is an optimal EEG headset because it is cheap considering the EEG headset market. More importantly, if it is possible to make a product out of the Neurosky Mindwave Mobile 2, then it means that there is a chance to develop a cheap BCI prosthetic, which would disrupt the prosthetic market. Most professional EEG headsets are used for medical purposes, thus aren't easily accessible to the public. However the Neurosky headsets are mostly used for commercial purposes. These headsets are used for small games, or for small research, thus it is one of the best candidates for this interactive device if this was to be commercial.

The Neurosky headset has a specific set of parameters which make it easy to interpret brainwave data. These parameters are *Attention, Meditation, RawValue, Delta, Theta, LowAlpha, HighAlpha, LowBeta, HighBeta, LowGamma, MidGamma, PoorSignal*. The Attention and Meditation parameters are both defined on the NeuroSky website as an *eSense* Meter, in which their own parser, ThinkGear Connector, does the calculations from the headset's brainwave data, allowing the user to know their attention and meditation levels without having to program a separate algorithm to calculate the attention or meditation of the user. Although the brainwave data is provided, for them to be used effectively, a deep learning algorithm would be needed to analyse and find patterns in the data. The *RawValue* is a data value of the raw wave sample, consisting of 2 bytes, one byte for the lowest value and the other byte for the highest value. This is the raw wave value before it is converted into individual brainwave values. The *PoorSignal* is a value that represents the headset signal strength. The *RawValue* and *PoorSignal* are mainly used for debugging purposes.

There are 2 ways of extracting data from the headset using Python, Serial communication, and a Telnet connection. The Serial communication bypasses Neruosky's own connector/parser, ThinkGear Connector. So if the code were to establish a serial connection, then it would also have to parse the data as well. The serial connection connects to the headset by sending it the connection byte, and so the headset connects to the program without any help from the ThinkGear Connector. This is a less restrictive way of gaining the data and allows for the user to force connect to the headset without any issue encountered in previous testing. Not only this but Serial connection allows for better control of the data, but that comes with the cost of inaccuracy because the parser has to be custom written.

The Telnet connection connects to the ThinkGear Connector. So, for the telnet connection to work, the headset must already be connected to the ThinkGear Connector. Then the ThinkGear Connector will parse the data from the headset, and the telnet connection allows for parse data to go through in a JSON dump. This allows for more accurate data but is harder to run as previous testing showed that the ThinkGear Connector was unstable.

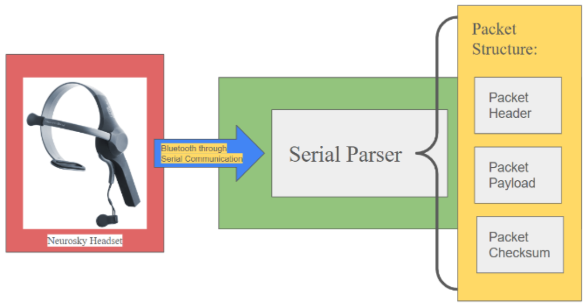

Fig.2 Serial Parser on the EEG Headset data.

3. Methodology

3.1. *NeuroSky Data over Serial Communication*

Many other people had used a Serial connection. So it was also decided to implement this method as it is easy to use and makes for the most direct and straightforward path to connecting to the headset. Other ways, like using a lab streaming layer, or using C or C# code, along with NeuroSky's own SDK was either not stable or not reliable. The NeuroSky Mindwave Mobile 2 has a very unique packet protocol, which consists of a header, payload and a checksum, as seen in Fig. 2. The Packet Header defines the packet's status code. It is very important to pay attention to this header, as this header is used to show what the payload is in reference to which parameter. For example, the code (0x04), which is used to label packets responsible for Attention. The packet payload contains the data for the specific parameter, which is saved into a local variable. The packet checksum to verify the packet before the process starts. As seen in Fig. 2, the headset would be force connected and start sending packets to the

Serial Parser. The first 2 packets are read and have been sorted and verified by its status code. The packet's payload is saved into the Serial Parser for later manipulation. The checksum is used to make sure that the packet was verified by that specific headset. The packet header defines where the payload information would go in the Serial Parser.

3.2. *Arduino data over Serial Communication*

Once sufficient data is collected, a new serial connection is made to communicate with the Arduino Uno [6]. For the prosthetic to correspond to the user's Attention data, a new serial connection has to be made, connecting the Arduino to the program. As seen in Fig. 3, a *DataManager* class is responsible for the Arduino receiving the data possible to have the prosthetic to move.

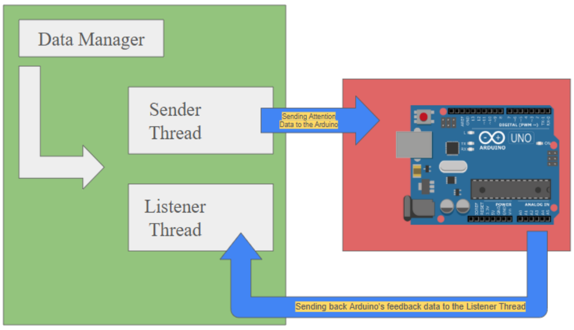

Fig. 3 Overall Serial Communication to the Arduino.

The *DataManager* would have 2 threads open, as shown in Fig. 3. The sender thread is responsible for sending the attention data to the Arduino. The listener thread is responsible for listening to the Arduino's feedback data.

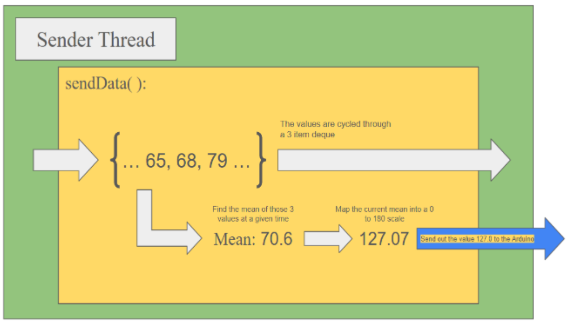

Fig. 4 Data Manipulation done in the Sender Thread.

The sender thread runs another target function called *sendData()*, which is shown in Fig. 4. The *sendData()* function keeps on sending a mean of attention values to the Arduino and rescales them to fit for the servos.

This *sendData()*, as seen in Fig. 4, fills a 3-item deque for data manipulation. The 3 data points are then converted to a mean which is rescaled to 0 ~ 180. For every new set of data, a new mean is calculated and rescaled. This rescaled mean is then sent to the Arduino for the servos to move. The rescaled mean acts as a target position for the servos to reach. This creates a correspondence between the user's attention and the prosthetic. The listener thread is used to verify the Arduino has gotten the data. It is also used to verify whether the data on both ends of Serial communication is the same. The listener thread is only used to check the feedback and debug the program as seen in Fig. 3.

3.3. *Prosthetic Controlled by Arduino*

Prosthetic is controlled by the Arduino end of the code. The Arduino opens up its Serial connection and connects to the main program. The Arduino will listen for the target position of the servos, based on an average rescaled value of the user's attention. The servo's position is based from a 0 to 180 angle.

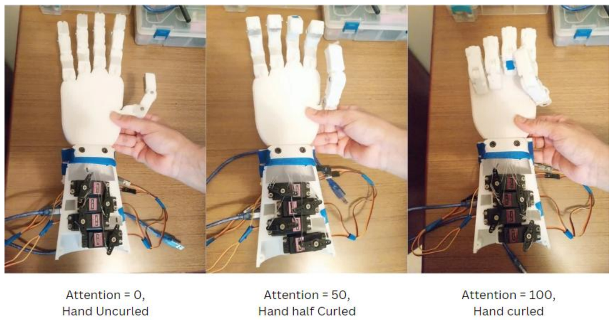

Fig. 5: Different Positions of the Hand based on the varying Attention level.

Thus, the prosthetic movement and the attention of the user is one to one, as shown in Fig. 5. This allows for more precise movement, instead of a simple Boolean condition, allowing for the prosthetic to be in a range of orientations from palm to fist.

3.4. *Mechanics of Prosthetic*

The prosthetic works off of 4 Tower Pro MG996R [7] Digital servo motors. Each servo has a wire that wraps around a whole finger as seen in Fig. 6. The wire runs through the palm and then goes through each segment of the finger before going back into the palm and then being tied to the same servo. This means that when the servo pulls clockwise, the finger curls into a fist. When the servo pulls counter-clockwise, the fingers extend into a palm. The reason why there are only 4 servos is because one of the servos has both the pinky and ring finger attached to it, shown in Fig. 6 (right image).

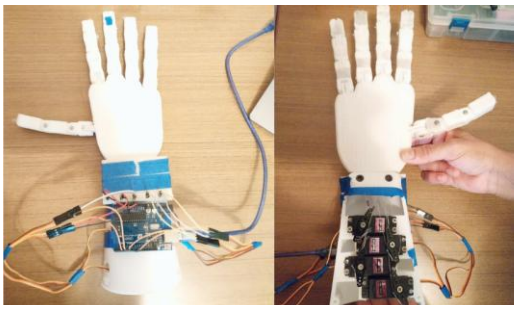

Fig. 6: The first image is of the back of the hand, the second image is of the front of the hand.

4. Results

The user takes the headset and after booting up the program, the data is already being streamed to the computer and then to the Arduino. A demonstration is shown in Fig. 8. Thus the user can increase or decrease their focus and cause the hand to curl up in the same interval that the data shows.

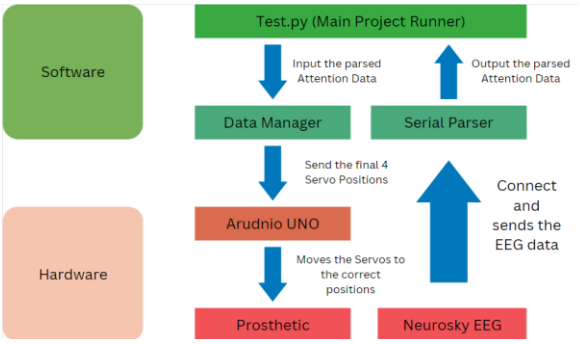

Fig. 7: Flowchart of the final prosthetic

As the user defocuses and focuses, the hard curls in a way that matches that same rate of attention given by the user due to the data manipulation done in the Data Manager in Software processing, as seen in Fig. 7 where the whole system is outlined.

Fig. 8: A Person wearing the headset and controlling the prosthetic

5. Reflections

5.1. *Future Technical Improvements*

An actual brain computer interface would use some sort of machine learning/deep learning to get accurate predictions of when the person is thinking of grasping or extending their fingers. EKG data can be involved in the analysis to allow for a completely synchronized prosthetic with the user's muscles and brain. All the extra analysis will allow for an actual prosthetic in which the user can think about the action they want to perform instead of focusing and focusing. For the future, a neural network would have to be implemented and with that better data would be needed as well. The neural network would need raw brain wave values to give it better pattern recognition. The headset could also be improved as well. Because the Neurosky Mindwave Mobile 2 only has 2 nodes, the data that it can collect isn't the best quality of data. The actual raw brain wave data and its parsing would also need to be improved. As for a neural network would need to run off of a lot more data and from more than 2 channels.

5.2. *Future Mechanical Improvements and Potential*

Because the prosthetic works by the wire pulling from one side to pulling the finger down or up, it isn't accurate at all. The mechanism must change if the user wants a high degree of accuracy in movement and high dexterity in the prosthetic. As it stands, the same positional data doesn't mean the same position on the prosthetic every time. This is because there are too many factors at play when moving the finger, primarily, the friction of the wire and the loosening of the wire over time.

Generation 2 of the prosthetic must have some sort of tension spring in the finger's joints. This would mean that without tension, the finger would spring back to the same place. If the same amount of tension was applied to the spring, then theoretically the finger would move to the same position proportionally to the tension. Thus, this makes for a much more dexterous prosthetic. This final product on the end of this development path would be the generation 3 of the prosthetic. Generation 3 would be a prosthetic with deep learning from both EEG and EMG data for a better prediction of what the user is thinking. From what action the user is thinking, the prosthetic will do that action from the prediction it makes from the EEG and EMG data. But as it stands this is a good proof of concept for a cheap Brain Computer Interface Prosthetic.

6. Conclusion

This prototype includes the communication ability between the headset and the computer. With this proof of concept, an experimental BCI prosthetic was developed to tie with the user's attention for interactive rehabilitation purposes. It should be noted that this result is definitely a prototype at best. As listed before in the problems, there are many sectors that we can improve on that can make for a much better system in the case of developing a full BCI prosthetic.

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Authors Introduction

Mr. Nethika Jayith Rajapakse

He is a high school student. He is currently a driver coach at this School's FRC Robotics team. Their team has gotten into the World Finals in 2022 and 2023. He has also done nation wide science fairs, entering in his robots. He has a current interest in Neural Networks, Machine Learning, Robotics and Prosthetics, and Procedural Generation.