Photo-NeuroFeedback:
Novel Light based Neurofeedback Delivery Method

Project Completion Report

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Introduction

The aim of this project was to build a novel Neurofeedback (NFB) device by using a pre-existing open source device called the Brain Machine, designed by Mitch Altman, an engineer and hacker. The goal was to incorporate a form of Photobiomodulation (PBM) technology which is used in Low Level Light Therapy (LLLT, primarily utilizing 810 nm wavelength light as a delivery for therapy), Electroencephalography (EEG) sensors, SD card reader and an EEG amplifier into Mitch's design. This Photo-Neurofeedback (PNFB) system would then use a program, written on the Arduino IDE, to acquire, process and store EEG signals retrieved from the EEG amplifier. Thresholds would then be set by using code which would control the output sequence of two 810 nm LEDs and two stereo speakers by using the acquired data.

Figure 1: Brain Machine by Mitch Altman

The thought process is that, by incorporating EEG control of the 810nm LEDs, the technology would be able to create a mental or emotional state change in the user, so that they can reduce stress. Another motivation for this design, is to create a novel neurofeedback system which is affordable, portable and easy to use.

Inspiration and Rationale

Evidence exists that NFB technology is useful for inducing physiological state change in the user [9]. In particular, the technology allows for a rapid change in the users Autonomic Nervous Systems (ANS) state, from Sympathetic (fight or flight) dominance to homeostasis. This evidence has been corroborated by several research studies [9] which show the efficacy of NFB as an effective tool to improve the outcomes of people suffering from acute stress, Attention Deficit Disorder and Anxiety. Similar evidence has also been found for the efficacy of PBM. Recent research shows the potential benefits of PBM, in improving retinal disease, stroke, traumatic Brain injury, neurodegeneration, and memory and mood disorders [6].

Incorporating PBM is a novel approach to neurofeedback since many of the current systems use an operant conditioning [11] paradigm, generally associated with sound and visual feedback in the form of music, images and videos games. PBM has generally been used as a stimulation device, to improve healing in damaged body tissue, and, more recently, as a device to stimulate Brain regions, specifically the default mode network of the Brain [8]. Brain stimulation is different from NFB in that stimulation simply provides a single stimulus (like light, magnetic or electric signals) pulsing at a set frequency, to a region of the Brain. This signal does not vary or change based on the current state of the Brain. NFB on the other hand, provides the user with a means to alter their Brain State, by observing the real time frequency patterns of their Brain. In essence, NFB gives the user a mirror into their Brain's activity, thus providing them with a means to observe and effectively change the functioning of their ANS.

In regards to this project, specific Brain lobes are not targeted for feedback, instead feedback is provided through the eyes. The retina of the eye is the only part of the Brain (retina tissue comprises of neurons and photoreceptors) and nervous system that is exposed to the external environment, since it is not covered with tissue such as bone, muscle, organs or skin. This feature of the Brain is utilized by the Brain Machine's design, which uses a pair of regular LEDs, to provide Brain stimulation via predefined pulsing binaural beat sequences. These sequences are controlled by a microcontroller which has been hard-coded with a program that delivers the sequences.

By incorporating 810 nm LEDs into the Brain Machine, as well as NFB protocols and EEG sensors and amplifier, it is reasonable to assume that one will be able to improve Mitch's design, and further promote healthy Brain states via this novel PNFB device.

Design and Build

Von Neumann Architecture

The design process used the Von Neumann Architecture Model as a template for the projects scope. EEG sensors acted as transducers to provide input, while an EEG amplifier, and Arduino Uno provide processing. Storage of acquired EEG signals was achieved via an SD card module which was incorporated into an Arduino Uno (by using the proof of concept amplifier) and used to store the acquired EEG signal into an SD card. The initial build involved using bread boarding to build and test the discrete components and write code. The components were then added to the form-factor of safety glasses to create the final PNFB device.

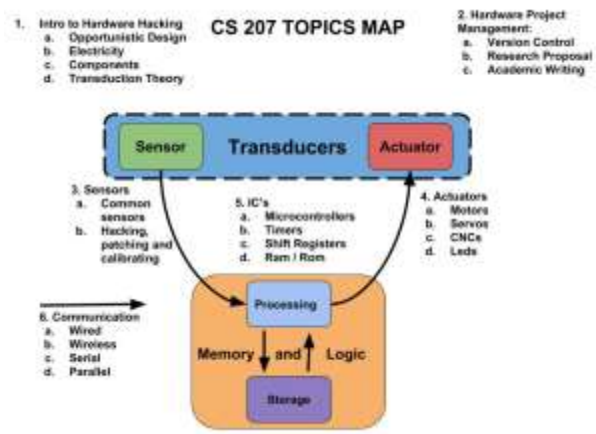

Figure 2: Von Neumann Architecture [12]

Hardware and Input

Designing the device required several steps. Firstly, the resources that described the design of the Brain Machine were gathered from several sources [5][7][10]. Then steps as described in those sources were followed to build the PNFB device.

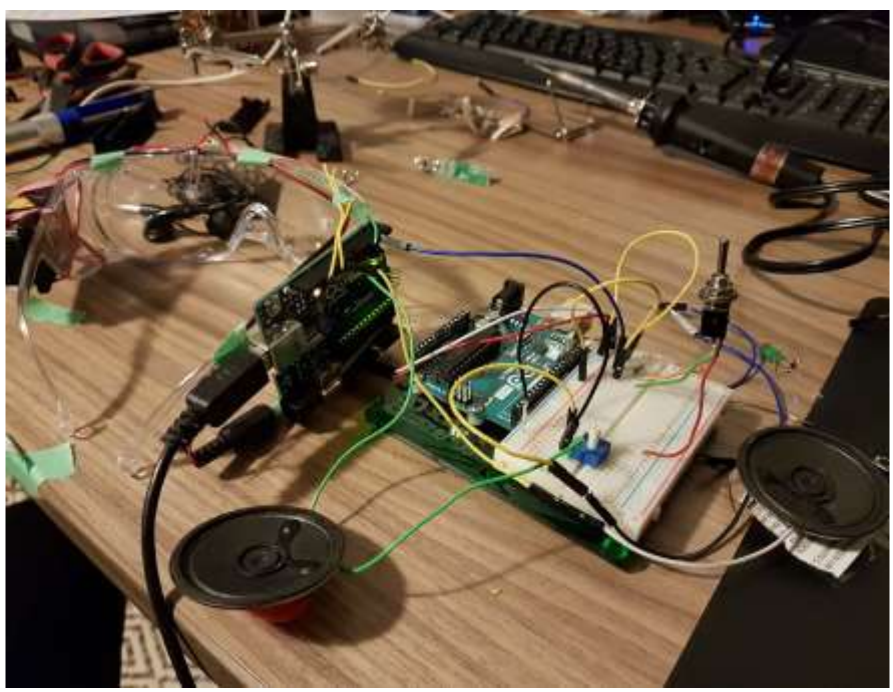

Figure 3: Bread Boarding and Glasses build

The lens of the safety glasses were measured to identify the center point, and two holes, slightly smaller than the LEDs, were drilled into the glasses using a variable speed Dremel drill, on low speed, to ensure that the lens did not shatter. One LED was then inserted into each hole of the lens, with the light source mounted on the eyes-facing side of the lenses and glued in place using a glue gun. The (Anode) side of each LED was then connected to an Arduino pin by using wires, and both LEDs shared a common ground pin on the Arduino. Two Speakers representing the left and right stereo channels were then attached to the Arduino pins and shared a common ground via a potentiometer which acted as a volume control. Initially a push button switch was implemented, however, it was decided to replace it with a toggle switch connected in series with a 540 ohm resistor, in order to keep the circuit active during its operation. This inclusion reduced the need for code which would have added extra complexity to the circuit. A 9 Volt battery was incorporated into the design, in order to provide power and portability to the device. However, the device would also be able to use a USB cable for power.

Two repurposed EEG sensors were then spliced and soldered to wire, in order to gather EEG signals from the left and right temporal lobe regions of the head and pass it on to the Arduino for processing. Since EEG acquisition requires a specialized amplification circuit to increase the visibility of the EEG signal to the Arduino, three options for EEG amplification were used to try to collect these signals. They included a 4 channel Braintellect Amplifier (Produced by Braintellect, INC), a Z-amp Amplifier (Zengar INC), and an Intellipoint device (Braintellect) which is used to detect the most active EEG signals location on the

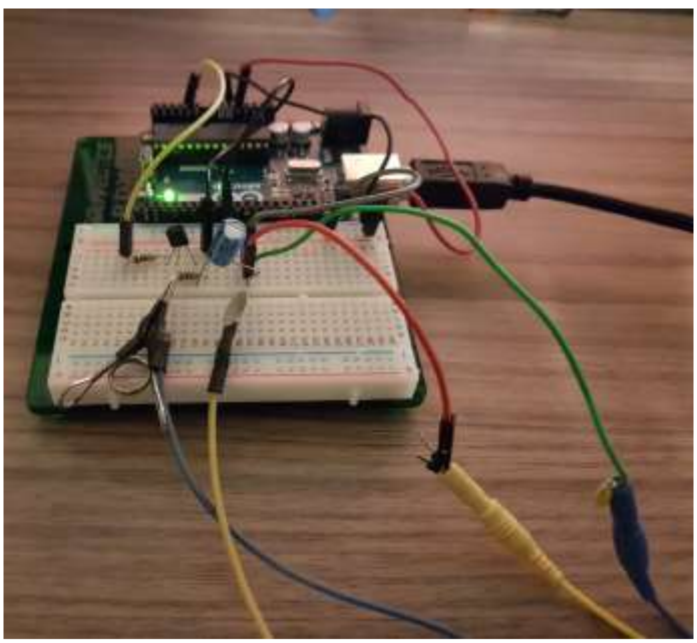

Figure 4: Repurposed EEG Sensors and Amplifier circuit

scalp. These devices were taken apart to find a header or exposed bus to extract EEG data from the device. The Z-amp and Braintellect amplifiers are proprietary technologies and required specialized NFB software and drivers to operate the amplifiers, and thus, simply taking the amplifiers apart, putting power to it, and probing different connection points and headers did yield the desired result. This barrier was solved by building a rudimentary amplifier by using a 2N2222 Transistor, capacitor, potentiometer circuit [2].

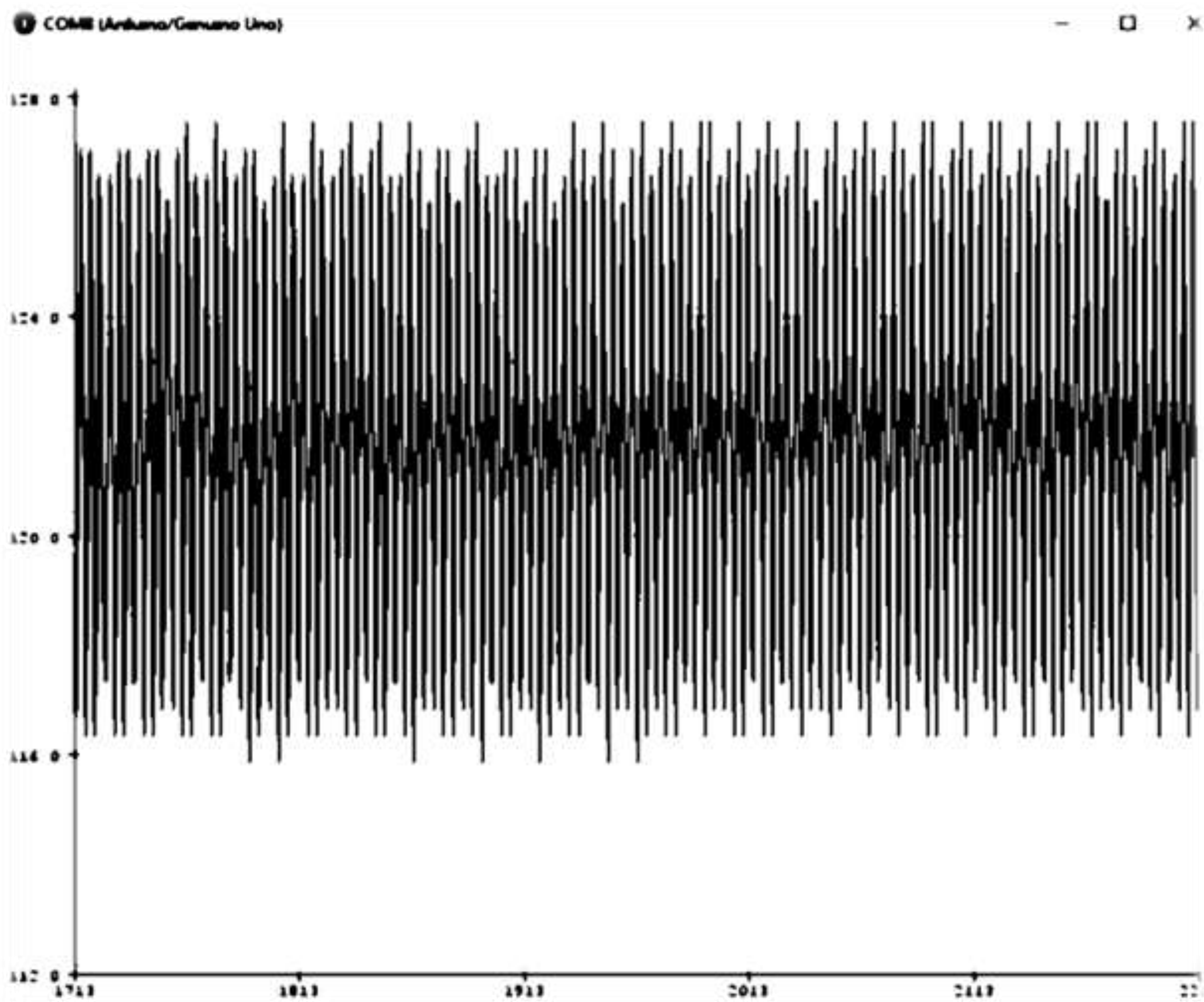

Figure 5: Signal Acquired from EEG Sensor & Amplifier circuit. Displayed in Arduino serial plotter 115200 baud rate

This circuit was able to acquire a signal, however it was not discernible as an EEG signal. Further explanation of this limitations is discussed in the Constraints, Setbacks and Challenges section of this paper.

Software and processing

In order to test the initial implementation of the circuit, the original software code was uploaded to the Arduino. The Brain Machine design used an ATTINY25V-10-PU microcontroller programmed using firmware designed by Mitch called the MiniPOV3. This software is incompatible with the Arduino hardware platform, and therefore, the software needed to be rewritten in the Arduino IDE. Luckily another project [3] had already solved this problem, therefore that code [1] was uploaded into the Arduino and provided an effective means to debug and test the hardware functionality.

Since one of the primary purposes of this project was to acquire EEG signals, and process those signals to provide neurofeedback, code would have been written to provide the required parameters to trigger the output devices (Speakers and LEDs). Due to the inability to acquire those signals via the chosen EEG amplifiers, it was not feasible to design the aforementioned code, instead it was decided to write this code at a later time when a better amplifier, with a better signal has been developed.

Storage and output

The proof of concept amplifier built for this project, allowed for a signal to be acquired through the EEG sensors placed on a user’s head during testing. Although time ran out to incorporate this circuit into the final project design, it provided a proof of concept, with which a signal (albeit, unrecognizable as an EEG signal input) was acquired and stored onto the SD Card, on a separate Arduino Uno.

Aesthetics

Safety glasses were used as the form factor of the final PNFB device. This form factor required that the wires and components were held in place adequately for reliable operation, transportation and user safety. The top lip of the glasses acted as a conduit to contain the wires. Electrical tape was used to

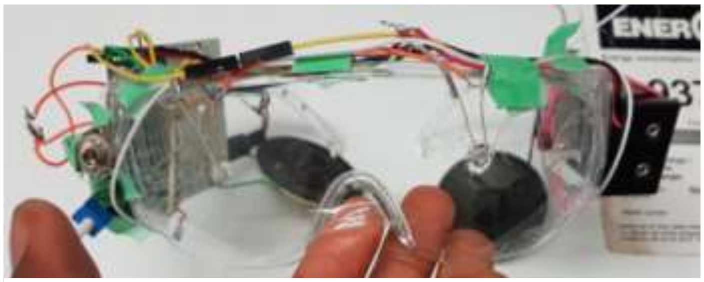

Figure 7: Finished glasses with circuit exposed

hold the wires in place, as well as to cover the transparent surface of the glasses, which exposed much of the circuitry, and gave the device an unpolished and intimidating appearance. The final product has a Steampunk look, which provides character and an interesting aesthetic.

Figure 6: Final Product in operation

User Manual

The PNFB device proved to be functional and easy to operate by using the following instructions:

1. Sit in a comfortable position, preferably in a quiet room.
2. Put on the device, as you would regular glasses.
3. Close your eyes, and keep them closed for the entire length of the session (14 minutes).
4. Turn on the device by flipping the toggle switch from the off position, to the on position.
5. Relax and listen to the tones from the speakers, while the LEDs flash pulses of light through the eyelids.
6. After 14 minutes the device automatically shuts off.
7. Carefully take off the glasses.
8. Turn the switch to the off position.

Constraints, Setbacks and Challenges

As discussed in prior sections of this article, it is to be noted that several challenges occurred during the development of this project, which caused a significant amount of difficulty and extended the project past the deadline described in the submitted project proposal.

Firstly, the acquisition of an adequate EEG signal posed several challenges during the project. The extremely small electrical signal strength of EEG acquired from the scalp (In the microvolt range), necessitated the use of an amplification circuit, which would increase the signal quality and strength of the EEG signal. Although several options for amplifiers were available, the ability to acquire an adequate signal from them via various hacking methods proved unfruitful. The first method used, was to open the casing on the amplifier in order to access the circuit board and its components. This was done with all three devices. Although each device had potential locations for signal acquisition, for instance, headers and bus wires, the proprietary nature of the devices, and "prevention of modification and repairs" mechanisms built into them, meant that the device could only be rendered operational by the software and device drivers with which they were designed to operate.

An alternate means to acquire the signal was proposed upon consultation with the course instructor, who suggested building an EEG amplifier. This approach was helpful, since many examples of EEG amplifiers built from discrete components are available on the internet [4], and were researched. A simple design using a 2N2222 transistor circuit [2] provided a signal, which was graphed by using the Arduino IDE Serial Plotter. Due to time constraints, this circuit was not integrated into the final design. There is a reasonable potential that the signal acquired may contain EEG, however, further investigation via signal processing and testing will need to be performed in order to understand what data is being captured by this circuit.

Learning and Milestones

Although the project was not completed to specifications, the final product is a functional and worthy attempt towards improving the Brain Machine. The attempt of acquiring EEG signals from an EEG amplifier device, provided important practice needed to utilize hacking techniques learned in class lectures.

The author gained valuable experience in project planning, product design, testing and applying the Von Neumann Architecture theory to real world applications. Through the difficulties encountered during this project, it was discovered that knowledge of signal acquisition and processing is an important factor needed to design functional EEG amplifiers, and collect information from the Brain. This realization instills the need for further study in this subject area by the author.

A good understanding of how different components come together to develop a working electronic prototype was also learned. This new understanding will aid in future iterations of the PNFB device, and will be used to develop other interactive gadgets in the future.

Conclusion

This project was a great introduction to hacking and building interactive gadgets. Despite the challenges, the future is bright for the creation of a novel PNFB device. By incorporating 810 nm LEDs into the Brain Machine, a step has been taken to improve the function of the device to potentially improve the user's ability to reduce stress. Replacing Binaural Beats with NFB protocols will potentially improve the utility of the system, from a Brain stimulation device, to a more advanced and efficacious Photo-Neurofeedback system which can improve the lives of its users; by improving portability, ease of use, and user outcomes.

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Appendices

Appendix A - Circuit Diagrams

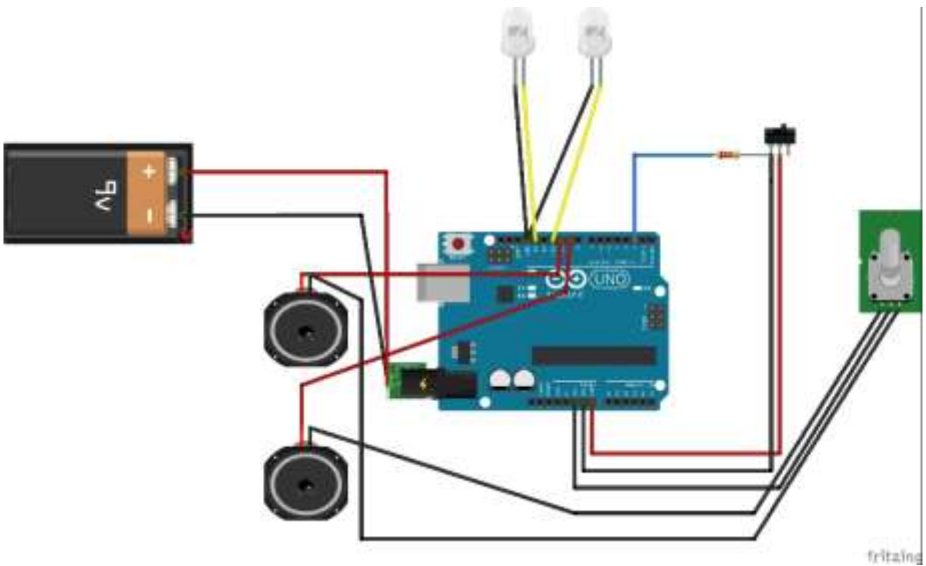


Figure 8: Brain Machine Schematic

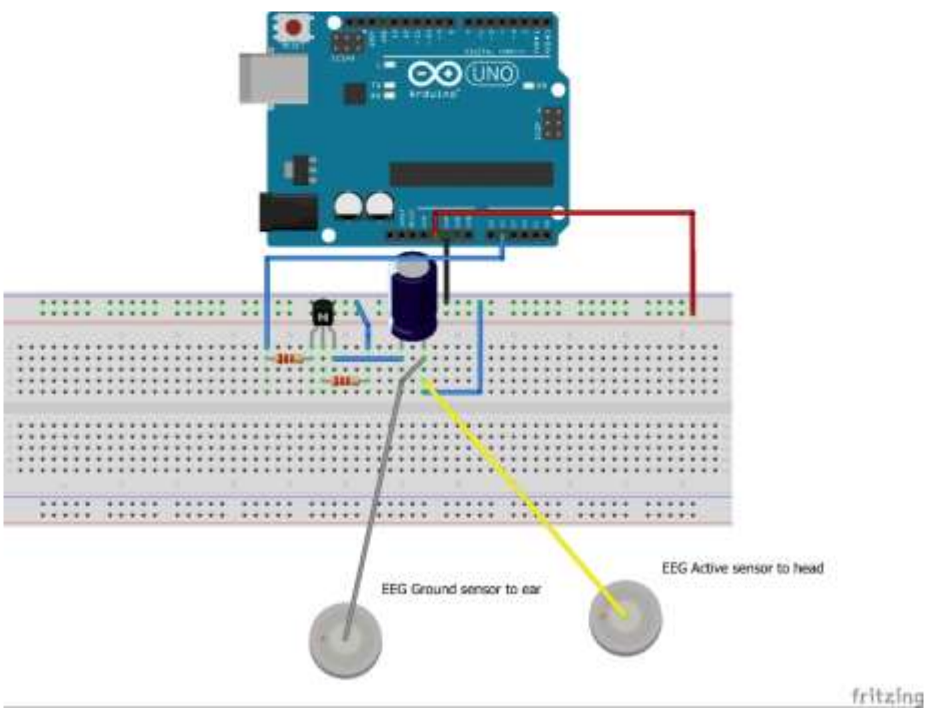
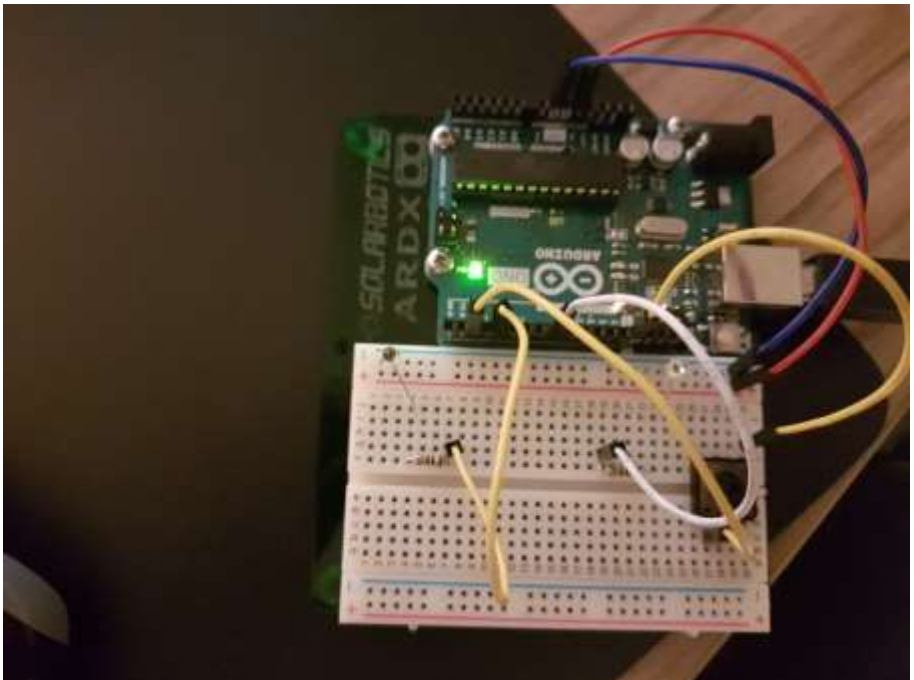
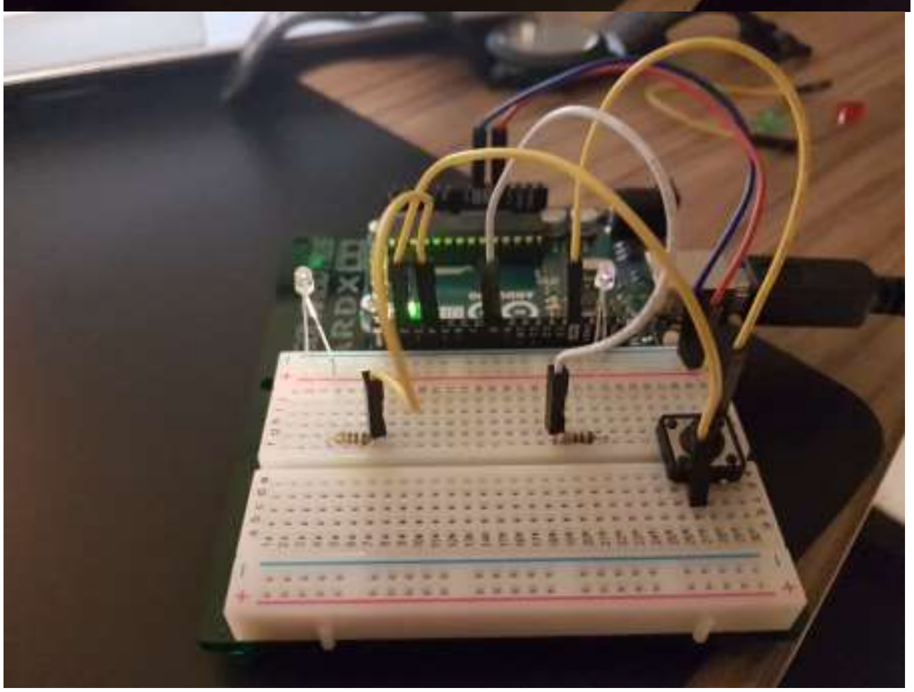
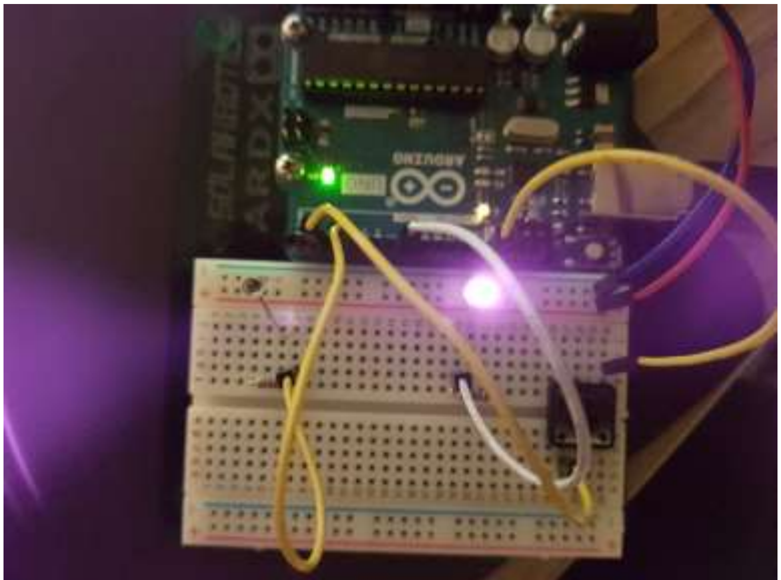


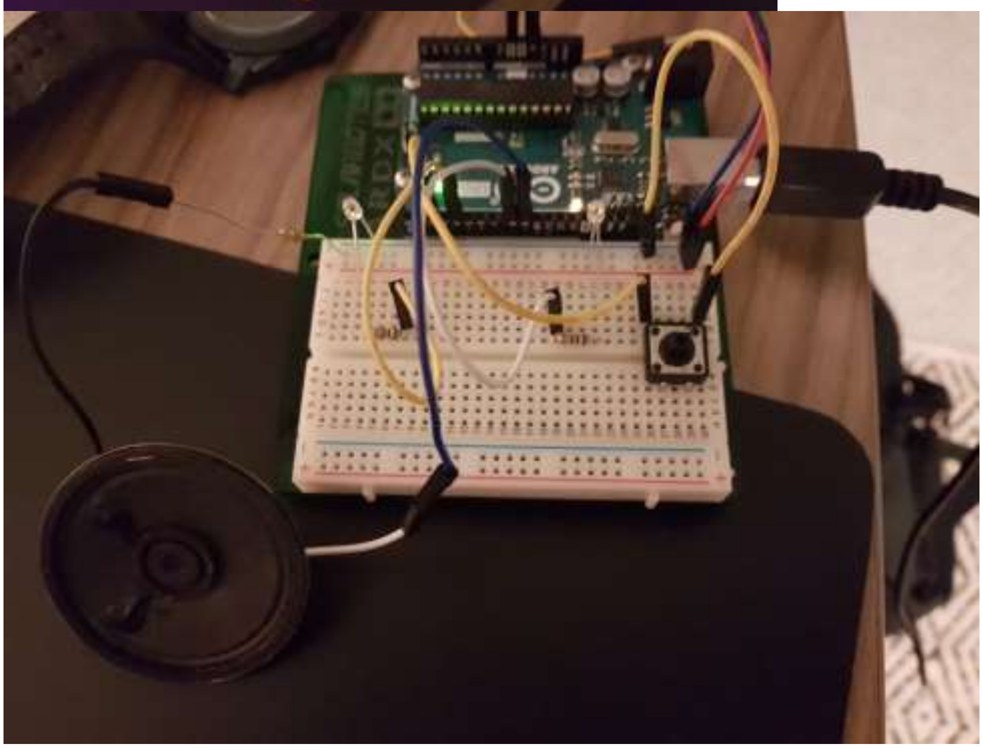
Figure 9: EEG Sensor, Amplifier circuit

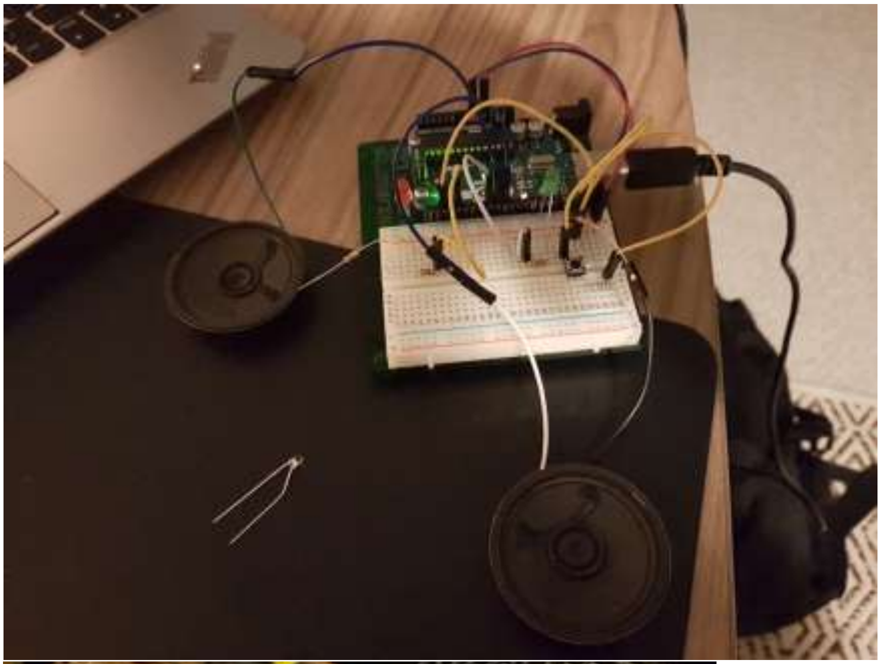
Appendix B - Circuit Implementation images

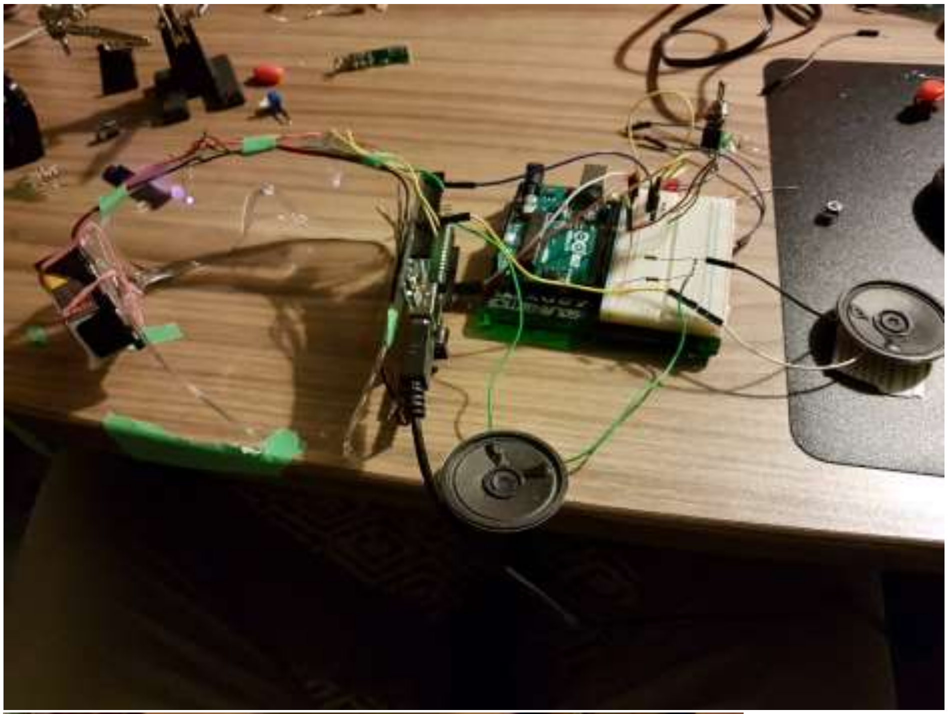


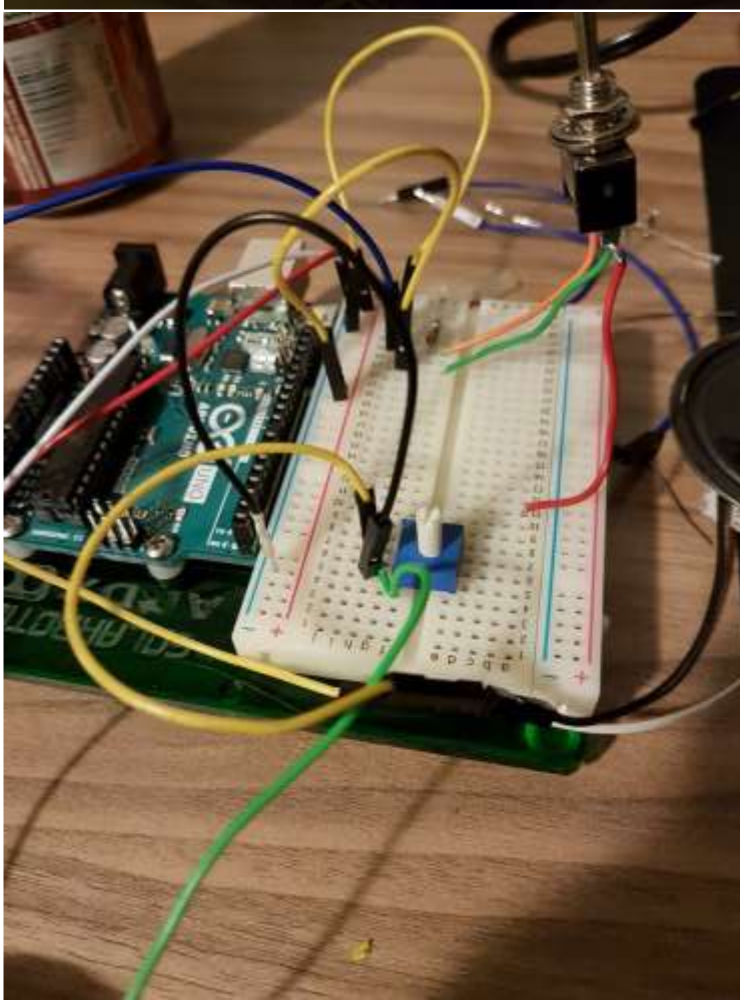


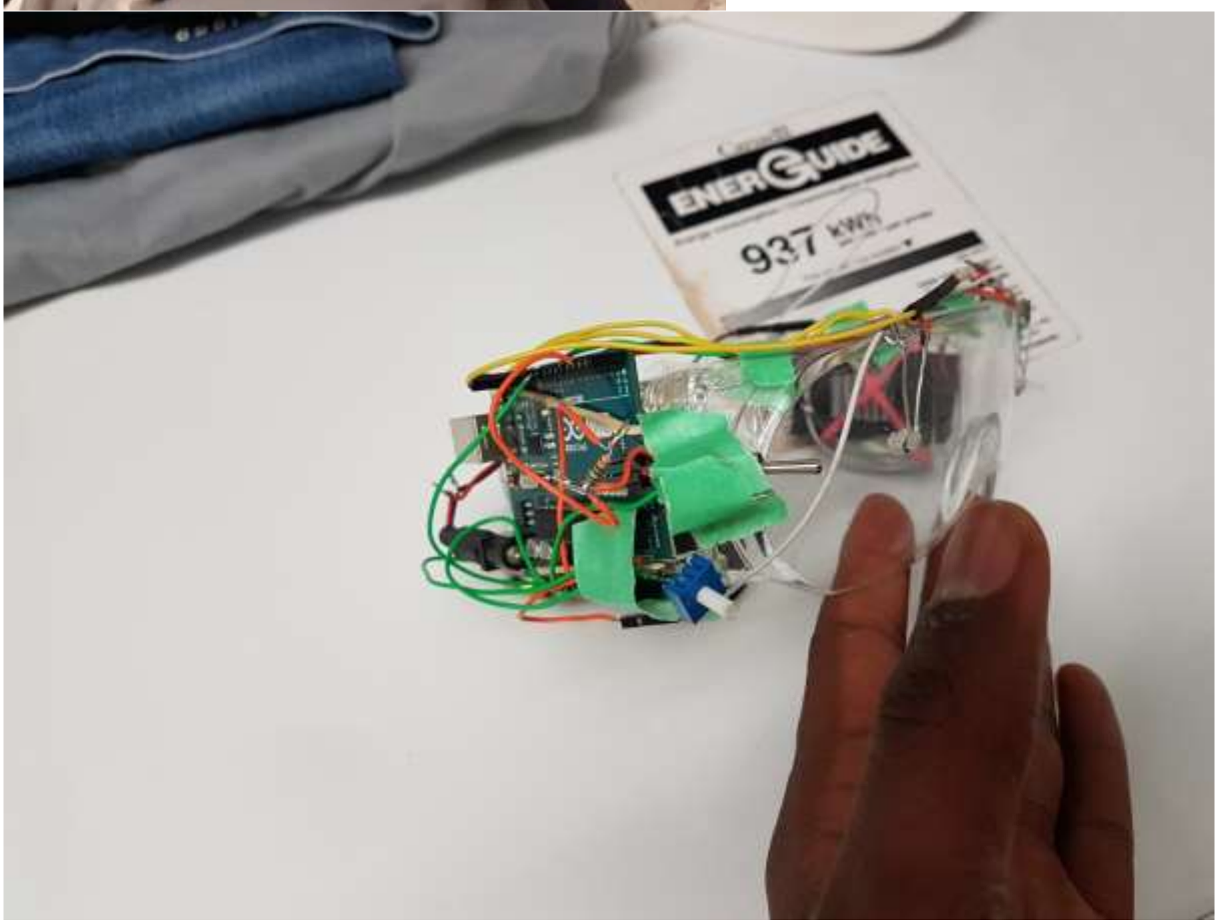








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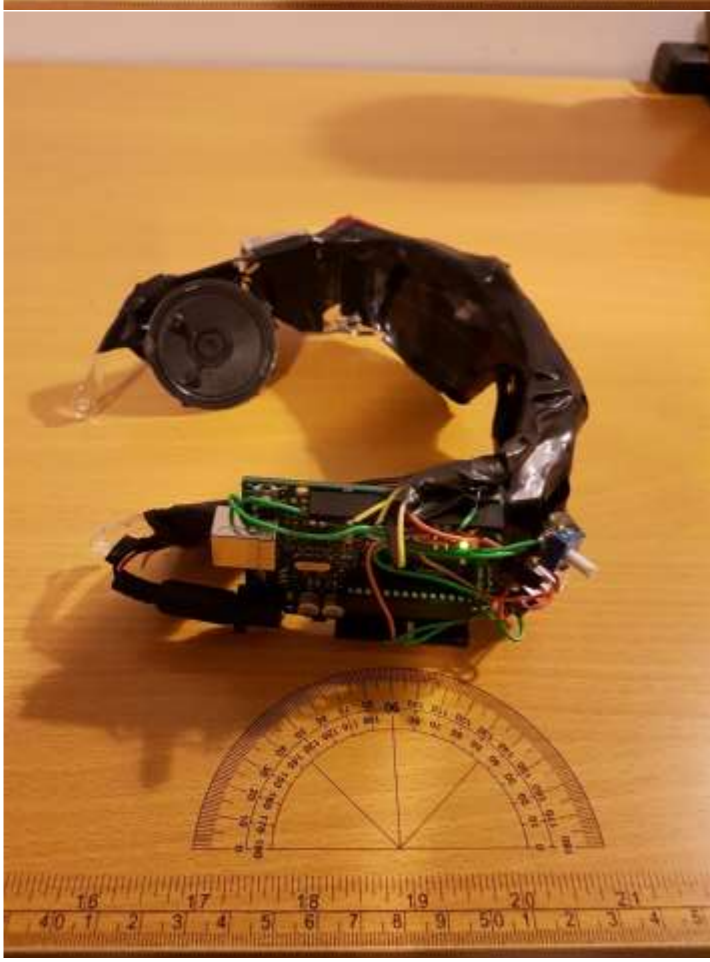

Appendix C - Code Examples

```
/*
Written by Dami Egbeyemi
Code to acquire EEG Signals from amplifier to Arduino for Photo-Neurofeedback Device
*/
#include <SD.h>
#include <SPI.h>

int CS_PIN = 10;

File BrainData; //

const float tXWire = A0; //usb green wire

void setup() {
  // put your setup code here, to run once:
  Serial.begin(9600);

  initializeSD(); //Initialize SD Card

  BrainData.write("EEG data from Sensor: "); //Write File header

  closeFile();

  Serial.println("tXgWire"); //signal acquisition wire
  Serial.println();

  pinMode(tXWire, INPUT);

}

void loop() {

  float tXPinState = analogRead(tXWire);
  float BrainState = 5.0 * tXPinState/1023.0; //Converts Pin state to 5 volt signal


  Serial.print(tXPinState); //Print Pin state to serial for Plotter
  Serial.print("    ");
  delay(1);
  Serial.print('\n');

  BrainData.write(tXPinState); //Prints Data to SD card
}
```