Electroencephalogram Control System

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Table of Contents

Abstract:

Electroencephalogram (EEG) control systems have been previously investigated for use in controlling an electromechanical device through the use of mere thought (Galan et. al., Provost et. al, The Local). Two readily available consumer products currently available on the market that employ this concept are the MindFlex by Mattel and the Force Trainer by Uncle Milton. Both of these devices use a third party EEG chip made by NeuroSky to vary the speed of a fan used to suspend a small ball at different heights. This project proposes combining two of these devices to create a single control device system capable of modulating two axes of control simultaneously by a single user. The outputs from the devices have been conditioned to give three discrete levels of control per axis. The three distinct levels of control were chosen for the purposes of reducing required training time and obtaining higher accuracy of control. The NeuroSky chips are able output a continuum of signal which is useful in controlling the speed of a fan. The output for the controller will be conditioned to output three discrete levels. Rather than having a fully variable output, one exemplary scheme would be as follows: all voltages less than 2 volts will fall into the off level, voltages between 2 and 3 volts will fall into the medium level and voltages larger than 3 will be considered high. This means that signals within a certain voltage will fall within one of three levels. However, to be able to control the signal at varying levels is quite difficult, especially controlling the low level. This can be overcome by increasing the threshold for the medium level and decreasing it for the high and off. This leaves us with three highly controllable levels: off, medium and high, where the device will output different voltages for each level. This device will then be able to control any device that contains a microcontroller or a device that can be mounted with a microcontroller. Since the two EEG control axes must be modulated independently of each other, the electrode leads are placed on opposite hemispheres of the brain. This allows for the least amount of crosstalk between them and the greatest voluntary independent control. The control system has been integrated onto a remote control vehicle made by Parallax called Board of Education Robot (Boe-Bot). This vehicle is designed to carry an array of circuits on layers of breadboards. The Boe-Bot also operates much like a wheel chair in that its motions are driven by two large wheels and the structure is supported

by one unmotorized wheel. With the two EEG devices integrated into one system to control two axes, the project relies on the electrode placement and the mind's ability to control the vehicle. The future expectations of the project are to implement the controller into other devices including a wheel chair.

Project Objectives:

The objective of this project was to develop a remote EEG controller system with two independent axes of control for widespread application. To fulfill this objective two consumer products, MindFlex by Mattel and the Force Trainer by Uncle Milton, were disassembled, analyzed and reverse engineered. The preexisting controllers were utilized to minimize cost, save time, and avoid the need for a more costly EEG. The goal in using the two devices was to develop two independent axes with three levels of control; off, medium and high. These values are to correspond to three levels in a TTL Compatible Digital Output which is the industry standard or the output can be adjusted with the source and drain voltages that lead to the conditioning circuit. This allows the controller to be adaptable into many devices that contain microcontrollers.

After the completion of the circuit, determination of ideal electrode placements was the next objective. To complete this objective, previous work done in regards to EEG manipulation was analyzed and an experimental process involving trial-and-error was performed. The analysis included three regions of the brain (frontal lobe, premotor cortex and occipital lobe) with two electrodes to construct a definitive placement scheme based on minimization of crosstalk between the two channels. Finally, the control system was demonstrated with a remote control vehicle capable of wheelchair-like movement. The final objective is a device that will read brain waves from a series of electrodes and then process the information and output a usable signal for three directions of control that will minimize training time and have reproducible results. Training time was minimized by adjusting the thresholds for levels of control as well as electrode placement, but around ten minutes of training time is expected and considered reasonable. The controller must also have reproducible control, meaning that it will be able to respond the same way multiple times and between individuals. This will be tested by measuring the vehicle's ability to follow a track multiple times with multiple individuals. The controller is expected to have the ability for the vehicle to respond to commands within a short reasonable amount of time. A reasonable response time for the controller will depend on the speed of the device. For the demonstration and the design of the controller it is expected to be around 15 seconds and the ability to sustain a particular level around one minute.

Background:

A human's neurological system transmits information through electrochemical pathways throughout the brain and the body. Consequently, these electrochemical events can be monitored from the surface of the skin using electrodes connected to an electroencephalogram (EEG) (Ohno, k et al). Because the occurrence of various types of signals read by the EEG can often be controlled consciously by a subject, this phenomenon has been applied to a wide variety of applications including wheelchair control by paraplegics, video games, light dimmers, and computer mouse control (Provost et al). This project consists of using two devices that are already on the market that each measure beta brain waves to control one axis. Beta waves are the brain waves of about 13-32 Hertz and are present while a person is alert or in thought (Hammond, D). In both devices, the one axis of control is developed into a game that controls the speed of a fan, which is used to control the height of a ball. In this project, both devices are reverse engineered to be used in a controller that could control forward as well as right and left by altering the speed of two wheels independently. The decision to reverse engineer the devices was made to save money and time, where the alternative would be to purchase an expensive EEG costing over several thousands of dollars. By using devices that are already on the market that work fairly effectively on responding to brain waves cuts the time for developing a circuit from scratch. Also, to read brain waves, very sensitive electrodes and a circuit that is highly resistant to noise is required. This is because brain waves are on the order of 10 to 100 micro volts (Galan, et al) and the environment provides many sources of noise such as 60 Hertz noise from electrical outlets and lights. After detection of brain waves, a circuit is still required to process and condition the output. Each device uses a wireless headset that contains three electrodes:

two reference electrodes and one signal electrode that is processed in the headset by a NeuroSky chip. Then the information is transmitted to the base where the signal modulates the speed of a fan that levitates a ball. Both devices use the same chip that is designed and manufactured by a third party company called NeuroSky. The NeuroSky chip is processing the information about the brainwaves received through the electrodes. First it is comparing the signal electrodes to the reference electrodes to eliminate unwanted noises and erroneous signals. Next, it verifies whether or not a human is connected to circuit by presence of frequencies about 45 Hertz. Next the NeuroSky chip translates the beta brainwaves which it uses to vary the speed of the fan into an outputted signal. The outputted signal is a pulse width modulation signal at about 470 Hertz. The pulse width modulation signal is a cycle that consists of an active part and an inactive part. The active part is the time the circuit is performing its task in this case pushing the fan. The inactive part is the time between the active parts of the cycle, when the fan is not being pushed. This means the portions of the active part and the inactive part of the cycle changes to regulate the speed of the fan. This translates to: the higher the amplitude of the beta waves detected from the electrodes which are processed by the NeuroSky chip, the longer the duration of the active cycle, the faster the fan spins and the higher the ball floats.

The design for the controller includes two devices, which all together include four reference electrodes and two signal electrodes with two processing circuits to converge into one controller with two axis of control. To best illustrate how this will work, think of a wheelchair with the two large wheels being motorized and controlled. If both of the wheels are moving at the same rate the wheelchair will move in a forward direction. But, if they move at different rates the wheelchair will turn right or left depending on which of the wheels are moving faster or slower. The project relies on this principle by having each consumer device control one wheel. The design to have three distinct levels of control: off, medium and high was made because it would be extremely difficult to receive equal outputs from two electrodes that would allow the tank to move forward. By assigning each level a range or a threshold of outputs that relates to it increases the robustness of the controller as well as the ability to move forward.

This design allows for use of many of the components already provided within each device. The alternative would be to use one device for strictly forward movement and two more devices to create a continuum between right and left, much like how a steering wheel operates within a car. This would provide many challenges in designing a circuit to control right and left as well as the cost of an additional device. After further analysis of the circuit's output to the fan that controls the height of the ball in both devices, conditioning of the circuit is required to make it adaptable to multiple devices. The output from the device is an Alternating Current (AC), the pulse width modulation signal, which is appropriate for the controlling the fan within the Force Trainer and the MindFlex. But it is not appropriate or useful in many cases that the controller is applicable. Conditioning of the output includes using an integrator circuit to translate the pulse width modulation signal length into a voltage magnitude and a differential amplifier to remove noise as well as other components to convert the AC into a direct current (DC). The circuit also includes creating cutoff voltages for the three levels of control mentioned earlier: off, medium and high. In order to make the controller adaptable to a wide range of devices the output had to be in a form that is commonly used the TTL. The TTL Compatible Digital Output outputs 0 volts for false or 5 volts signal for true depending on whether the signal it receives is above or below a set cutoff. But to really ensure that the controller was adaptable to a widespread of devices the output was not limited to just TTL. But by creating inputs for the source and drain the output voltage can be adjusted. This way if a devices microcontroller is not adaptable to TTL the controller can be adapted to meet the need of that particular device.

For each wheel of the wheelchair there will be two Compatible Digital Outputs that will produce two leads. Each lead would transfer two levels of control an off and a medium or a high depending on the cutoff voltage and the designated level of control. This design will produce the three levels of control by combing the two leads. Where if signal is below the cutoff strength both of the leads will give a false voltage and the device will not move. If the signal is above the cutoff for medium one lead will give a true voltage and the high will still give a false voltage and the medium level will be activated. Also if the signal strength is above the high cutoff both leads will produce a true voltage and the high level will be activated. By implementing a Compatible Digital Output that has an adjustable output the controller will be able to be adapted for use in multiple devices with greater ease. For this project, the controller was implemented onto a robot that can simulate wheelchair-like movement. The robot that was chosen was a Board of Education Robot or Boe-Bot. A Boe-Bot is a programmable robot that has a circuit board, a microcontroller and two servos that serve to drive the wheels.

After the circuit is developed, placement of the signal electrodes is critical to read desired brainwaves. The most important aspect of the project requires two independent signals that can be consistently detected and consciously controlled by a subject. Research has shown that placement on the frontal lobe gives a consistent and independent signal the location of the frontal lobe can be seen in figure 1. This is also where the consumer devices have placed their electrode that reads brain activity. Between the frontal lobe and the parietal lobe contains the motor and the premotor cortex where movement of the body is controlled by the brain (Galan, F et al). The premotor cortex location can be seen in figure 1 as well. From research by Ohno et al this seems to be a potential location for a second electrode. For the electrode to receive a good signal from the brain, the surface of the brain that is active must be parallel to the surface. Therefore, sulci or indentations, which are located all over the brain, will not provide a good signal (Ohno, K et al). Other possible locations include the occipital lobe where the visual cortex is located. The occipital lobe is normally observed as to be activated by visual stimuli but Quick et al has shown that concentration can activate this region as well. With a complete circuit with our demonstration device, an experimental process involving trial-and-error can be performed. From current research, six regions of the brain (left and right front, middle, and posterior regions) have been selected as having the most potential for a reliable location for the electrodes. Another criterion for the locations of the two signal electrodes must be to limit as much crosstalk as possible. Crosstalk is when the electrodes are picking up the same signal and losing their independence. This means that if both electrodes are to be placed on the frontal lobe on the forehead there would be a high degree of crosstalk and the two axis would lose their independence.

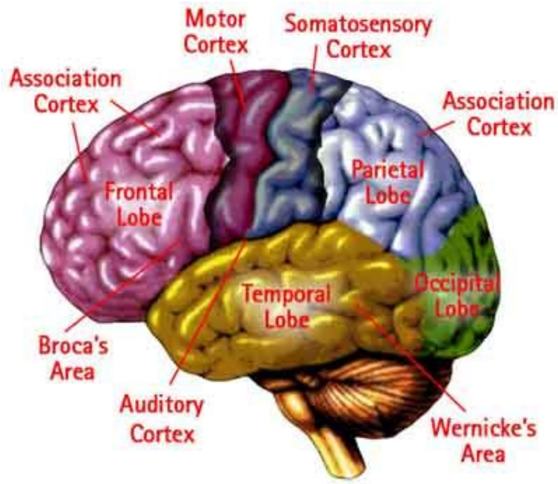


Figure 1 diagram of the regions of the brain. The places that were thought to be ideal for the best electrode placement were the Frontal lobe, premotor cortex and the Occipital lobe. The frontal lobe was where the consumer devices placed their electrodes. The premotor cortex is activated when thinking about moving. And the occipital lobe is a place that is usually activated by visual stimulus but Quick et al has shown that concentration can activate this region.

The controller can be implemented in many situations in which a robust hands free device with an insignificant amount of training time could prove useful. Situations include medical use such as controlling an overhead light during surgery, exams, and dentistry work. Another use is to provide a method of personal mobility for individuals that are disabled and require a wheelchair. Wheelchairs can be designed to operate similarly to the way a tank operates, but instead of tracks the EEG controller could control the set of large wheels on a wheelchair. Other applications include making daily tasks hands free such as controlling a vacuum cleaner, a computer mouse, or a combination of lights or fans. Another field that the controller has a potential to be a successful product in is the game industry, which includes video games and remote control vehicles including tanks. The response time as well as how robust the device is will limit the applications for the device such as driving a motorized vehicle at high speeds. There are many business opportunities that involve products and situations where a hands-free device can be implemented.

Prior Art Review:

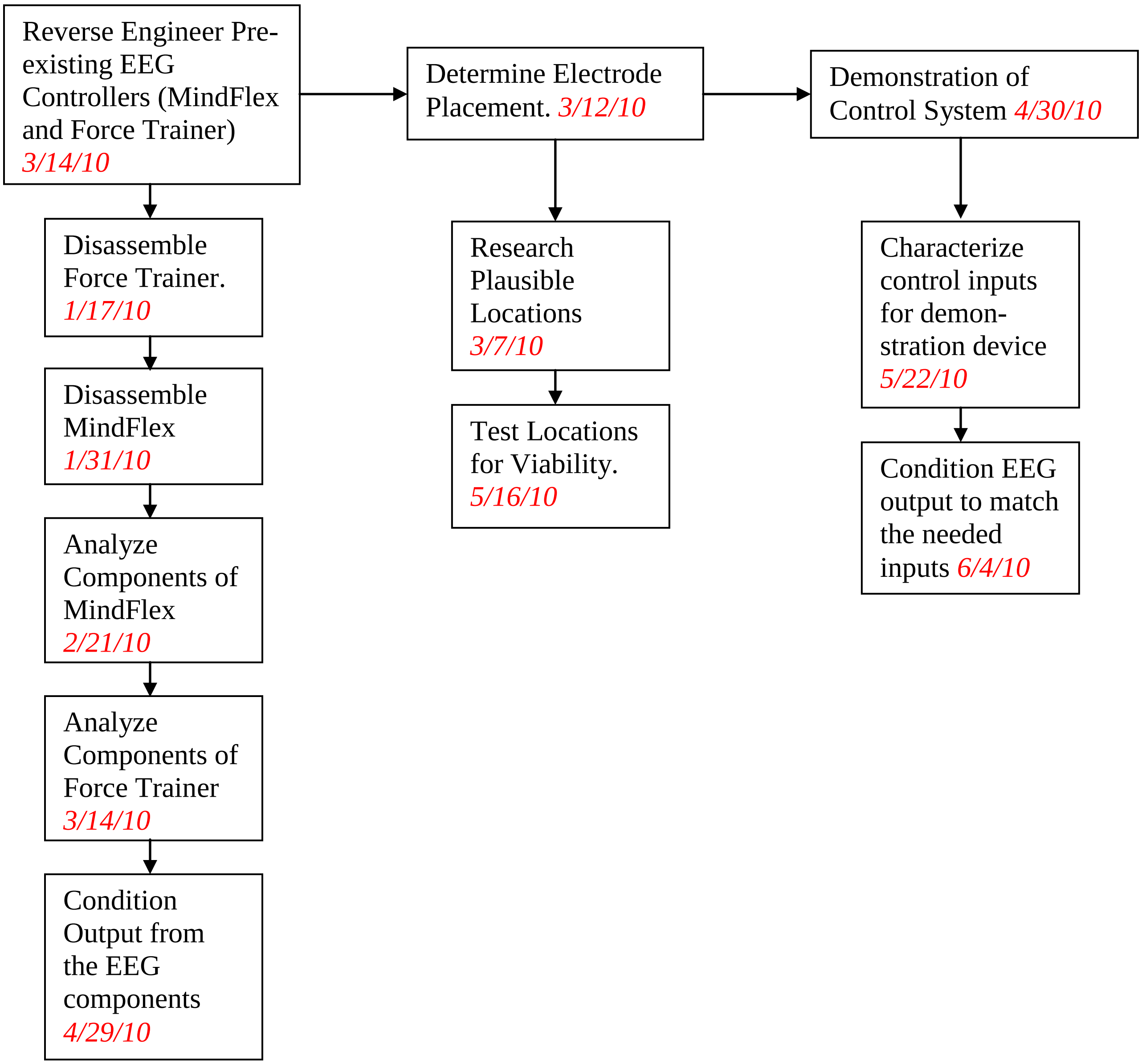
Our project focuses on using the mind to be able to control various objects such as a wheelchair or the arm of a light device in a dentist's office, for example. There have been some recent breakthroughs in the field of EEG control. One such breakthrough is the mind-controlled wheelchair created by Toyota (Abolfathi). Toyota uses a brain machine interface (BMI), which is made up of an electrode cap that is placed on someone's head. The output from the electrodes is sent to a computer to translate the brain wave patterns into instructions that direct the wheelchair. The response time for this system is 125 milliseconds. With three hours of training a day for one week the system can be trained to a particular persons thought pattern and achieve 95% accuracy. A safety sensor is incorporated, which is done by puffing on the cheek so that if a person feels that they are unable to control the wheelchair, the wheelchair will stop. The University of Utah's department of neuroscience planted electrodes on the brain itself but did not penetrate it (Quick). They were, however, able to achieve a high accuracy of control that can be used one day by patients with spinal cord injuries. The technology is called micro electrocorticography (ECOG). Dr. Christopher James from the University's Institute of Sound and Vibration Research is working on sending a person's brainwaves or thoughts over the internet to a recipient that can than open up communication (Quick). So by imagining moving the left arm or right arm will generate its own specific binary digits zero for the left arm and one for the right arm. This will then be transmitted over the internet. The recipient's computer will pick up the stream of digits, which will then light up LED's at different frequencies. The recipient will look at the light and the visual cortex will be measured and the activity recorded will let the computer know whether a one or a zero was transmitted providing a true brain-to-brain communication. Lastly Honda created Advanced Step in Innovative Mobility (ASIMO) that is controlled through a system similar to Toyota's wheelchair (Blain et al). ASIMO moves a certain body part that the user has imagined using with 90% accuracy. The products all have the same goal in mind and for the most part the wheelchair seems to be the most popular device to be used with an EEG control. Our device itself will not be as technologically advanced as the other products out there but we will demonstrate that we can produce the same results without the use of a computer.

Functional and Performance Specifications:

Table 1:Specifications	
# Independent Axes	**2**
Time able to sustain one signal level	**1 minute**
Time to switch between signals	**15 seconds**
Crosstalk between each axis	**<20%**
Power Source (EEG reader)	**6V (4 × AA batteries)**
Power Source (Controller)	**18V (2 × 9V batteries)**
Three levels of control per axis (2 bit TTL compatible digital output)	**off(0V, 0V), medium(5V, 0V), and high(5V, 5V)**
Size (EEG reader)	**Headset + Electrodes**
Size (Controller)	**4” × 3” × 3” + Leads**
Training Time	**<15min**
Number of Electrodes	**6 (4 references)**
Signal	**Continuous**
Wireless Range	**25 ft**

Table 1 is a table of the specifications of the controller

Block Diagram of Problem:
(*Projected Completion Date*)



Evolution of Final Design:

The first step taken in our design was characterizing the output from the MindFlex and Force Trainer devices. Both devices employ the use of the NeuroSky chip so the outputs from both devices are relatively the same. The following outputs were taken from the NeuroSky chip in the Force trainer.

Tested Output from NeuroSky chip to Fan

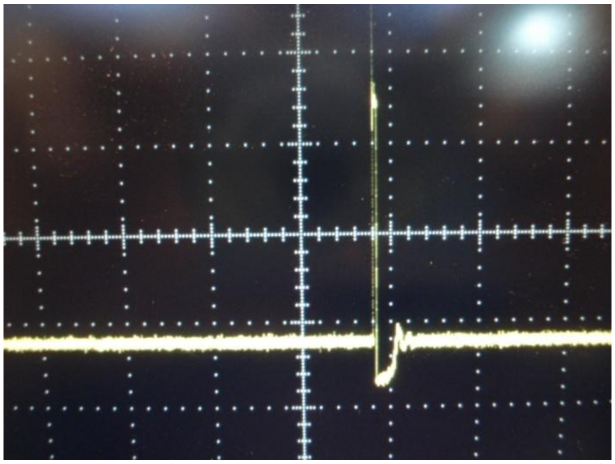


Figure 2 – Output from NeuroSky chip. This signal occurs at a rate of 470hz when the fan is off

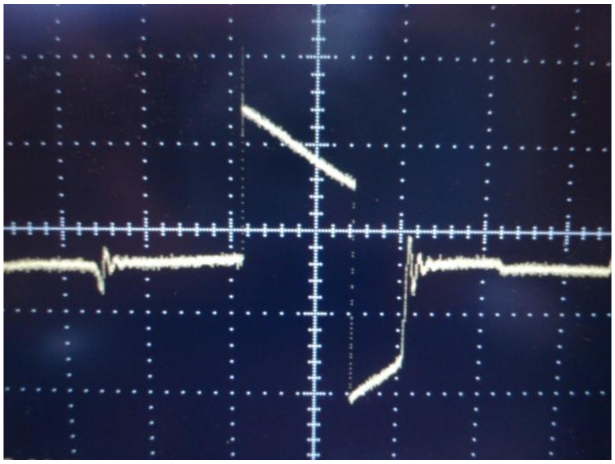


Figure 3 – Output from NeuroSky chip. This signal occurs at a rate of 470hz when the fan is at a medium speed.

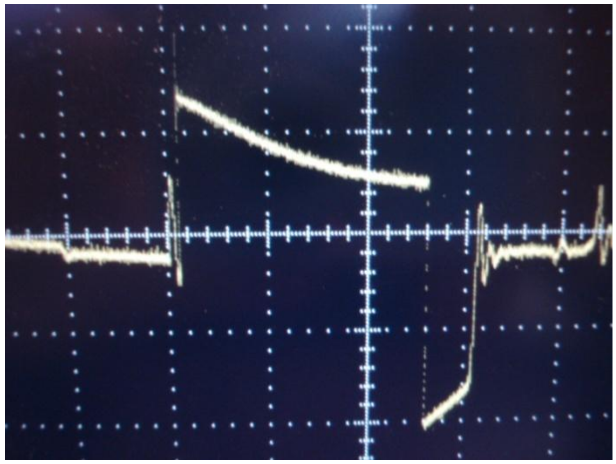


Figure 4 – Output from NeuroSky chip. This signal occurs at a rate of 470hz when the fan is at a fast speed.

From the above graphs, it was concluded that the chip modulates the fan speed by controlling the duration of the active portion of the duty cycle. The above signals occur at 470 Hz regardless of the width of the signal. Thus NeuroSky chip translates an increase in brain activity to an increase in the pulse width. The next step would be to turn this signal into a signal usable by an external device.

Before conditioning our signal we must first determine what the output signal must look like. Originally, we were going to have our output have three distinct voltage levels that each correspond to a range of voltages from our circuit's output. The output would be off (0V), low (1mV), and high (2mV). Using our circuit in conjunction with LabView, we were able to successfully. Implement this. Below shows a successful test run.

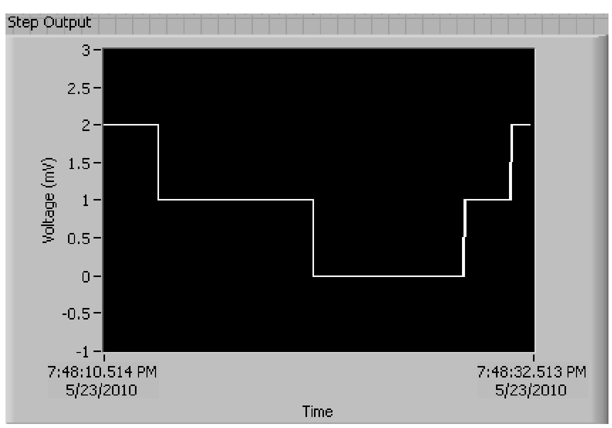


Figure 5 – The above is an example of what we first proposed to be the output from our device. Each level corresponds to an output level: off(0mV), medium (1mV), and high (2mV)

When looking for a suitable device to attach our device to we found no devices that could directly interface with this type of ternary signal. The device that we would like this device to interface with quite commonly employ the use of a microcontroller. Microcontrollers are only capable of receiving binary signals not ternary signals. Upon discovering this, we decided to change our output scheme to a 2-bit binary output. Below shows a simulation of how we will map out ternary signal of two binary channels

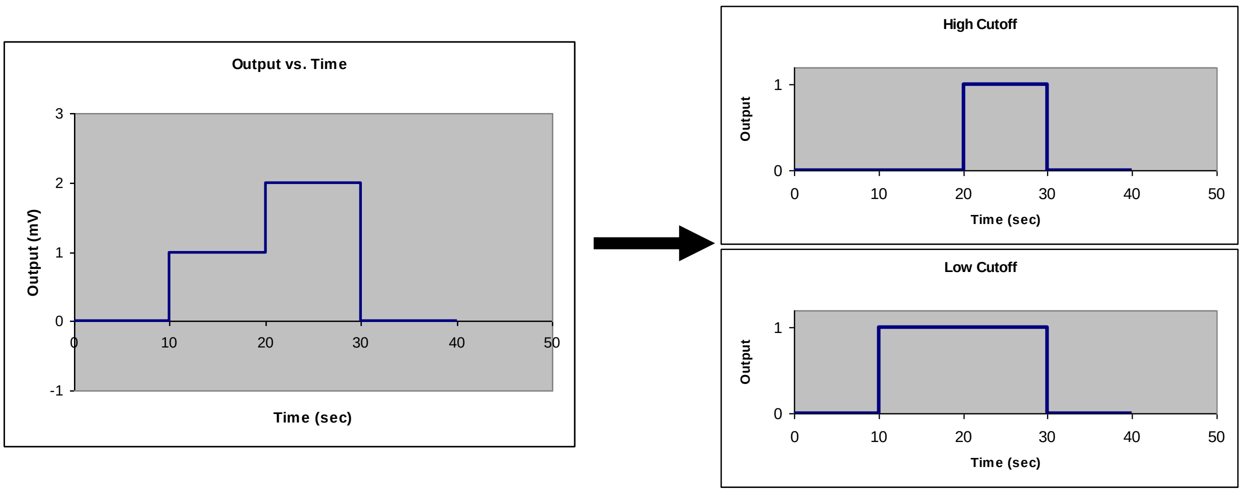


Figure-6 Between 0 and 10 seconds, the off signal will map to both binary channels off. The 1mV signal will map to one binary signal on and one off. The 2mW signal will map to both binary channels on.

The next step would be figuring out how to translate the pulse width modulation from the NeuroSky chip into the binary signal show previously.

The first step take was translating the pulse width modulation into a voltage magnitude. Such that the wider the pulse width, the greater the voltage. To accomplish this we proposed the use of an integrator circuit shown below

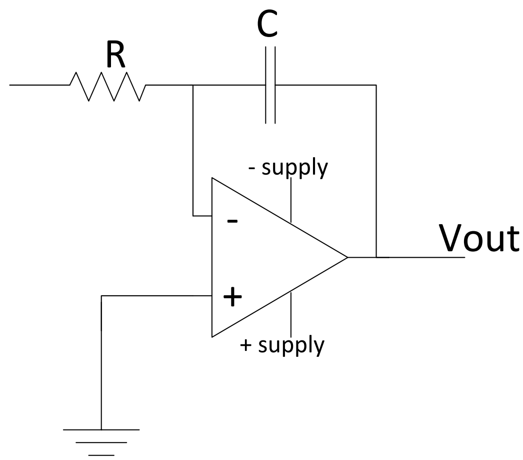
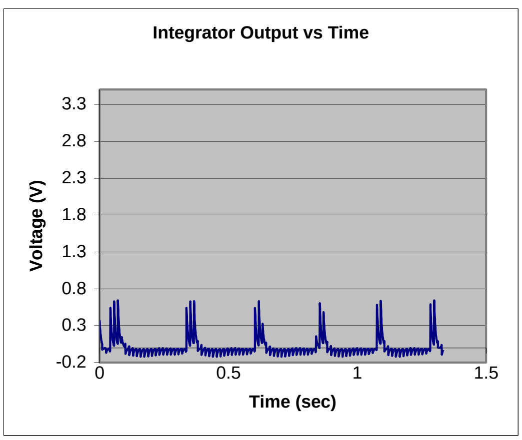


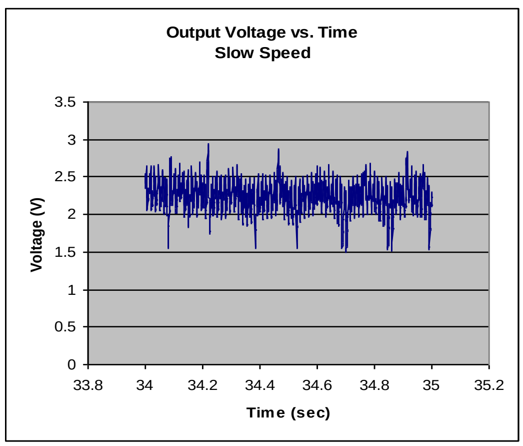
Figure 7 – The integrator circuit was first proposed to translate the pulse width modulation into a change in voltage magnitude.

This circuit was able to moderately translate the duty cycle length into voltage magnitude. Figure 8 below show to results of this circuit.

~Zero width pulse



Medium width pulse



Wide width pulse

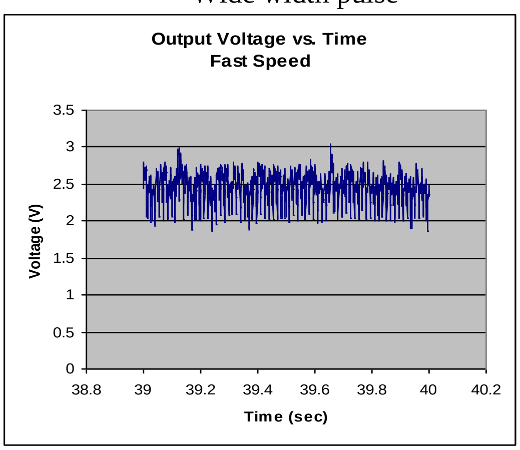


Figure 8 – Output from the integrator circuit in figure 7

The problem with this is that the difference between the fast and slow speed are not significant. Their average values may be different but the overlap of the noise between the signals would make differentiating the signals quite difficult. Because of this problem, we proposed a more complex circuit as shown below.

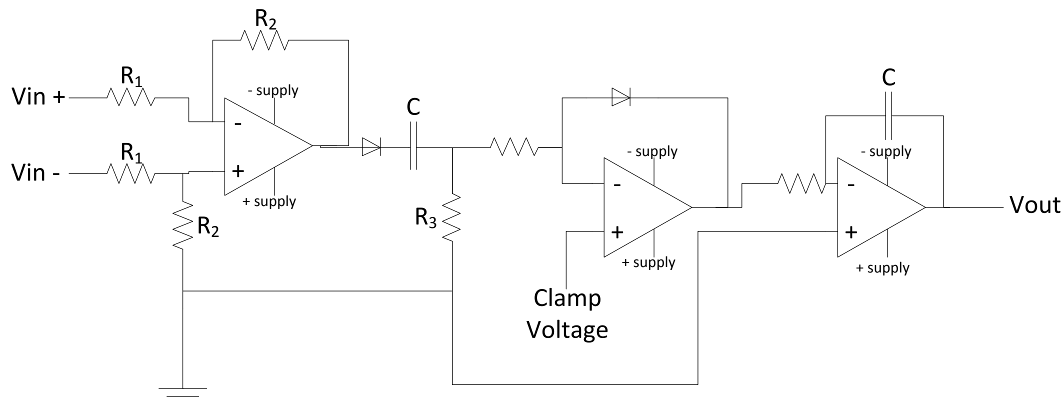


Figure 9 - This circuit eliminates all properties of the signal not related to the pulse width. From left to right, differential amplifier, rectifier, high pass filter, voltage clamp, and integrator.

As stated before, the fan speed is directly controlled by the pulse width. Thus, the rationale for the above circuit is to eliminate all variations that do not effect the duration of the pulse. There are three characteristics of the output that we want to remove. The first is the dip below 0V that occurs at the end of the pulse. The rectifier should only allow voltages above 0V to pass thus eliminating this. The second is the Direct Current (DC) offset voltage. Any variation in this will significantly affect the integrator. Thus, we proposed a high pass filter. The third characteristic is the height of the pulse. We noticed that the height slightly varies regardless of the signal. A voltage clamp should turn that pulse into a simple square wave. Below shows a simulated signal of what the square wave should look like (DC drift correction not shown due to simulation issues).

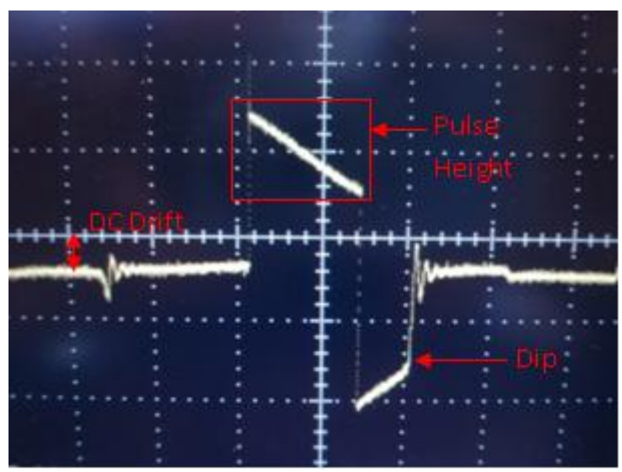


Figure 10 – A descripition of all characteristics that do not have to do width the pulse length. Removal of these will create a more contrasting output from the integrator circuit.

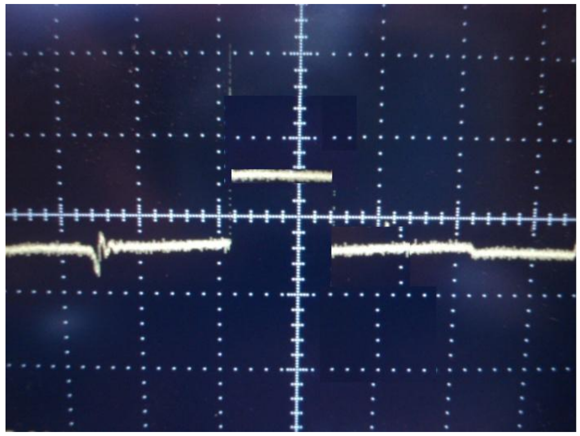


Figure 11 - Simulated signal of what the proposed circuit would do to the NeuroSky output.

Ultimately, the integrator component should be able to integrate this signal and provide a much greater resolution than previous with a much greater signal to noise ratio. A problem that we ran into with this circuit is the response time of the components. The diodes we had available were not able to respond fast enough to properly rectify or clamp the voltage down. In theory, this circuit would provide a plausible solution but, in actuality, the diodes were operating in a non-ideal state.

This being the case, we decided to go back to our original integrator circuit and develop a circuit without having to use non-ideal diodes. The first step we took in modifying our integrator was to add a differential amplifier before the integrator. As it did in the previous circuit, it will eliminate any common mode noise and give us an output voltage with respect to ground as opposed to a pair of leads from the NeuroSky chip. What we noticed was that if we increase the time constant of our integrator, much of the noise disappears. Thus, we decided to increase the time constant in conjunction with a low pass filter. The following circuit was proposed:

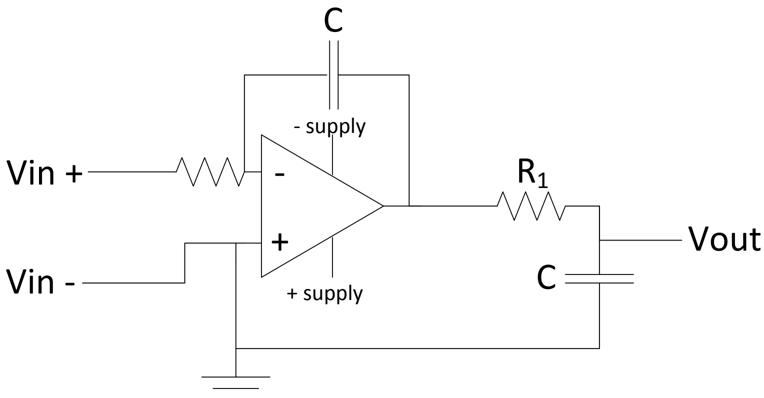


Figure 12 - Integrator circuit with a low pass filter. This circuit will clean up the signal an allows greater contrast between pulse width levels.

This circuit proved to be a valid method of translating duty cycle duration into a voltage amplitude. The following shows the output of our circuit.

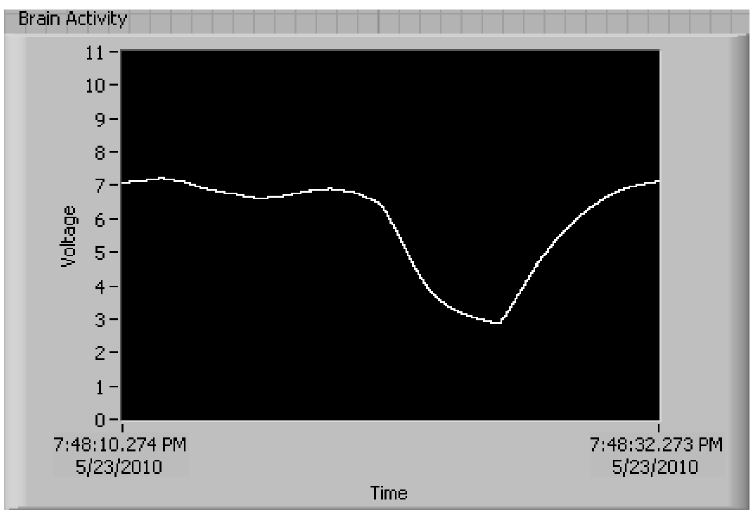


Figure 13 - Output from integrator and low pass filter circuit. This output showed the circuit provides a valid way to differentiate between varying pulse widths

The next step in our design was to turn this continuously varying signal into our proposed output signal

To turn this varying voltage magnitude into a binary signal, we first used a LabView program in conjunction with the ELVIS-1 prototyping board.

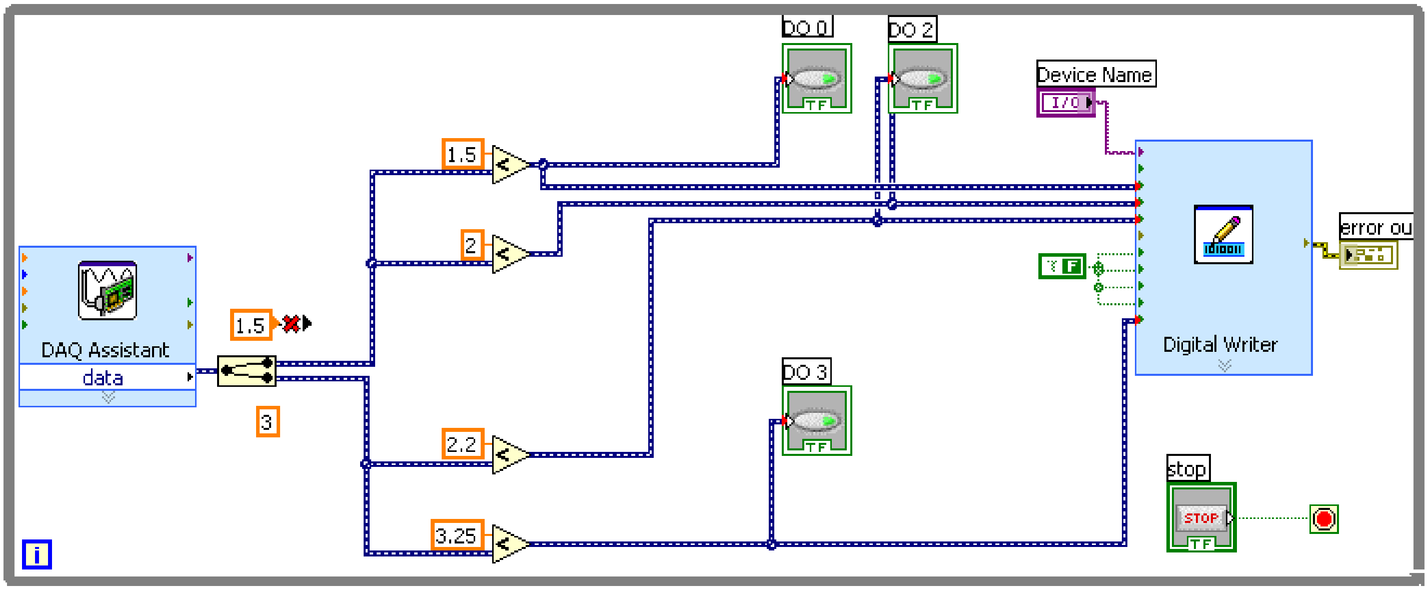


Figure 14 - This LabView program captures the output from the integrator circuit (DAQ Assistant block) it then compares each value to a chosen cutoff value and creates a Boolean output based on which one is greater. The Digital Writer block outputs the results to the Digital Outputs on the ELVIS-1 board. ELVIS uses a digital scheme 0V off, 5V on.

Thus with the completion of this program we successfully created our device. We dubbed this first prototype device the Brain Operated Remote Interface System 1 or BORIS-1. This prototype works fairly well, however, one of the most striking issues is that it used LabView. Thus, the device needs a Windows operating computer and the device needs to be tethered to the device with cables. Thus, the next step is to eliminate LabView from the device and turn it wireless. The headsets from the MindFlex and Force Trainer are already wireless. We will incorporate the receiver of the MindFlex and Force Trainer directly into our device which will enable it to be wireless. However, the most problematic portion is translating our continuous output into a digital output without using LabView and using electrical components only. We will use operational amplifiers and voltage comparators. Using two comparators per channel, we will be able to output an on or off signal based on whether the inverting input voltage is larger or the non-inverting input is larger. This is, basically, an analog to digital converter. The circuit is as shown below

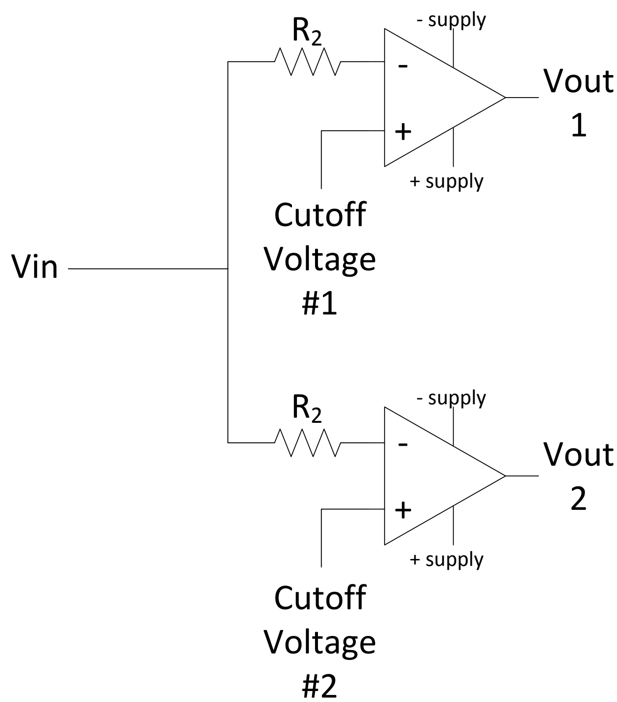


Figure 15 - The above circuit compares the Vin voltage to the cutoff voltages. Based on which one is greater the Vout will take on values of + supply or – supply. The voltage scheme for our binary signal will be set but the +/- supply voltages.

Electrode Placements

A quite important aspect of this project is the placement of electrodes for voluntary control. We have postulated 3 different positions per hemisphere based on literature research. The first position is on the forehead approximately 1 inch off center. This is where the MindFlex and Force Trainer devices are made to work. The second place will be approximately 2 inches above the ear. The objective with this placement will be to detect signals from the pre-motor cortex. The pre-motor cortex is known to be excited voluntarily while thinking about moving muscles yet the actual movement does not have to occur (Murph et. al.). The third place will be approximately 1 inch off the center-line and 3 inches posterior to the midline of the head. According to Ohno et. al. there is a level of voluntary control that can be achieved from this portion of the brain. See the below picture for electrode placement.

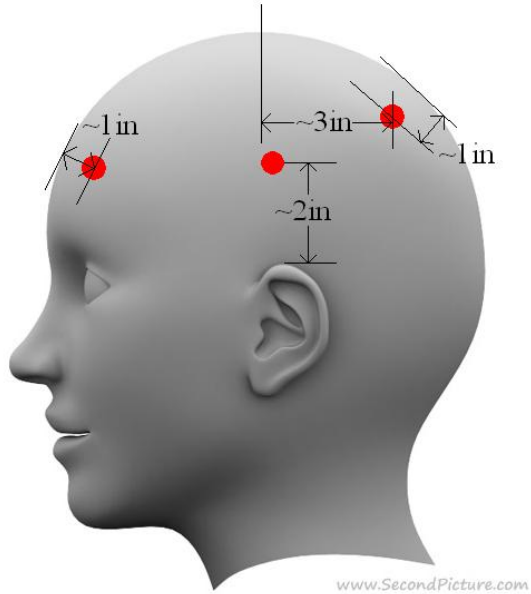


Figure 16 - Proposed electrode placements

We tested each position for controllability and consistency. See section on Performance Testing Protocol. Based on the results we placed the Force Trainer electrode on the occipital lobe and the MindFlex electrode on the frontal lobe.

Detailed Description of Final Design

This device combines two on the market devices used for interpreting brain waves for single axis control: MindFlex and Force Trainer. Both of these devices use a chip developed by NeuroSky to read and interpret the brain waves and then output the control to a DC motor to control a fan. Our device, BORIS-2, has taken one of each of these devices and combined them to create control along two separate axes. Not only is it able to control two axes, but the device interfaces with other devices through a 2 bit digital output scheme allowing it to interface a plethora of devices. The output conditioning and interfacing circuit diagram is as shown below.

The final electrode placements are as diagramed below

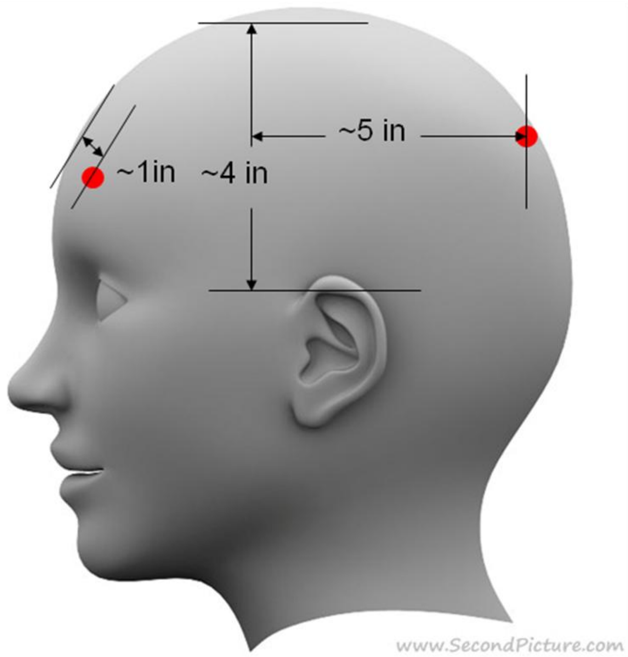


Figure 17 - Diagram of electrode placement

Figure 18 - Final Headset with electrodes

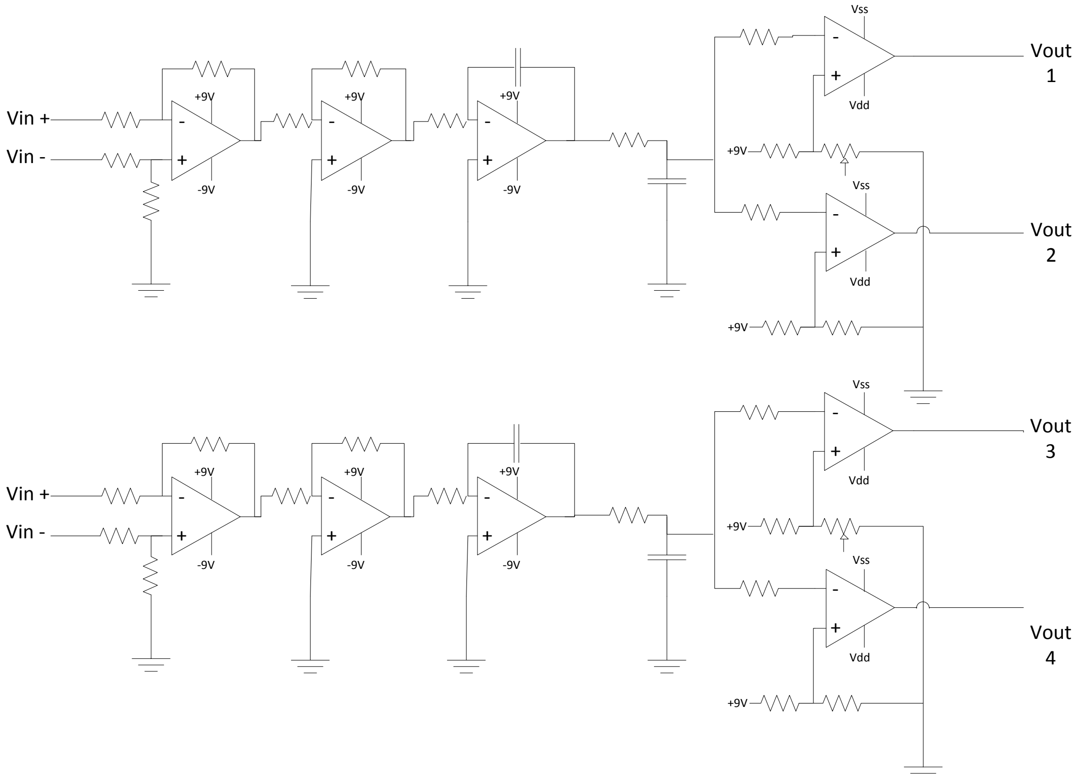


Figure 19 – BORIS-2 Conditioning Circuit

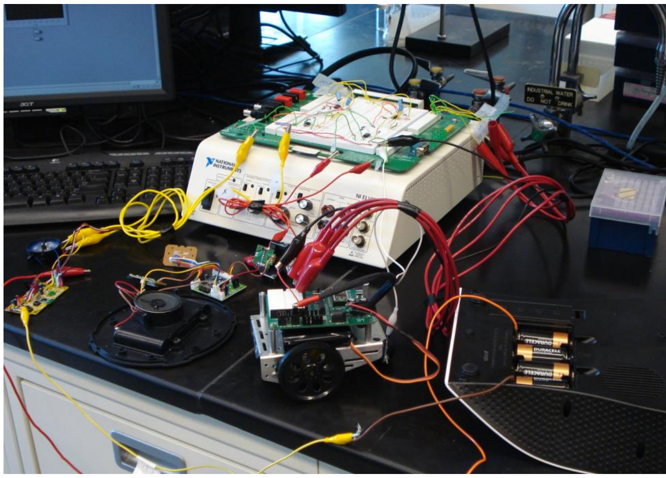


Figure 20 - BORIS-2

Figure 21 - BORIS-2

Materials Selection:

ELVIS Software

The ELVIS-1 prototyping board allows for easy electrical circuit construction and for integration with a PC. This software was chosen because of Group F's prior experience with the software in BIEN 130L and for its ease of application. Group F utilized the following capabilities of the software: Function Generator, Oscilloscope, and Variable Power Supplies.

LABVIEW Software

LABVIEW was used to convert the analog signal from the conditioning circuit into a digital signal in BORIS I, that could be utilized by the microcontroller on the Boe-Bot. LABVIEW was chosen for its versatility in the manipulation of signals. Our methods allowed control of cutoff voltages that enable TTL compatible output.

Boe-Bot

In lieu of demonstration with a consumer R/C Vehicle, a Boe-Bot was chosen for the demonstration device. The Boe-Bot consists of a microcontroller and servos attached to wheels. The microcontroller reads a digital signal, which is translated into position commands by the servos. The servos directly controls the movement of the wheels. One of the Boe-Bot's advantages over the traditional R/C Car is its programmability. The microcontroller on the Boe-Bot can be programmed to follow a specific pattern determined by the user. This enabled Group F to program the Boe-Bot to respond to the TTL output from the conditioning circuit. The Boe-Bot also runs at speeds akin to wheelchair movement as opposed to the high speeds of the R/C Vehicle. In addition to these advantages, microcontrollers have seen widespread use in various robotics applications.

Method of Prototyping Discussion:

BORIS-1

BORIS-1 (Fig 22) consists of the Mind Flex and Force Trainer Platforms with their respective headsets. Both headsets are worn by the subject. Wires from the Mind Flex and Force Trainer platforms (Fig 22A) are connected to 2 conditioning circuits (Fig 22C) designed on an ELVIS breadboard and powered by its platform (Fig 22B). The platform is connected to a computer (Fig 22D), which, with LABVIEW software, converts the analog signal from the conditioning circuit into a digital output. The signal from LABVIEW is outputted from 4 digital outputs (Fig 22E) on the ELVIS Prototyping Board (2 speed levels for 1 axis and 2 for the other). The digital outputs are then connected (via wire) to the inputs on the microcontroller (Fig 22F), which is programmed to interpret the signals from the digital outputs as speed controls.

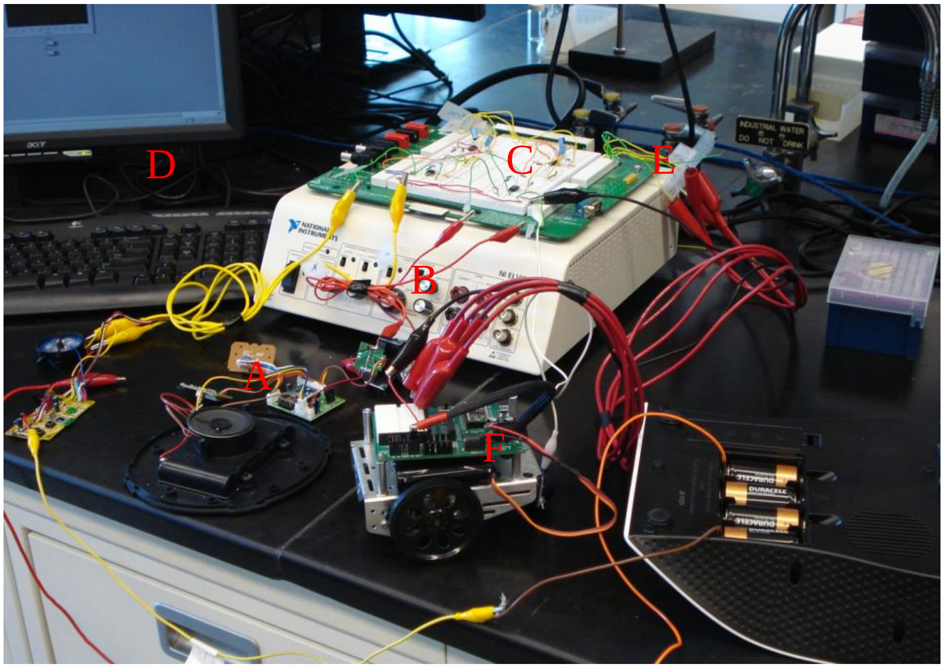


Figure 22 BORIS-1 is the first prototype of the EEG controller. It relies on a desktop computer as well as Elvis prototyping board to power the circuit. Boe-Bot is tethered to the board by cables which limits the ability of the Boe-Bot.

BORIS-2

BORIS-2 (Fig 23) is the wireless configuration of BORIS-1. It consists of the Mind Flex and Force Trainer circuitry (Fig 23A), with all nonessential components removed attached to a plexiglass platform mounted on the microcontroller (Fig 23C). The two headsets are modified and combined to form a single headset with 4 reference electrodes and 2 signaling electrodes. The Mind Flex and Force Trainer circuitry are connected to a breadboard with the conditioning circuit (Fig 23B), which is also mounted on the plexiglass platform. The conditioning circuit is powered by 2 x 9 volt batteries. This conditioning circuit includes a voltage comparator, which converts the continuous signal into a digital signal, replacing the need for a LabView script. The outputs from the conditioning circuit are connected to the inputs on the microcontroller via a small breadboard attached to the plexiglass platform (Fig 24).

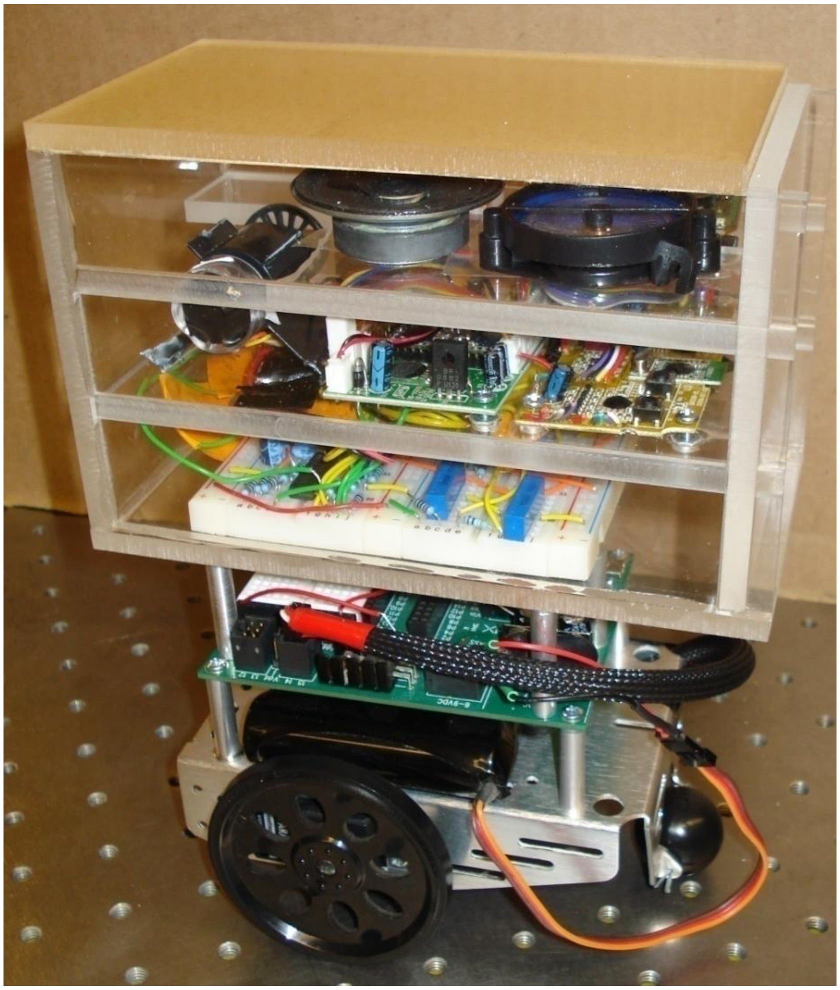


Figure 23 BORIS-2 is the second prototype of the EEG controller. All of the circuitry is contained within a custom made Plexiglas box. It is wireless and battery powered which frees the Boe-Bot for full movement.

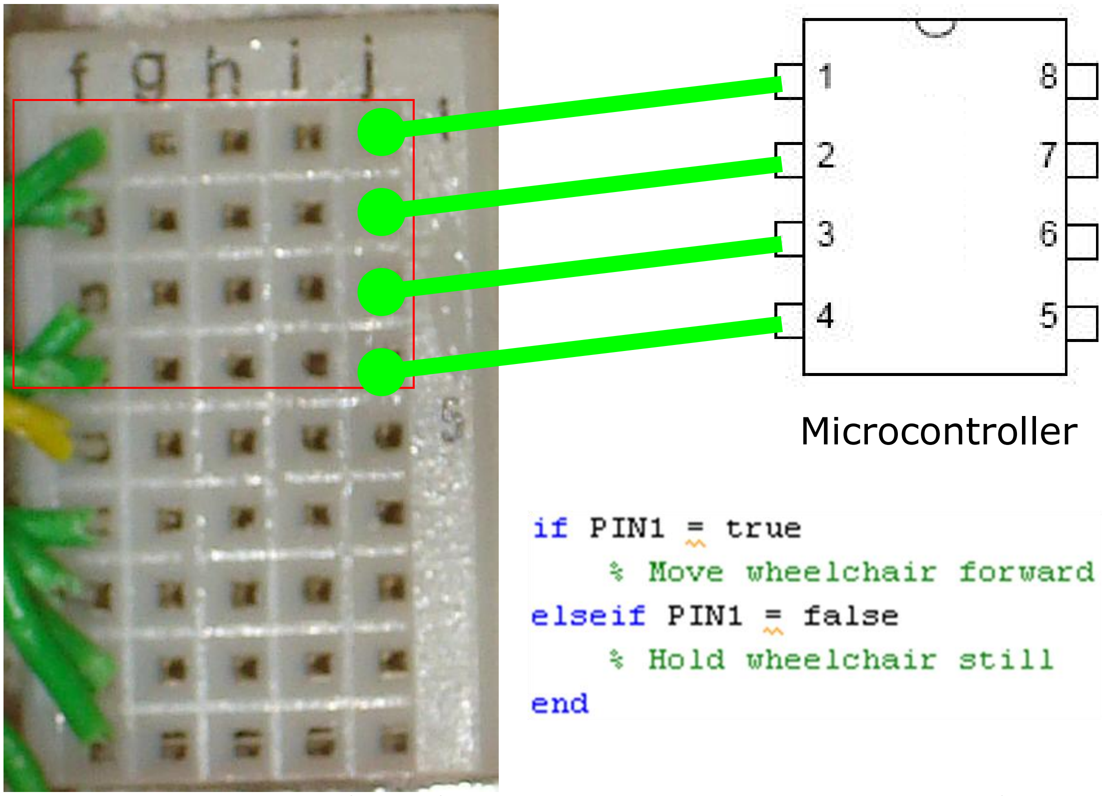


Figure 24BORIS-2/ Microcontroller Interface. This figure shows how the BORIS-2 outputs to a microcontroller. The first two pin 1 and 2 refer to one axis. Pins 3 and 4 refer to the other axis. The microcontroller is a small computer with memory, processing core and programmable inputs as shown above. So when give a true or false signal each pin can be programmed to carry out a programmable action. For example if pin 1 receives a true signal the wheelchair will move forward.

Performance testing Protocol Discussion:

When testing any new technology or an improvement upon an existing technology one must take into consideration the correct process in examining the performance. For our 2-axes EEG control system we took into consideration that our performance rested in many key areas such as: our circuit, electrode placement, training time, and the efficiency of using the headset to control the object at hand. For our circuit design we decided that to obtain the best performance possible we needed to be able to distinguish between the fast, medium, and off signals that were generated from the fan of either the Mind flex or Force trainer. The differential amplifier is simply a means of reducing any common mode noise and also allowing us to easily amplify or attenuate our signal per out need. The next part of our circuit is the rectifier and this basically eliminates the spikes seen in the signal. The most important aspect of our circuit design is to distinguish between the different fan speed signals. Our voltage clamp helps to give our signal a square wave like signal which upon integration using the integrator we our able to distinguish the differences in the three signal. These signals will now be a clear command to our Boebot as to what direction it should move.

The other part of the project was determining how each of the EEG toy devices worked. Upon feeding in various frequencies into the force trainer and plotting the number of lights that lit up per frequency, we determined that the headset reads in a high frequency to sense the connection with the brain and acts upon about a 20 hertz signal. This is within the normal range of beta waves emitted by the brain. This gives us some hints as to where we should place the electrodes in order to gain optimum performance. The goal is to find two positions on the brain that gives a person conscious control of the device without the two electrodes interfering with each other. The first region to test is the frontal lobe of the brain since this is where the Force Trainer and MindFlex set their electrodes for their consumers. Upon doing a literature search for the next two positions we found that the pre-motor cortex and the occipital lobe have been used in various studies. The pre-motor cortex was used in studies done by K. Ohno in which he showed that all a subject has to do is think about moving their limbs without actually moving them. Darren Quick illustrated in his article “What’s on your mind-microelectrodes offer poke free brain control” that a person who increases their concentration will trigger brain activity in the occipital lobe region. The results of testing the two consumer products at these three positions are displayed in the next section of the report in tables 2 and figure 25. In these test we test for sustainability (how long can one hold the ball at a particular height) and reproducibility (can one hold it at that height for about the same amount of time each trial). The goal is to find the best placement for both electrodes that will give the least amount of crosstalk so that they keep their independence as well as conscious control.

Performance Testing Results:

Frontal Lobe Force Trainer Take (Maintain) seconds Table #2a				
Trial	Off	Level 1	Level 2	Level 3
1	20 (30)	6 (10)	3 (2)	55(13)
2	30 (15)	14 (15)	36 (11)	58 (3)
3	13 (10)	2 (3)	28 (20)	16 (22)
4	3 (13)	3 (3)	38 (5)	39 (24)
5	10 (23)	12 (3)	38 (9)	15 (31)
6	13 (25)	2 (5)	38 (3)	33 (23)
7	2 (20)	33 (3)	21 (3)	13 (35)
8	5 (13)	10 (15)	13 (3)	42(30)
9	14 (5)	27 (10)	38 (12)	16 (18)
10	9 (11)	18 (4)	8 (2)	33 (26)

Motor Cortex Force Trainer, Take (Maintain) seconds table #2b				
Trial	Off	Level 1	Level 2	Level 3
1	4 (3)	29 (13)	9 (2)	8 (5)
2	2 (20)	3 (7)	27 (13)	16 (9)
3	16 (4)	15 (17)	22 (2)	9 (15)
4	14 (25)	24 (3)	9 (2)	17 (2)
5	11 (23)	26 (3)	20 (5)	30 (16)
6	13 (12)	6 (7)	5 (3)	6 (4)
7	5 (7)	10 (2)	5 (4)	9 (10)
8	5 (13)	10 (15)	13 (3)	17 (19)
9	14 (16)	5 (5)	31 (2)	33 (15)
10	9 (25)	28 (8)	27 (11)	30 (15)

Occipital lobe Force Trainer, Take (Maintain) seconds table #2c				
Trial	Off	Level 1	Level 2	Level 3
1	23 (3)	22 (16)	6 (3)	18 (4)
2	14 (10)	12 (2)	8 (3)	12 (13)
3	7 (9)	21 (4)	16 (5)	50 (20)
4	7 (6)	27 (10)	15 (5)	23 (17)
5	29 (16)	12 (7)	7 (4)	25 (16)
6	11 (26)	14 (2)	4 (2)	10 (8)
7	12 (10)	3 (6)	24 (3)	14 (11)
8	5 (13)	10 (15)	13 (3)	17 (19)
9	6 (11)	4 (4)	16 (12)	49 (5)
10	12 (2)	6 (2)	24 (11)	5 (14)

Frontal Lobe MindFlex Take (Maintain) seconds table #2d			
Trial	Off (0-1 lights)	Med(2-3 lights)	High (4 lights)
1	7 (15)	23 (24)	20 (14)
2	2 (30)	4 (36)	15 (17)
3	10 (20)	3 (30)	3 (18)
4	22 (21)	4 (36)	86 (15)
5	32 (7)	6 (29)	41 (13)
6	5 (35)	10 (36)	30 (9)
7	16 (15)	3 (39)	47 (12)
8	16 (12)	5 (22)	2 (18)
9	2 (11)	3 (11)	5 (12)
10	7 (13)	5 (17)	4 (20)

Occipital Lobe MindFlex Take (Maintain) seconds table #2e			
Trial	Off (0-1 lights)	Med(2-3 lights)	High (4 lights)
1	18 (7)	7 (2)	34 (4)
2	3 (20)	12 (2)	13 (15)
3	9 (3)	2 (5)	2 (4)
4	23 (6)	71 (5)	7 (25)
5	17 (3)	7 (4)	45 (6)
6	5 (10)	50 (3)	8 (20)
7	16 (5)	13 (10)	11 (28)
8	3 (2)	6 (2)	7 (11)
9	8 (4)	12 (4)	100 (5)
10	4 (22)	5 (5)	97 (6)

Premotor Cortex MindFlex Take (Maintain) seconds table # 2f			
Trial	Off (0-1 lights)	Med(2-3 lights)	High (4 lights)
1	60 (4)	13 (5)	20 (4)
2	2 (6)	4 (4)	32 (3)
3	6 (8)	22 (5)	57 (5)
4	5 (5)	5 (10)	100 (4)
5	5 (22)	4 (2)	23 (10)
6	7 (5)	6 (4)	100 (3)
7	13 (15)	7 (7)	18 (3)
8	8 (5)	54 (4)	12 (7)
9	5 (6)	5 (4)	14 (2)
10	13 (5)	16 (6)	7 (3)

Table 2(a-f) show the time it takes for the ball to reach a certain height in seconds outside the parenthesis and the time the ball was maintained at that particular level in seconds within the parenthesis. The data was obtained when a group member gave a command to go from one height position to another and timed how long the other group member could maintain the ball at that height. Ten trials were run for both devices in each of the three regions of the brain selected. The time was averaged out for each level (off, medium, high) and plotted in Excel.

Figure 25a MindFlex

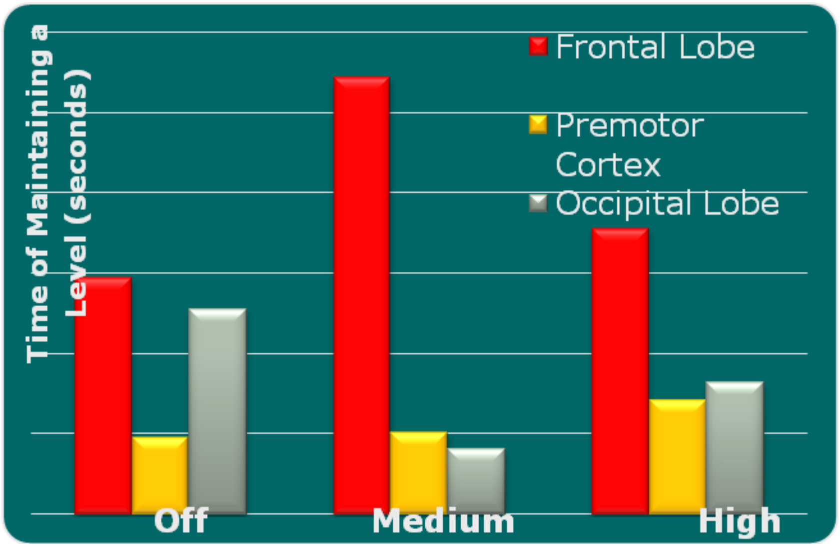


Figure 25b Force Trainer

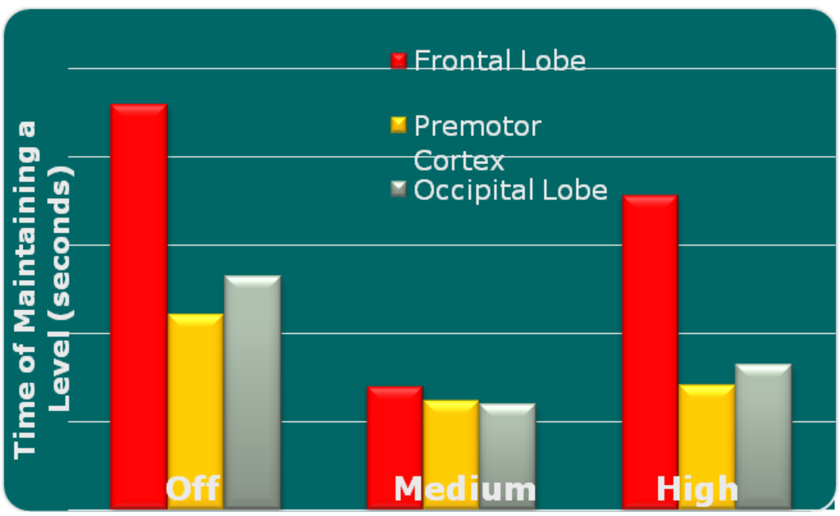


Table 25(a-b) compare the ability of the MindFlex and the Force Trainer to maintain one of the three levels off, medium and high in seconds between the three brain positions: Frontal lobe, premotor cortex and Occipital lobe. It was observed that the front lobe is the best placement for both devices. Unforntately both devices cannot be placed on the frontal lobe because the two axis would lose their independence because they would be reading the same brain activity. So by looking at the data the next best option was to place the Force Trainer on the Occipital lobe.

It is clear that the frontal lobe is the dominant position for both devices. Unfortunately we want independent axes control, thus setting both electrodes on the frontal lobe region will only cause them to interfere with each other. Thus, for the Force Trainer we decided that, since the occipital lobe gave the second highest control we placed the electrode at that position of the brain. Our goal is to have a device that will allow a person to maintain a certain speed and direction for as long as they need.

Financial Considerations:

The estimated required materials are as follows:

2	Star Wars Force Trainer	$99 ea	Provided by Dr. Park
2	Mind Flex Game	$99 ea	Provided by Dr. Park
1	Oscilloscope	$--	Provided by Dr. Park
1	Multimeter	$--	Provided by Dr. Park
1	Pre-amp	$--	Provided by Dr. Park
1	Soldering and supplies	$--	Provided by Dr. Park
1	Boe-Bot	$--	Provided by Ron Poutre
1	Elvis platform by NI	$11000	Provided by Bioengineering Dept
2	Elvis Breadboard and parts	$--	Provided by Bioengineering Dept
1	Lab View software	$--	Provided by Bioengineering Dept
-	Wires, clamps, etc	$25	
26	4/40 x 3/8’’ nut	$0.15 ea (+tax)	
1	Breadboard Set	$19.99 (+tax)	
16	Panhead screw, 4/40, ¼	$0.15 ea (+tax)	
10	Panhead screw, 4/40, 2 in	$0.55 (+tax)	
4	Round Standoff 4/40, 0.625 in	$0.40 (+tax)	
8	Round Standoff 4/40, 1.25 in	$0.45 (+tax)	
Total		$72.05	

Conclusions:

Group F has developed a two-axis EEG control system that allows for hands-free control that can be adapted to many devices, including a wheelchair. The control system was adapted from parts of two consumer products that were broken down analyzed and reverse engineered. The consumer products have a wireless headset that contains three electrodes that read the brainwaves and then transmit the information to the base component of the product. The outputs from each of the devices were originally designed for one-axis of control: speed control of a fan that would levitate a ball. These products ran with pulse-width modulation, thus, a conditioning circuit was used to make the signal continuous. This signal was subsequently converted into a TTL digital output, which could be inputted into a microcontroller. With modifications, this control system could be applied to various hands free applications. For the purpose of demonstrating the controller, it was applied to a Boe-bot made by Parallax Inc., which simulates a wheelchair's motions with two large motorized wheels and one unmotorized support wheel. The first prototype was designated BORIS-1, which was limited by a connection to a desktop computer with LabView software and an NI ELVIS board. The subsequent prototype, BORIS-2, was liberated from its wires and contained the base of the consumer products as well as the conditioning circuit and the microprocessor. Despite the success in the development of this two-axis system, final specifications could not be obtained, because of damage that was incurred on the MindFlex. Therefore, a feasibility/usage analysis could not be made. The proof of concept that the EEG controller was able to record brain activity and condition the signal into three distinct levels of control with two independent axes was successful.

Future Work:

The prospect of controlling devices hands-free that read brain waves has many applications and much potential. Future work on this project would include designing a system with an increased sensitivity of control and a decreased response time. This would be done by designing a method to detect brainwaves more precisely. These improvements may only be possible invasively, which is outside the scope of this project. The final product of this project is a controller that can remotely control a mechanical system that functions based upon two axes. Another aspect of potential future improvement would be the development of a third generation BORIS system. This system would have a conditioning circuit enabling floating cutoff values, which are intended to improve precision by allowing cutoff thresholds to change when they are crossed. This prevents digital output impulses resulting from an oscillating signal occurring at or near the cutoff, thus, enabling continuous movement. BORIS-3 would also rely on obtaining a chip directly from Neurosky instead of obtaining consumer products like the MindFlex and Force Trainer, which have unnecessary components that would hinder the functionality of the device. This and the conditioning circuit would be printed on a circuit board, enabling a drastic decrease in size and a decreased reliance on power.

Statement of Societal Impact:

This project has huge societal impacts if successful. It could help people with limited use of all limbs to become mobile. This product could help in improving the efficiency of the operating room, therefore, decreasing the time required for an operation. The controller is applicable in many situations in society from improving the standard of living to making small tasks easier. For example, people with disabilities will be able to move around in their wheelchairs with ease and could rely on their thoughts to control house care robots to provide them the assistance required.

Appendix I: Table of Abbreviations

Table 3 Abbreviations	
AC	Alternating Current
ASIMO	Advance Step in Innovative Mobility
BIEN	Bioengineering
BMI	Brain Machine Interface
Boe-Bot	Board of Education Robot
BORIS	Brian Operated Remote Interface System
CMOS	Complementary Metal Oxide Semiconductor
DC	Direct Current
ECOG	Electrocorticography
EEG	Electroencephalogram
ELVIS	Education Laboratory Virtual Instrumentation Suite
LABVIEW	Laboratory Virtual Instrumentation Engineering Workbench
NI	National Instruments
TTL	Transistor-transistor logic

Appendix II: Project Budget

The estimated required materials are as follows:

2	Star Wars Force Trainer	$99 ea	Provided by Dr. Park
2	Mind Flex Game	$99 ea	Provided by Dr. Park
1	Oscilloscope	$--	Provided by Dr. Park
1	Multimeter	$--	Provided by Dr. Park
1	Pre-amp	$--	Provided by Dr. Park
1	Soldering and supplies	$--	Provided by Dr. Park
1	Boe Bot	$--	Provided by Ron Poutre
1	Elvis platform by NI	$11000	Provided by Bioengineering Dept
2	Elvis Breadboard and parts	$--	Provided by Bioengineering Dept
1	Lab View software	$--	Provided by Bioengineering Dept
-	Wires, clamps, etc	$25	
26	4/40 x 3/8’’ nut	$0.15 ea (+tax)	
1	Breadboard Set	$19.99 (+tax)	
16	Panhead screw, 4/40, ¼	$0.15 ea (+tax)	
10	Panhead screw, 4/40, 2 in	$0.55 (+tax)	
4	Round Standoff 4/40, 0.625 in	$0.40 (+tax)	
8	Round Standoff 4/40, 1.25 in	$0.45 (+tax)	
Total		$72.05	

Appendix III: List of Equipment and Facilities

Bioinstrumentation Laboratory (BRNHL B342D)

- Wires
- Clamps
- Capacitors
- Resistors
- Multimeters
- Computers w/ ELVIS software
- Computers w/ LABVIEW software
- ELVIS Prototyping Board
- ELVIS Platform

Park Lab (BRNHL B232)

- Oscilloscope
- Soldering and Supplies
- Pre-amp

Other Equipment

- Mind Flex Game
- Star Wars Force Trainer
- Boe-Bot
- Equipment for Boe-Bot Modification (Screws, plexiglass, standoffs, etc.)
- Operational Amplifiers

Appendix IV: Team Job Responsibilities

Ryan LaCroix and Kenneth Sugerman

The above were responsible for characterizing the output from the MindFlex and Force Trainer devices and the conditioning of such output to conform to the design specifications

Joseph Fletcher and Gary Stroup

The above were responsible for determining appropriate placements of the electrodes on the head and creating the headset capable of holding the electrodes in that place

AppendixV: Detailed Design Drawings

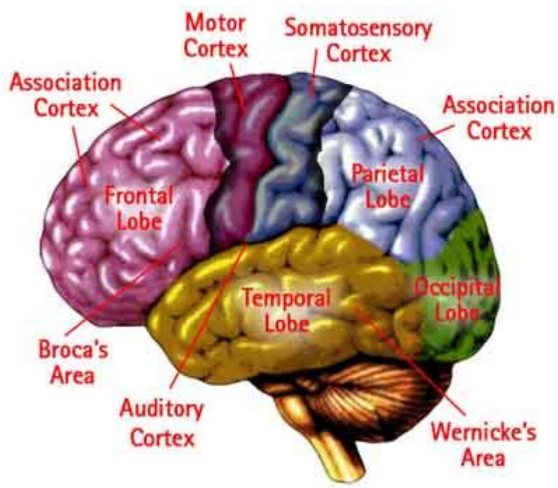


Figure 1 diagram of the regions of the brain. The places that were thought to be ideal for the best electrode placement were the Frontal lobe, premotor cortex and the Occipital lobe. The frontal lobe was where the consumer devices placed their electrodes. The premotor cortex is activated when thinking about moving. And the occipital lobe is a place that is usually activated by visual stimulus but Quick et al has shown that concentration can activate this region.

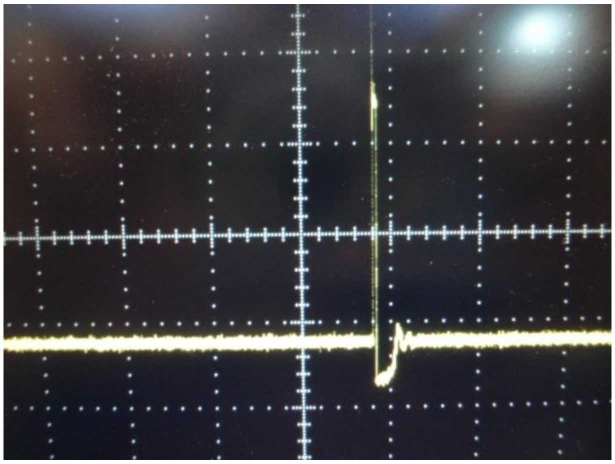


Figure 2 – Output from NeuroSky chip. This signal occurs at a rate of 470hz when the fan is off

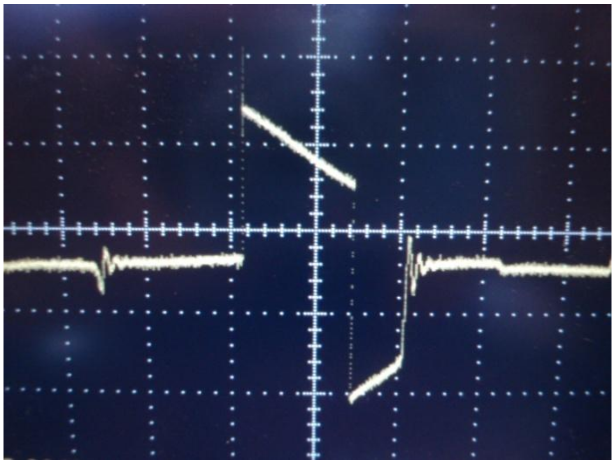


Figure 3 – Output from NeuroSky chip. This signal occurs at a rate of 470hz when the fan is at a medium speed.

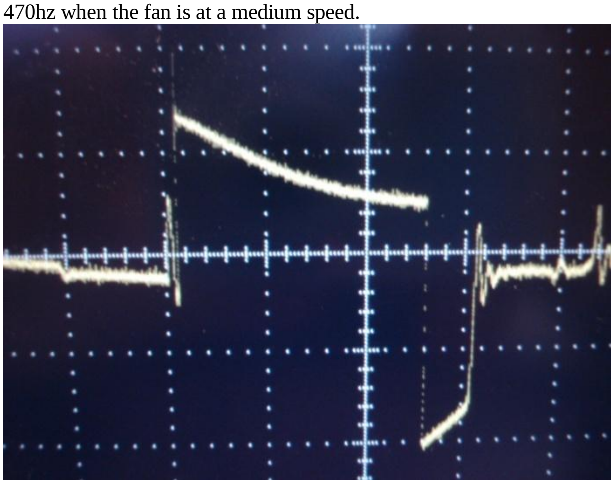


Figure 4 – Output from NeuroSky chip. This signal occurs at a rate of 470hz when the fan is at a fast speed.

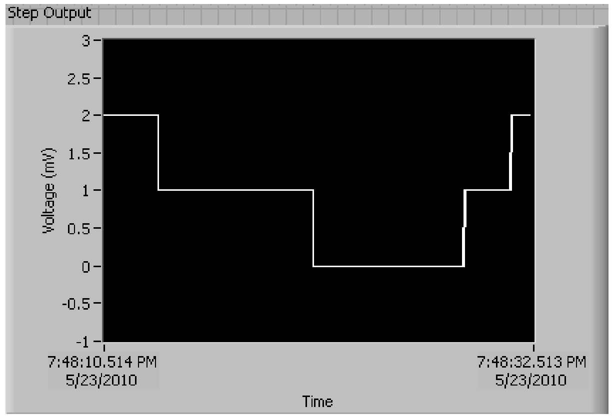


Figure 5 – The above is an example of what we first proposed to be the output from our device. Each level corresponds to an output level: off(0mV), medium (1mV), and high (2mV)

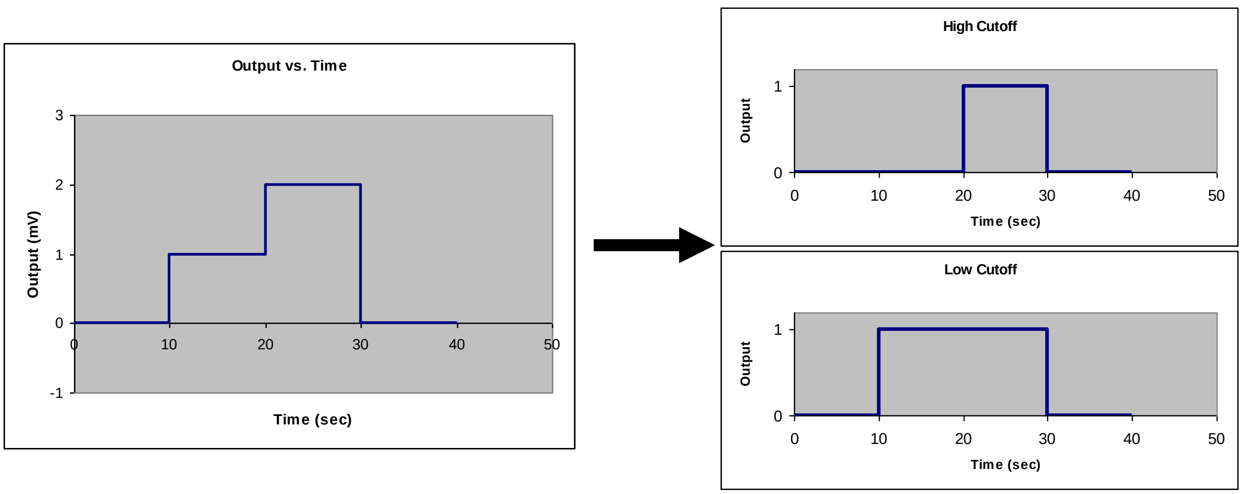


Figure-6 Between 0 and 10 seconds, the off signal will map to both binary channels off. The 1mV signal will map to one binary signal on and one off. The 2mW signal will map to both binary channels on.

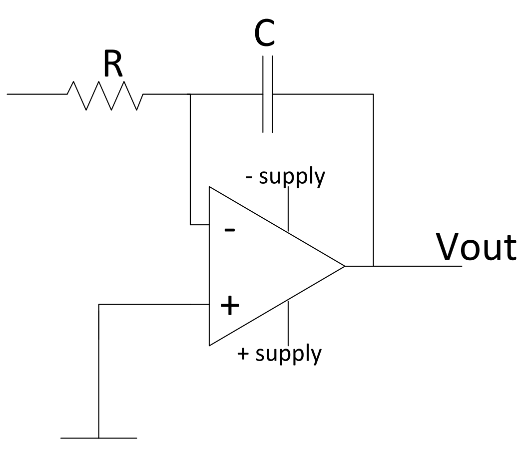
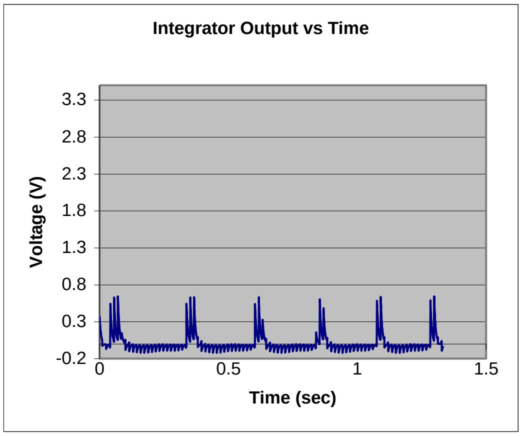
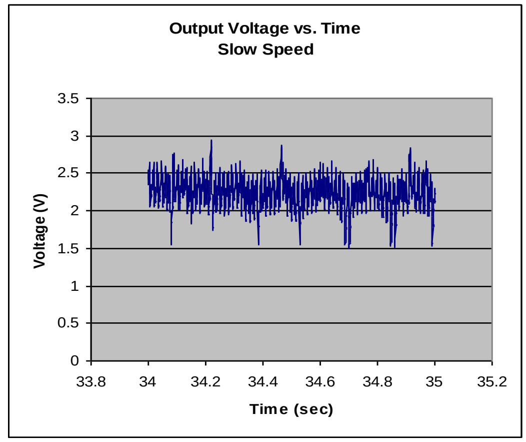


Figure 7 – The integrator circuit was first proposed to translate the pulse width modulation into a change in voltage magnitude.

~Zero width pulse



Medium width pulse



Wide width pulse

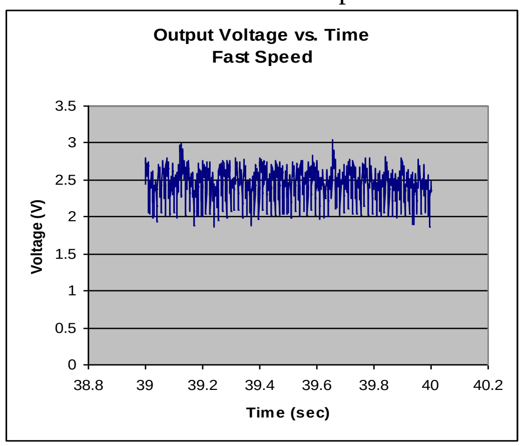


Figure 8 – Output from the integrator circuit in figure 7

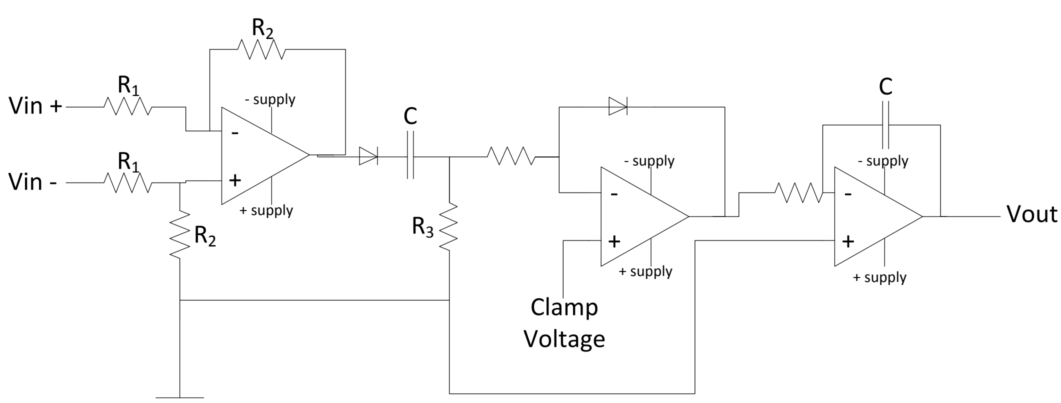


Figure 9 - This circuit eliminates all properties of the signal not related to the pulse width. From left to right, differential amplifier, rectifier, high pass filter, voltage clamp, and integrator.

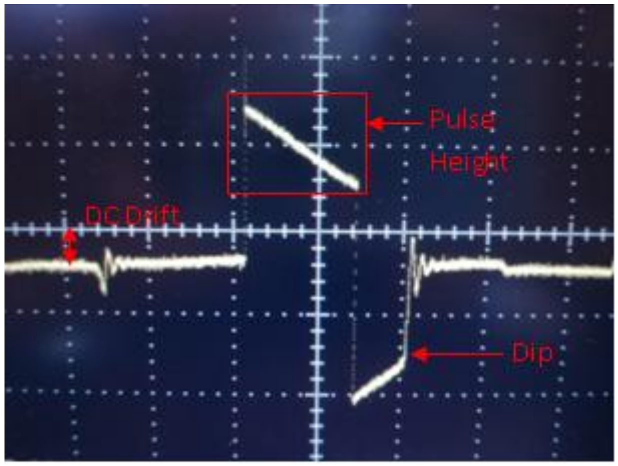


Figure 10 – A descripition of all characteristics that do not have to do width the pulse length. Removal of these will create a more contrasting output from the integrator circuit.

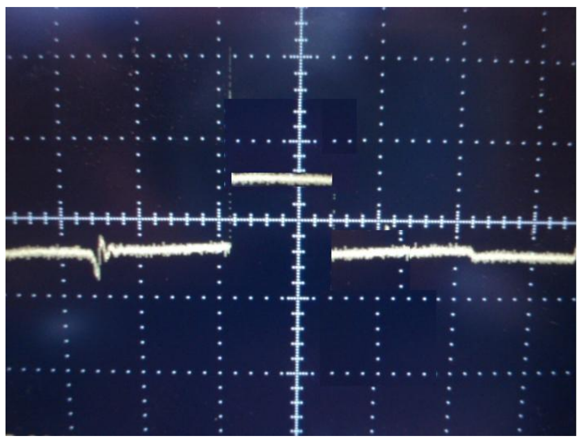


Figure 11 - Simulated signal of what the proposed circuit would do to the NeuroSky output.

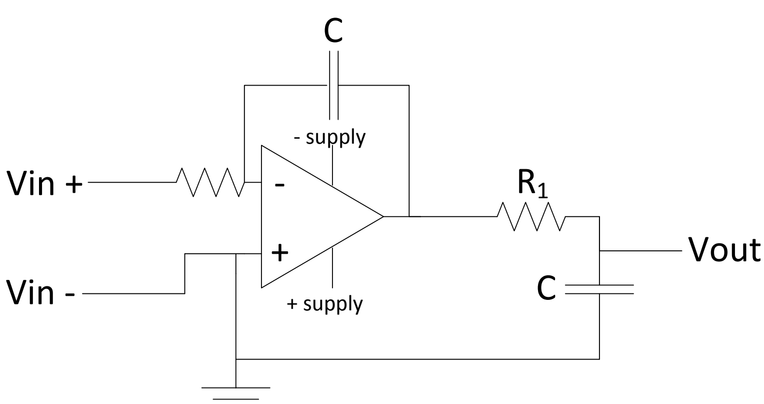


Figure 12 - Integrator circuit with a low pass filter. This circuit will clean up the signal an allows greater contrast between pulse width levels.

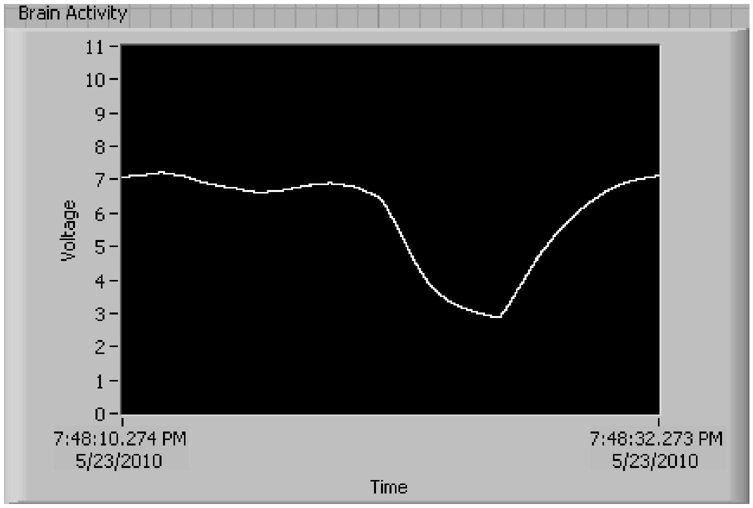


Figure 13 - Output from integrator and low pass filter circuit. This output showed the circuit provides a valid way to differentiate between varying pulse widths

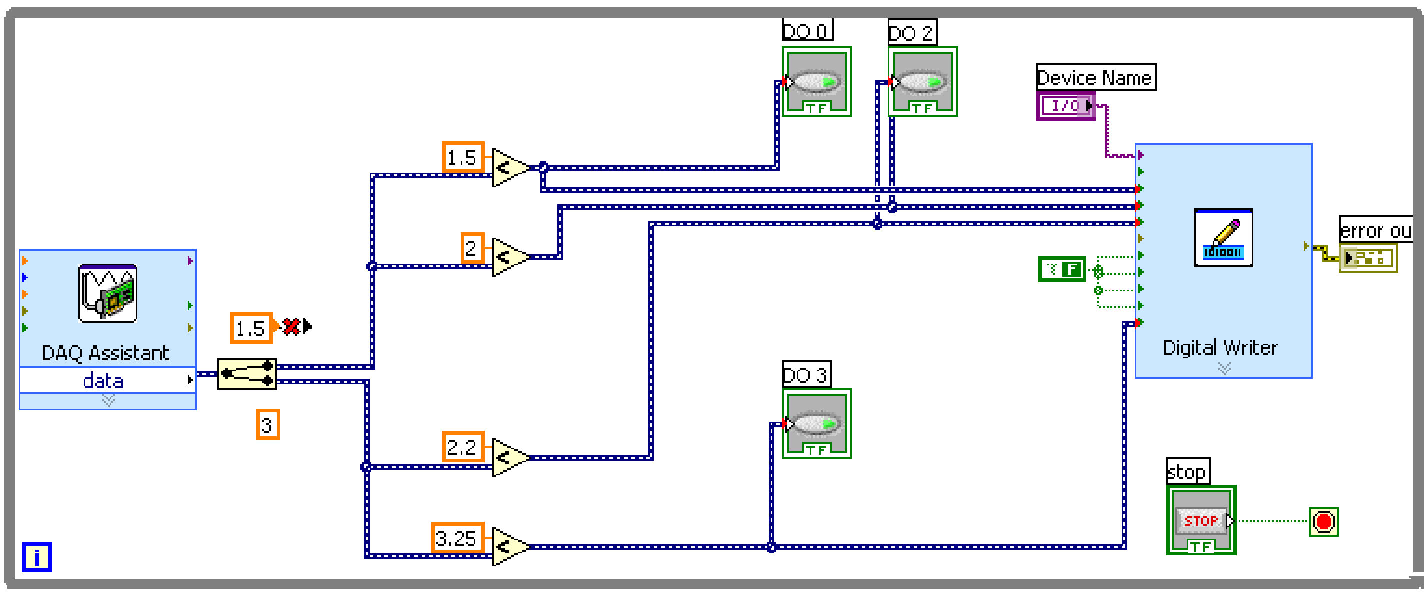


Figure 14 - This LabView program captures the output from the integrator circuit (DAQ Assistant block) it then compares each value to a chosen cutoff value and creates a Boolean output based on which one is greater. The Digital Writer block outputs the results to the Digital Outputs on the ELVIS-1 board. ELVIS uses a digital scheme 0V off, 5V on.

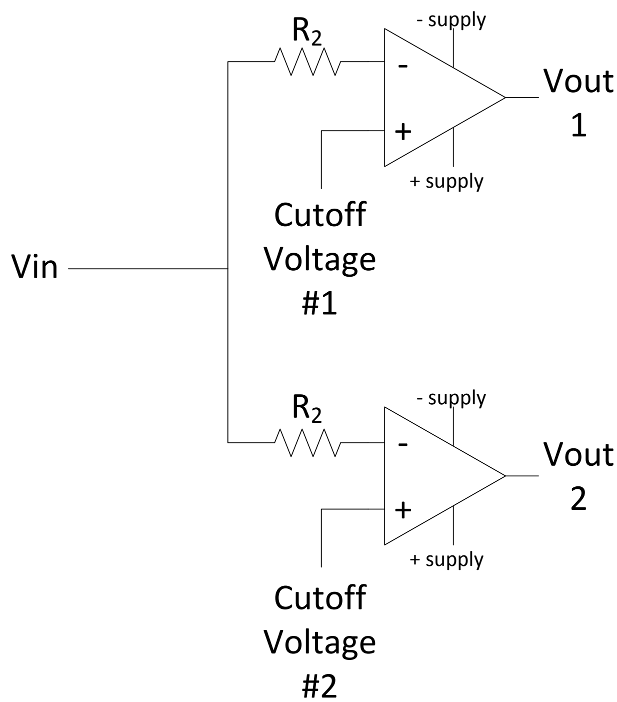


Figure 15 - The above circuit compares the Vin voltage to the cutoff voltages. Based on which one is greater the Vout will take on values of + supply or – supply. The voltage scheme for our binary signal will be set but the +/- supply voltages.

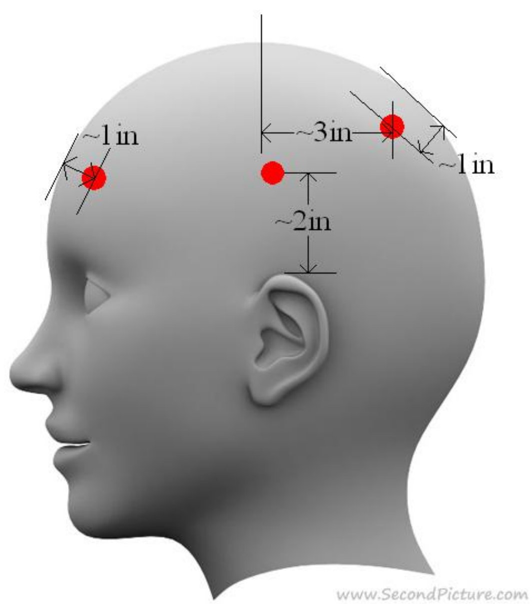


Figure 16 - Proposed electrode placements

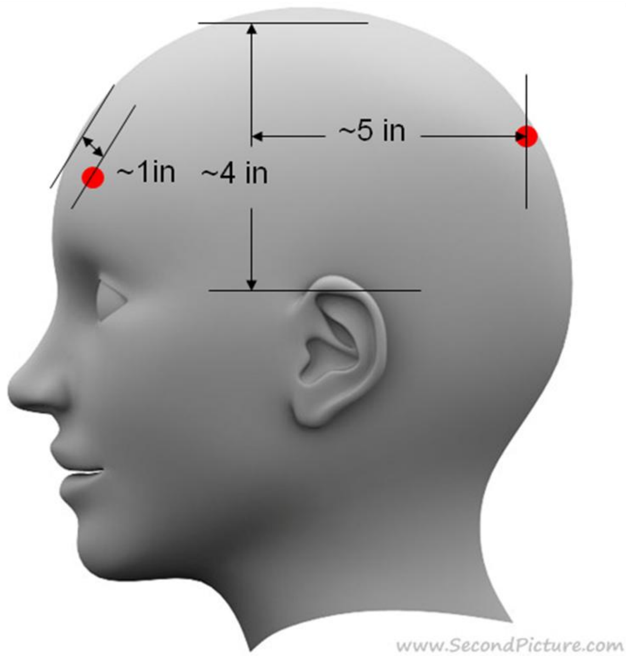


Figure 17 - Diagram of electrode placement

Figure 18 - Final Headset with electrodes

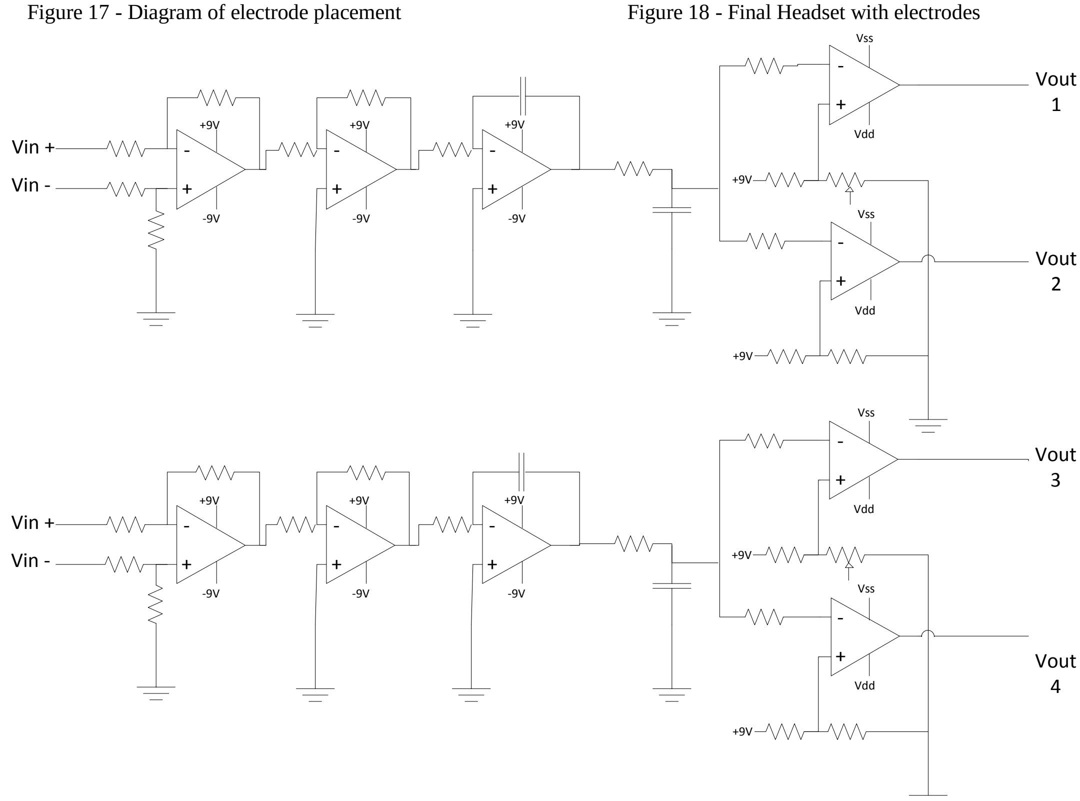


Figure 19 – BORIS-2 Conditioning Circuit

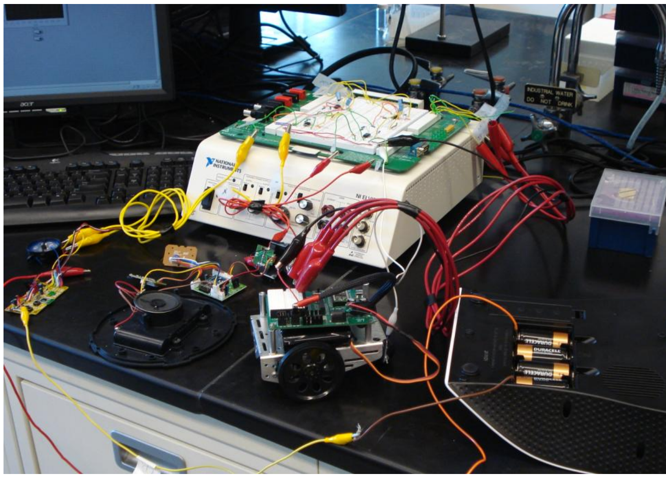


Figure 20 - BORIS-2

Figure 21 - BORIS-2

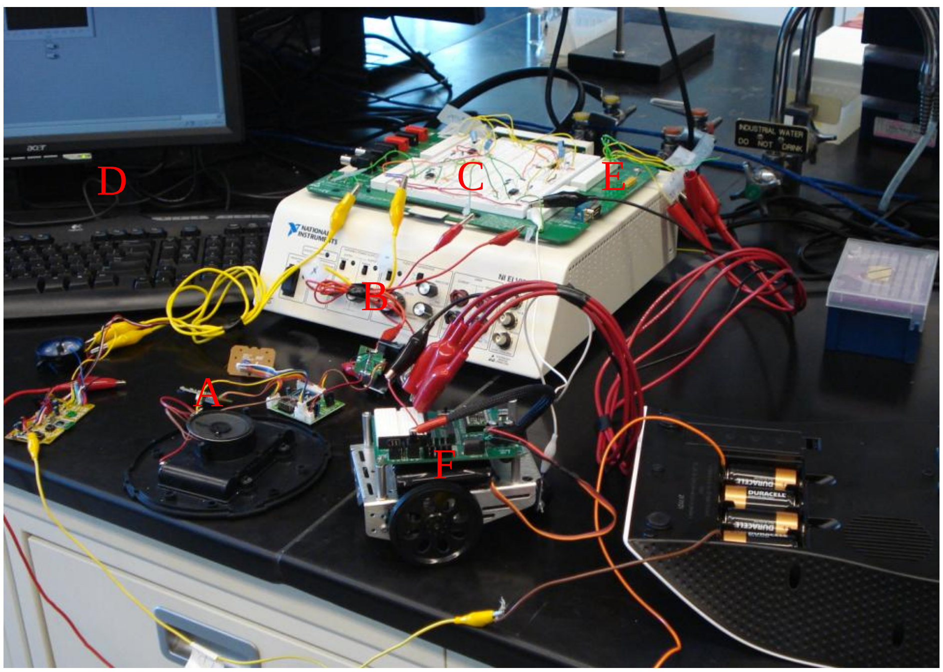


Figure 22 BORIS-1 is the first prototype of the EEG controller. It relies on a desktop computer as well as Elvis prototyping board to power the circuit. Boe-Bot is tethered to the board by cables which limits the ability of the Boe-Bot.

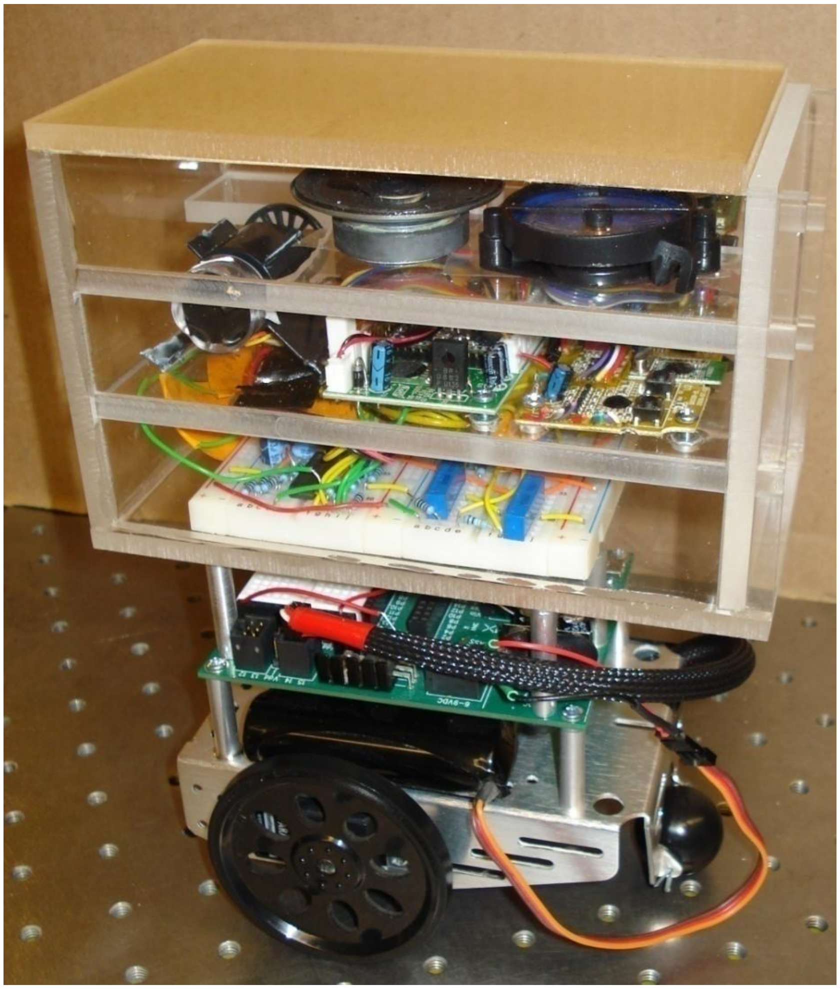


Figure 23 BORIS-2 is the second prototype of the EEG controller. All of the circuitry is contained within a custom made Plexiglas box. It is wireless and battery powered which frees the Boe-Bot for full movement.

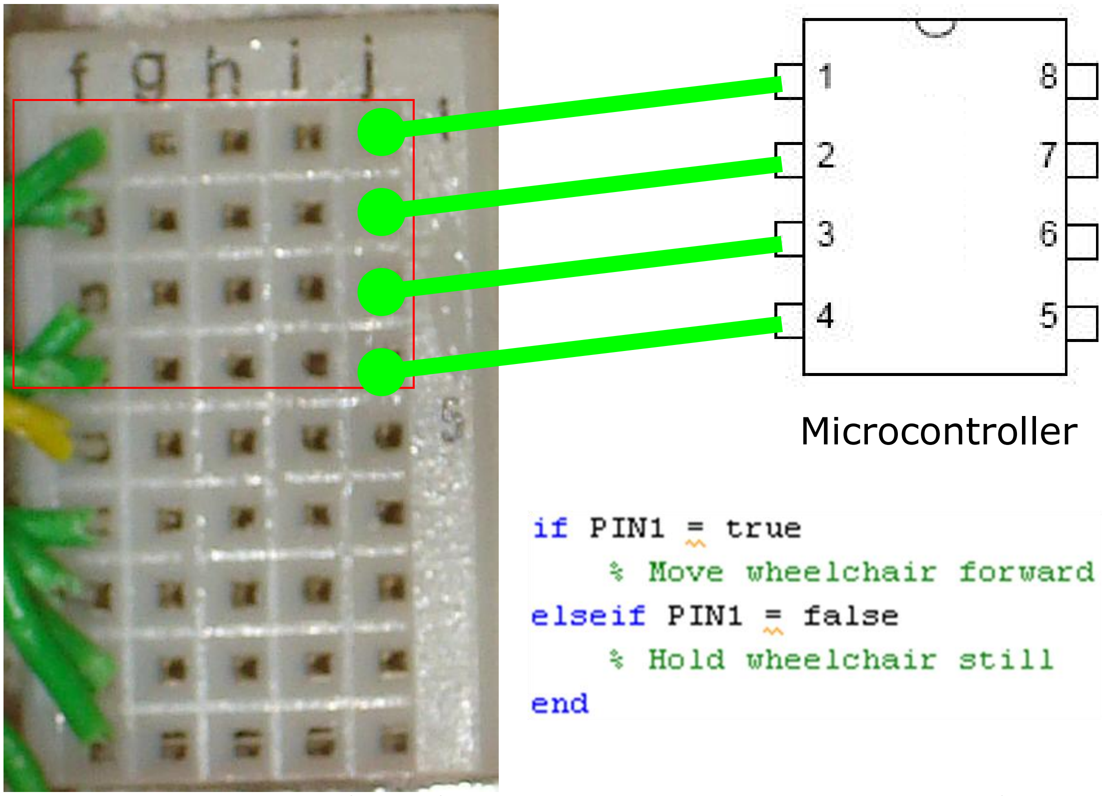


Figure 24BORIS-2/ Microcontroller Interface. This figure shows how the BORIS-2 outputs to a microcontroller. The first two pin 1 and 2 refer to one axis. Pins 3 and 4 refer to the other axis. The microcontroller is a small computer with memory, processing core and programmable inputs as shown above. So when give a true or false signal each pin can be programmed to carry out a programmable action. For example if pin 1 receives a true signal the wheelchair will move forward.

Appendix VI: Testing Results

Frontal Lobe Force Trainer Take (Maintain) seconds Table #2a				
Trial	Off	Level 1	Level 2	Level 3
1	20 (30)	6 (10)	3 (2)	55(13)
2	30 (15)	14 (15)	36 (11)	58 (3)
3	13 (10)	2 (3)	28 (20)	16 (22)
4	3 (13)	3 (3)	38 (5)	39 (24)
5	10 (23)	12 (3)	38 (9)	15 (31)
6	13 (25)	2 (5)	38 (3)	33 (23)
7	2 (20)	33 (3)	21 (3)	13 (35)
8	5 (13)	10 (15)	13 (3)	42(30)
9	14 (5)	27 (10)	38 (12)	16 (18)
10	9 (11)	18 (4)	8 (2)	33 (26)

Motor Cortex Force Trainer, Take (Maintain) seconds table #2b				
Trial	Off	Level 1	Level 2	Level 3
1	4 (3)	29 (13)	9 (2)	8 (5)
2	2 (20)	3 (7)	27 (13)	16 (9)
3	16 (4)	15 (17)	22 (2)	9 (15)
4	14 (25)	24 (3)	9 (2)	17 (2)
5	11 (23)	26 (3)	20 (5)	30 (16)
6	13 (12)	6 (7)	5 (3)	6 (4)
7	5 (7)	10 (2)	5 (4)	9 (10)
8	5 (13)	10 (15)	13 (3)	17 (19)
9	14 (16)	5 (5)	31 (2)	33 (15)
10	9 (25)	28 (8)	27 (11)	30 (15)

Occipital lobe Force Trainer, Take (Maintain) seconds table #2c				
Trial	Off	Level 1	Level 2	Level 3
1	23 (3)	22 (16)	6 (3)	18 (4)
2	14 (10)	12 (2)	8 (3)	12 (13)
3	7 (9)	21 (4)	16 (5)	50 (20)
4	7 (6)	27 (10)	15 (5)	23 (17)
5	29 (16)	12 (7)	7 (4)	25 (16)
6	11 (26)	14 (2)	4 (2)	10 (8)
7	12 (10)	3 (6)	24 (3)	14 (11)
8	5 (13)	10 (15)	13 (3)	17 (19)
9	6 (11)	4 (4)	16 (12)	49 (5)
10	12 (2)	6 (2)	24 (11)	5 (14)

Frontal Lobe MindFlex Take (Maintain) seconds table #2d			
Trial	Off (0-1 lights)	Med(2-3 lights)	High (4 lights)
1	7 (15)	23 (24)	20 (14)
2	2 (30)	4 (36)	15 (17)
3	10 (20)	3 (30)	3 (18)
4	22 (21)	4 (36)	86 (15)
\5	32 (7)	6 (29)	41 (13)
6	5 (35)	10 (36)	30 (9)
7	16 (15)	3 (39)	47 (12)
8	16 (12)	5 (22)	2 (18)
9	2 (11)	3 (11)	5 (12)
10	7 (13)	5 (17)	4 (20)

Occipital Lobe MindFlex Take (Maintain) seconds table #2e			
Trial	Off (0-1 lights)	Med(2-3 lights)	High (4 lights)
1	18 (7)	7 (2)	34 (4)
2	3 (20)	12 (2)	13 (15)
3	9 (3)	2 (5)	2 (4)
4	23 (6)	71 (5)	7 (25)
5	17 (3)	7 (4)	45 (6)
6	5 (10)	50 (3)	8 (20)
7	16 (5)	13 (10)	11 (28)
8	3 (2)	6 (2)	7 (11)
9	8 (4)	12 (4)	100 (5)
10	4 (22)	5 (5)	97 (6)

Premotor Cortex MindFlex Take (Maintain) seconds table # 2f			
Trial	Off (0-1 lights)	Med(2-3 lights)	High (4 lights)
1	60 (4)	13 (5)	20 (4)
2	2 (6)	4 (4)	32 (3)
3	6 (8)	22 (5)	57 (5)
4	5 (5)	5 (10)	100 (4)
5	5 (22)	4 (2)	23 (10)
6	7 (5)	6 (4)	100 (3)
7	13 (15)	7 (7)	18 (3)
8	8 (5)	54 (4)	12 (7)
9	5 (6)	5 (4)	14 (2)
10	13 (5)	16 (6)	7 (3)

Table 24(a-f) show the time it takes for the ball to reach a certain height in seconds outside the parenthesis and the time the ball was maintained at that particular level in seconds within the parenthesis. The data was obtained when a group member gave a command to go from one height position to another and timed how long the other group member could maintain the ball at that height. Ten trials were run for both devices in each of the three regions of the brain selected. The time was averaged out for each level (off, medium, high) and plotted in Excel.

Table 25a MindFlex

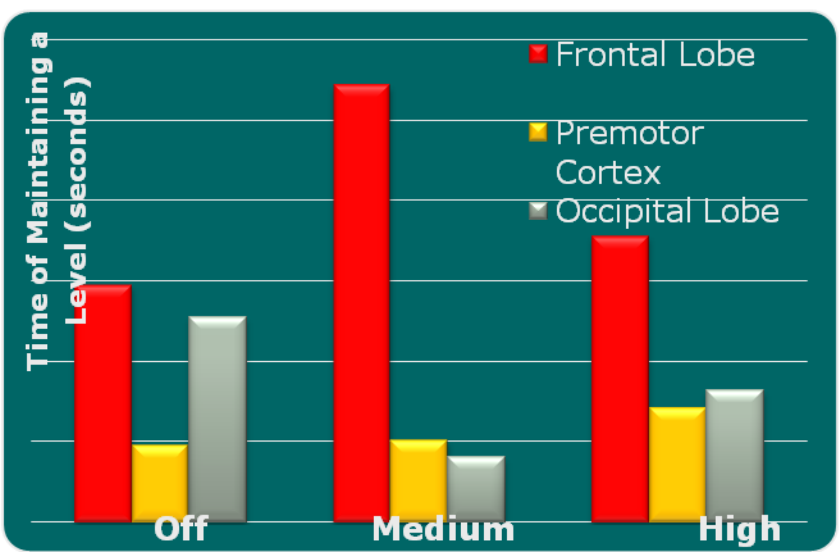


Table 25b Force Trainer

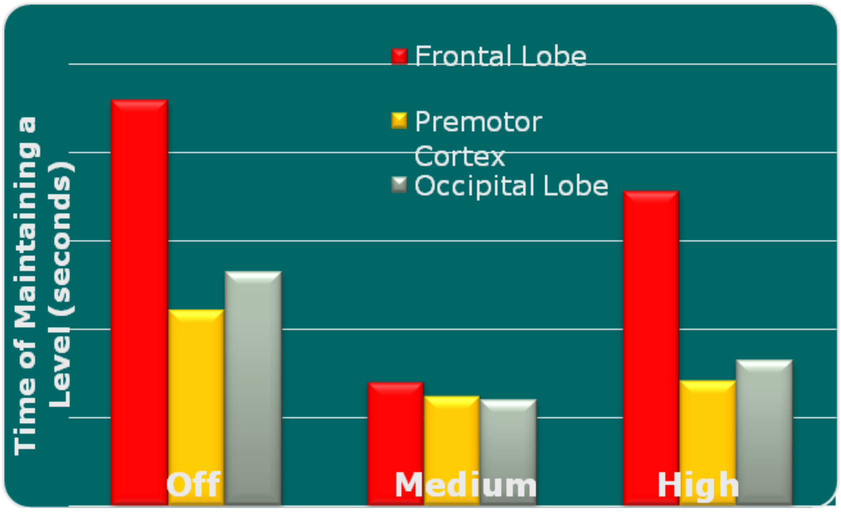


Table 25(a-b) compare the ability of the MindFlex and the Force Trainer to maintain one of the three levels off, medium and high in seconds between the three brain positions: Frontal lobe, premotor cortex and Occipital lobe. It was observed that the front lobe is the best placement for both devices. Unforntately both devices cannot be placed on the frontal lobe because the two axis would lose their independence because they would be reading the same brain activity. So by looking at the data the next best option was to place the Force Trainer on the Occipital lobe.

Appendix VII: References

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