

Neural Testing for User Interface Design of Project Resource Integration Gear

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Resource Integration Gear (R.I.G) is a system of smart tools that work together to provide real time, on demand, information for field operators. The goal is to build non-intrusive and intuitive field operation controls. To attempt this, electroencephalography (EEG) technology along with a BCI (Brain Computer Interface) was used to find viable User Interface (UI) mechanics for controlling software with brain activity. Experiments were conducted with subjects wearing an EEG headset. The subject performed physical activities, to stimulate brain activity. During the physical movements the subject's brain activity was monitored. The data collected from the sessions were analyzed to identify any pattern that might suggest a correlation between a certain movement, or stimulus and a particular brain activity. Once a pattern was identified it was marked as a signal signature of that movement, or stimulus. This signature has been assigned to a variable to call a function that will perform a certain task within software.

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Introduction/Background

Resource Integration Gear (RIG) is a system of smart tools that work together to provide real time on demand information for field operators. The system was built for the field operator use case of an astronaut. The system consists of a wearable central computer integrated into the space suit, a heads up display in the helmet, and three modules (a camera, a flashlight and a thermometer & oxygen sensor). In the first prototype the system was designed to be controlled by a remote technician, which the field operator dictated actions to. The second prototype of this system challenges to give the field operator control of the system. As a sub-project of RIG, electroencephalography (EEG) technology was investigated for viable user interface (UI) mechanics, to build non-intrusive and intuitive field operated controls.

The EEG headset used is made up of a series of electrodes, an amplifier and the potentials emitted by the neurons as a part of the circuit. The setup used in the experiments is called the referential montage. In this setup, there are two electrodes designated as the ground, one as a reference and others are placed throughout the scalp, on the regions where brain activity is to be

recorded. The ground electrode acts very much like the ground of a circuit, but in this case it is enhanced to cancel out some of the "noise" of the surrounding brain activities, this allows for more accurate readings. The reference electrode is used as a reference point, and all activities recorded from the other electrodes are done in relation to this particular electrode. The reference electrode is not required to be placed in any particular spot, but it is often suggested to place it in a region away from where the other electrodes that are recording. In this experiment the earlobes were selected as the reference point and ground. The potentials read by the electrodes were amplified and displayed on a computer screen [1][2].

Hypothetically, each physical movement produces unique activity in the brain, represented in the BCI software as graphs corresponding to the potential difference between the electrodes. There were two things observed in these graphs: the amplitude and frequency of the waves. The goal was to find a pattern in these features that might be unique to a certain movement. Once that was accomplished, a wave containing certain specific features could be assigned a value, and used in software to determine a conditional line of code [3].

The motor cortex was monitored in these experiments. It is divided into three main parts, and in this experiment the main focus was the Primary Motor Cortex (M1). The M1 is a slab of brain matter, located in the mid section of the brain that extends into both hemispheres of the brain (Figure 1). Each hemisphere is further divided into seven sections. The first section is at the top of the brain, and the last down towards the temporal lobe. Each of these sections is responsible to coordinate movements for a certain region of the body and are located in this particular order starting from deep within the brain and working itself up to the top, and then down each hemisphere: foot, hip, trunk, arm, hand, face, tongue, and larynx. The amount of brain matter allocated for each section is corresponded to the complexity of movements each section is responsible for coordinating. For example, the section responsible for the hands and fingers cover a larger area of the brain, than the area responsible for the movements of the trunk. The left hemisphere of M1 controls the right side of the body, and right hemisphere controls the left [4]. The main goal of these trials was to isolate waves created by certain brain activity. M1 was chosen to conduct these experiments for a number of reasons. First reason was because, the motor cortex runs close to the scalp and covers a large surface area of the brain, which means it was easier for the electrodes to pick up the potentials, created in this area. Second reason is because on M1, the section, which controls voluntary arm and leg movement, was easily identified. This meant that the section of the brain that needed to be monitored was narrowed down, according to the movements being observed. Finally, the movements required to trigger a potential in M1 was easier to perform so it provided better control. During these trials, M1 was monitored for a correlation between any movement and brain activity.

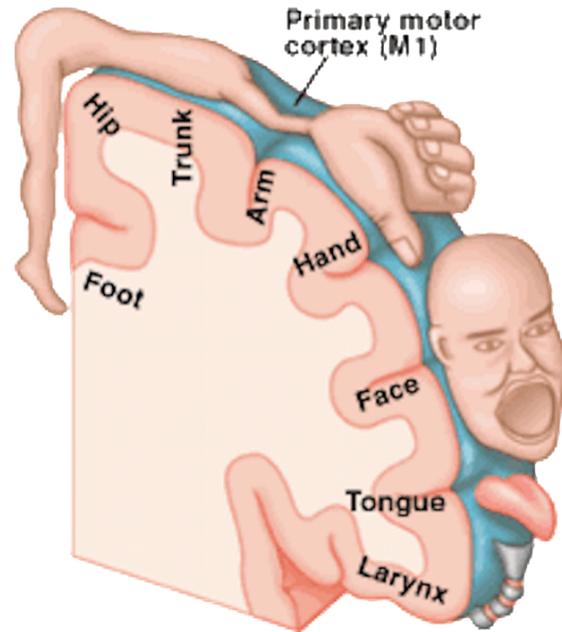


Figure 1. A representation of the body map encoded in the primary motor cortex. The sections corresponds to body parts with complex repertoires of fine movement, like the hand, require more cortical space in M1, while body parts with relatively simpler movements, like the hip, require less cortical space.

Data/Methodology

For each trial of the experiment a determined set of steps were followed. First, electrodes were placed in the relevant parts of the brain of the subject, according to the activity being monitored. In this case, it was mostly the region that covers the Motor Cortex. Then a brief session, where the subject sat still was recorded. The data collected here, was used as the base line. The subject was then told what movement to accomplish in the next session. These sessions were each one-minute long, and the subject was asked to alternate during this period between rest and movement, in intervals of ten seconds. The graph representing the subject's brain activity, and the subject was recorded simultaneously. Then each graph was analyzed, and compared to the state of the subject. These steps were repeated ten times for the movement. In total, 10 trials were recorded.

The analysis of these graphs were focused on the type of waves created by each brain activity and which electrode picked up the potential. The potential measured between each electrode was on

the microvolt scale. The BCI software provided by the manufacture of the hardware (OpenBCI GUI) used, displayed two graphs representing real time data. Software called Neuromore studios was also used to collect and export raw data.

The first graph, displayed in Figure 2 showed the potential captured by each electrode as a function of time. In this graph real time any changes in the potential between the electrodes over parts of the brain was monitored. These changes were represented in sinusoidal waves, rising above the x-axis, when it was positive and dipping underneath it, when it was negative. The data displayed by the GUI is raw data captured by each electrode on the EEG headset. There are eight electrode represented by eight channels of streamed 0-250Hz sample rates. The raw data gets filtered through threshold filters that are configured to remove noise created by the hardware, or environment. The filtered data gets stored in buffer arrays. The arrays are then called on by a processing function, which averages the values for the GUI.

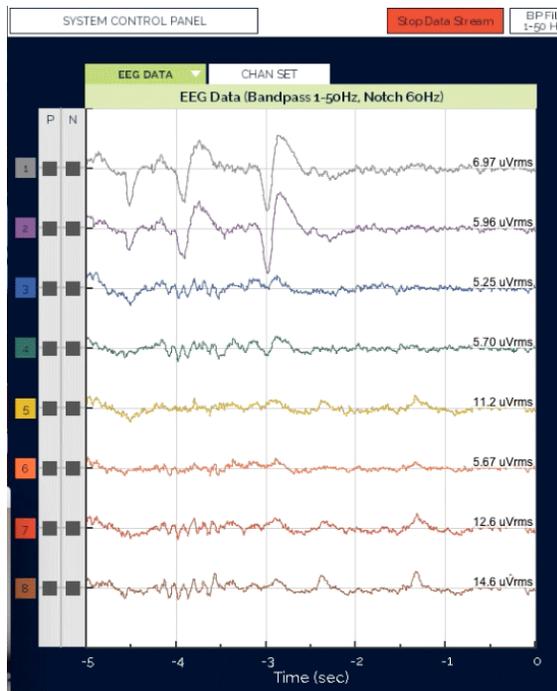


Figure 2: The graph above is a real time representation of the EEG activity captures by the electrodes on the headset. Channels one and two are placed over the occipital lobe. The artifacts seen on -4 and -3 time scales are EMG (Electromyography) from eye blinks.

The second graph, as seen in Figure 3, displayed data from the same set of electrodes, but the potential was represented as a function of frequency, using a Fast Fourier Transform (FFT) plot [5]. This was useful because, using the data in this format made possible the detection of Alpha waves, and other “brain waves.” These Alpha waves are mostly detected when the subject is at rest, with the eyes closed or in heavy concentration. Alpha waves range in the between eight and twelve hertz. The software provided by OpenBCI takes in the raw data captured by the headset and returns to the user the information represented in two different ways. First, it plots the average of the raw data after it has been filtered to eliminate outlier data. The second set of data is represented in a smaller graph and it is filtered through a Fourier Transform. To calculate these values in real time, the software runs on a continuous loop that only stops when a boolean variable is switched to off. To ensure a smooth representation, of the data the software buffers the data into arrays in between calls to a function that processes the data. This function takes in the raw and filtered data and the frequency spectrum shown in the FFT plot.

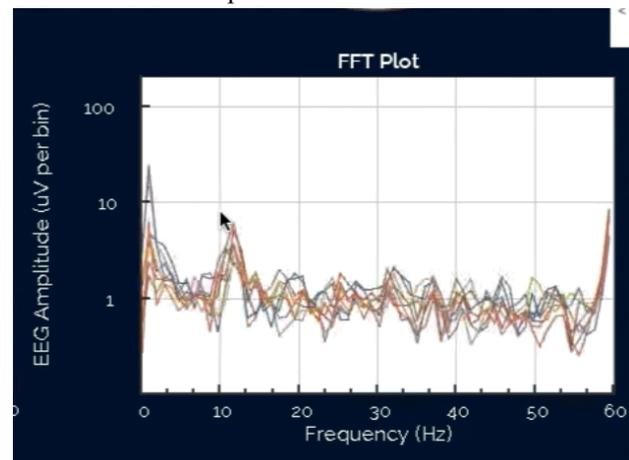


Figure 3: Alpha activity monitored; ten microvolts per bin at the ten hertz frequency.

To process the values for the time-domain graph the software calculate the average and standard deviation of the filtered data. The function that processes it receives this data in a

two dimensional array, where each one-dimensional array within that two-dimensional array represents the data collected for a specific node. It then iterates through these arrays to find the values for the data set's mean, standard deviation, and the mode. The mode allows the software to determine where in the headset a higher rate of potential is being recorded. This piece of information is also displayed to the user through the GUI. It is represented in an animation in its corner, that displays a representation of a top view of a skull and its sections change colors, between blue and red to distinguish where in brain the headset is picking up the most potential - red represents a higher potential and blue represents a lower potential. This set of information that the software outputs would be helpful to the design of brain computer interface that allows a user to control a computer. (The code provided by OpenBCI is open source). Because it is known what part of the brain is activated with each specific activity, an algorithm can link a certain activities with a spike in a potential in a certain section of the headset. For example, if it is decided that a function in a software should be called by a hand movement, all the software would need to look for in the data from the headset given to it is an increase of the potential being received at the node located near the M1.

To process the values represented in the FFT plot, the software filters the raw data it collects through a Fourier Transform. The function that processes it receives two arguments: a two-dimensional array that stores the raw data, and an array storing the frequency spectrum shown in the FFT plot. The software takes the raw data and maps it to the basic function of Fourier Transform, using, as it is suggested in the title of the graph, FFT algorithm. This function is a circle (created by a sine and cosine function) moving at different rates - in this cases the rates are the frequency received by the functions as arguments. The magnitude of the resulting vectors is then grafted into the FFT plot. This graph represents the

potential power at each frequency. This is useful because types of waves created by brain activity is ranked by at what frequency they were created, so this allows the software to identify what types of waves are being created by the subject's brain. This would make an implementation of a user interface controlled by brain activity possible, because certain activities result into different kinds of brain waves. All the software would need to control would be the frequency of the "waves" being created by the subject's brain activity. For example, we know that closing its eyes would cause a subject's brain to create an Alpha wave - a wave between eight and thirteen Hz. So the software can monitor the line graphs created on the FFT plot and trigger a function, once one of them reach a 10 Hz mark.

Neuromore Studios was used to collect the raw data output from the experimental trials. Neuromore recorded the raw EEG data into a time stamped csv files, which were analyzed in excel. The individual data collected from each electrode was stitched together into one data sheet and analyzed the brain activity as a whole. We also graphed the individual data from each electrode separately as well to analyze the activity under that electrode alone. This way any anomalies brought out by the data could be cross-examined by the video captured of the subject during the trial.

Analysis

During the tryouts, some patterns started to appear. Each time a movement was completed by the subject, the graph that represented the change in potential as a function of time showed a drop in the potential, followed by a spike. The graph in the FFT plot, which showed the potential as a function of frequency, also showed some activity, although no pattern could be observed. When the subject was asked to close his/her eyes, the graph monitoring the potential as a function of time that was correspondent to the Frontal Lobe area experienced a slight drop. During that same experiment, the graph in the FFT plot, that

represented the electrode located over the Occipital Lobe, also rose. The ten hertz waves being produced in this section, approached the 10 uV mark on the graph. It was concluded that this pattern occurred because Alpha waves were being captured in that region.

Conclusions

It was sometimes difficult to ensure that the subject was focused when the procedure was being completed. To remove visual distractions subjects were asked to focus on a point drawn on a piece of paper directly ahead of them. It was also important to ensure that the subject was completing the movement as it was described to them. These interferences could disturb the data collection, because their effect could be misread as the result of the experiment. To ensure that all data could be observed alongside the subject movements were recorded and put alongside the graphs. This way each change in the graphs could be traced back to the state of the subject during that time. This allowed any extraneous data created by an unwanted movement to be discarded.

The data collection could also be interfered by involuntary functions of the brain and the body and noises produced by the hardware. The hardware and software provided by OpenBCI is supposed to cancel out most of these “noises,” but it offers no guarantee on the degree to which it is effective. To work around this problem, a more extensive data set can be collected [6]. Working with a large volume of data would allow an expected value of this data to be computed, and any outlier data produced by these interferences could be discarded. Additionally, the OpenBCI GUI provided a heat map (Figure 4) that allowed us to virtually see where the brain activity was concentrated at any given moment. This helped match artifacts that appeared in the graphs to the physical brain space when reviewing the montage recordings.

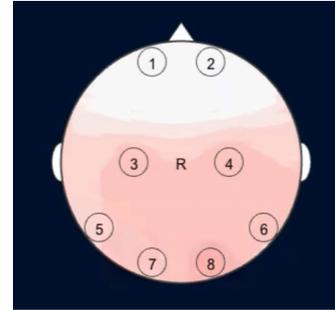


Figure 4: The OpenBCI graphical user interface provides a top view image illustrating where the electrodes are placed on the subjects head. Over that image a realtime heat map of the active electrodes can be observed during montages.

EEG is still not able to produce 100% clear representations of the activity in the brain, mainly because there are some parts of the brain that are more sensitive to EEG than others. There are parts of the brain that provide clearer EEG readings, for example the potential generated near the scalp are more accurately picked up than those generated deep in the brain. This was confirmed throughout the experimental trials.

The purpose of this project was to learn about neurology, and EEG hardware. With all that has been learned; there is a clearer sense of what step to take next. The next stage is to keep collecting montages of different sections of the brain and to look for strong distinct signals that have good mechanics for a user interface. After a set of signals has been identified a basic program will have to be written for testing. An example for that program could be two functions, each mapped to a brain signal. When signal “a” is registered function “a” is executed. When signal “b” is registered function “b” is executed. Once testing is complete then an extension of that program can be written into more robust commands as part of a complete UI. While the UI is created a more streamlined headset can be designed to only capture signals from the necessary parts of the brain. A more streamlined design would facilitate the integration of the EEG headset into a helmet with a heads up display. Montages will be

collected and analyzed, March through May 2016 with the plans to start coding a test UI summer 2016.

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