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WirelessEEG: data aquisition + handheld device

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Acknowledgements

We would like to thank our project sponsor, Dr. Mark Myers, for his commitment and guidance throughout this project.

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Executive Summary

The brain, made up of billions of neurons and synapses, is the marvelous core of human thought, action, and memory. It can allow a person to do incredibly complicated tasks such as quantum mechanic calculations or architectural design, but it also gives us the freedom to breathe and walk subconsciously. However, if neuronal activity becomes abnormally excessive, it will induce a seizure. If unprovoked seizures occur repeatedly, a patient will be diagnosed with epilepsy. According to the Centers of Disease Control and Prevention, roughly 2.3 million adults and 467,711 children in the United States have epilepsy. Nearly 150,000 Americans develop the condition every year.[1] People with epilepsy live in constant fear of an impending seizure. For extreme cases, they are unable to drive or do many of the daily functions most people take for granted and therefore are limited in the daily activities. When a patient with epilepsy has a seizure, they must stay in a hospital bed while EEG (electroencephalography) tests are being done in an attempt to diagnose the cause and severity of the seizures. Although there are no complete remedies for epilepsy currently, many researches are invested in finding a cure.

The scope of this project is to develop a seizure prediction system that can be used away from a hospital, making it possible for the user to stay at home. The WirelessEEG is a research device that has been developed with the objective of acquiring a portable, clean EEG signal and transmitting it wirelessly to a handheld device for processing and notification. This device is comprised of four phases: acquisition, transmission, processing, and notification. During the acquisition stage, the EEG signal is detected using EEG electrodes; these signals are filtered and amplified before being transmitted in the second stage. The processing stage encompasses the signal processing and seizure prediction. A notification is sent to the patient and designated contacts, given an impending seizure. Each of these phases are comprised of various design components, hardware and software.

This report documents the project requirements, solution investigation, prototyping, final design details, test process, and system evaluation for the WirelessEEG system.

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[1] Center for Disease Control and Prevention - http://www.cdc.gov/epilepsy/basics/faqs.htm

Requirements

Data Acquisition

1. System shall acquire EEG signals from the user
   1.1. The system shall implement a 2-lead scheme for EEG data acquisition
      1.1.1. The leads shall not use any wet interfaces
      1.1.2. The leads shall be incorporated in a wearable cap structure
   1.2. The system shall amplify the raw EEG signal
      1.2.1. Amplifier gain shall convert signal to millivolt range

Device Communication

2. System shall be able to communicate over a network
   2.1. Signal shall be transmitted in digital format
      2.1.1. Signal shall be sampled at 256 Hz
   2.2. Data transmission shall be wireless
      2.2.1. Continuous connection to the network shall be maintained between the phone and the rest of the system

Data Processing

3. System shall be able to perform data processing on the EEG signal
   3.1. System shall convert EEG signal to a digital format for processing
   3.2. System shall have two modes for reading data
      3.2.1.One mode will be an offline mode to read data from a file
      3.2.2. Another mode will be an active mode to read signals directly from the EEG cap
   3.3. System shall implement Dr. Myers's algorithm
      3.3.1. System shall pass EEG data to this algorithm for processing
      3.3.2. System shall use algorithm to determine seizure prediction output

Notification System

4. System shall be able to notify the user
   4.1. System shall notify the user when seizure is predicted
   4.2. User notification shall be on a mobile device
      4.2.1. System shall use mobile platform notification (audio, vibrate, visual) and/or SMS
   4.3. Notification shall be configurable
      4.3.1. User shall be able to specify types of notifications

Mobility

5. System shall be mobile
    5.1. System shall be wearable and ergonomic
    5.2. System shall be constrained on its size and weight for user’s comfort
        5.2.1. System shall be no larger than 216 cubic inches (6x6x6 in)
        5.2.2. System shall weigh no more than 3 lbs

Power System

6. System shall be powered remotely
    6.1. System shall have a continuous up-time of 3 hours on a remote power source
6.2. Power source must be rechargeable

Investigation

Electrodes

During research of the current electrode market, several solutions were found. Two main types of electrodes are currently available in the medical market: active and passive. Passive electrodes are less expensive; however, they require a conductive gel or glue to secure the connection to the area being sensed. Without the glue, accurate brain signals could not be acquired. Because the device required a non-intrusive application to the patient, active electrodes were required. The active electrodes allowed brain signals to be read without a glue or adhesive being applied. This made the device less intrusive to the user.

Cap

In order to secure the electrodes to the patient during acquisition, the electrodes must be embedded into some sort of cap-like garment. A simple headband or a baseball cap were considered. The primary concern regarding the type of cap was the ability to place the electrodes in various locations for acquiring brain signals. There is not a specific location on the head where EEG signals are captured. Therefore, the ability to move the electrodes around the cap was crucial. Also, general comfort was desired.

Amplifier

In hopes of not building the ModularEEG Analog and Digital Boards by hand, the team set out on finding a pre-assembled version that would alleviate much time spent with debugging and making sure the circuit would perform to specification. A link on the OpenEEG community website lead to a company called Olimex, which makes pre-assembled versions of many open-source circuit designs available online. The team was relieved to find not only the ModularEEG Analog and Digital Boards pre-assembled, but also Olimex's own custom 2-Channel USB EEG Amplifier that combines both the analog and digital boards of the ModEEG onto one chip. The team chose the Olimex SMT as the amplifier of choice, because it had the inexpensiveness and robustness of the ModularEEG design encapsulated into a professional pre-assembled piece of hardware.

Wireless Communication

There were two main options that met the wireless communication goal: bluetooth and WiFi (ad-hoc). Bluetooth was chosen because it is cheap, compatible with nearly all smartphones, and is designed for inter-device communication. For the project, a simple bluetooth module (HC-06) was chosen that is configured to be a slave device. This device is designed to replace a wired serial connection with a wireless connection. This enabled the serial data from the EEG SMT board to be read directly on the data pins of the bluetooth module. The module was also configurable so the baud rate and name were changed.

Mobile Application

The mobile application was essentially the heart of the system. It has to set up and maintain all of the bluetooth connectivity, process the data, control the patient and health provider settings, and invoke the notification system. Android was chosen for its familiarity (Java) and open platform architecture. The overall architecture of the application includes: searching, pairing, and connecting to the bluetooth module, receiving data via bluetooth, processing the data using the seizure prediction algorithm, configuring the notification and patients settings, and sending notifications. The Android OS has built-in interfaces to an RFCOMM class that assist with bluetooth connections. While the OS handles the searching and pairing, the connection must be completely maintained by the application. The mobile application implements a bluetooth service that spawns a thread to handle setting up the connection in the background, along with another thread to handle the incoming data. The data is passed to another class via a Handler which maintains a buffer and processes the data in chunks. When a seizure prediction biomarker occurs, a broadcast is sent to the notification system which handles all of the notifications that were set up by the patient in the GUI application. All of the settings configured by the patient and the health provider are stored as private elements in Android’s SharedPreferences database. This was chosen because the variables can be accessed from any part of the mobile application, but can only be called from within the mobile application that created them (the app). This ensured security and also allowed the application to be extended for other purposes.

Algorithm (Java)

The original algorithm was written in Matlab and needed to be transferred to the phone. The available methods were limited and after searching for viable options to fit this need, it was decided to rewrite the algorithm in Java. For each function call in Matlab an equivalent function was developed in Java. This allowed for much more robust control over the functions and how they are called in the phone. By doing this, it also allowed for optimization by controlling memory allocations and allowing threading in the Android application that helped speed up the algorithm run time. The main concern to this approach is if the algorithm changes substantially or more complex Matlab functions are used, it would require implementing these new functions in Java.

Batteries

To keep the device portable, it needed a mobile power source. A battery was the first and only choice. However, the type of battery depends on the amount of power needed to keep the device working for the specified time of three hours. Also, following the requirements, the power source needed to be rechargeable. These two requirements narrowed the choices of batteries considerably, from hundreds of types to just a few. Types of rechargeable batteries that met the requirements included: lithium-ion, lithium-polymer, and nickel-metal hydride. Lithium-ion and lithium-polymer batteries are very similar, however, the nickel-metal hydride type is much different. Pending more research on the power consumption of the entire system, it was easier to choose which type of rechargeable battery was best for this application. The battery pre-installed in the phone was used. The team was still conscious of power consumption, as they did not want the processing to deplete the phone battery.

Prototyping

The primary goal of this system was to function as a prototype. Therefore, minimal prototyping was required or necessary. However, several cap designs were used throughout the course of this project. These designs include a rugby cap and a headband. For the scope of this project, a headband was most effective.

Design

Acquisition: Electrodes & Amplifier

Four dry, active electrodes were used to detect the EEG signals. These small sensors were placed in various locations on the patient's head. A dry, passive electrode was placed on the patient's ear to serve as a reference. For convenience and a reliable connection, the electrodes were held by a cap. The EEG signals were then fed into an 2-channel amplifier, the Olimex SMT. This open-source amplifier is designed specifically to process EEG signals. The Olimex SMT has 5 inputs and a single serial output. The inputs are described in the Table 1.

Table 1

Name	Description	Location
CH1+ CH2+	Positive channel	Forehead
CH1- CH2-	Negative channel	Earlobe
DRL	Reference	Earlobe

The electrode configuration is diagramed below in Figure 2.

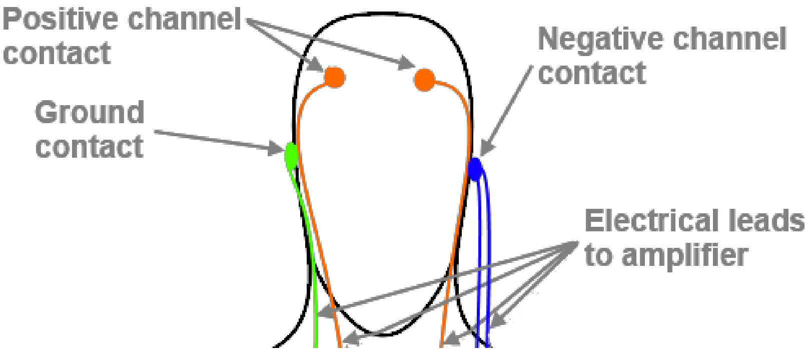


Figure 2

Transmission: Bluetooth (SMT to Android)

For the data to be processed, the data must be transmitted from the Olimex SMT to the Android device. Therefore to transmit the data via bluetooth, RFCOMM sockets must be established between the two devices. A Serial Port Profile (SPP) HC-06 Bluetooth Module was used to transmit USB serial data from the Olimex SMT board to the Android device via the data pins. This set up the Android device as the master and the bluetooth module as the slave. Therefore, the Android application handled the searching, pairing, and connecting to the Bluetooth module, and the module acted as a server that transmitted all of the data from it data pins over the sockets.

In order to pair with the Bluetooth module, the Android application required a Bluetooth capable and Bluetooth enabled device. The app verified the Bluetooth is ready, then it spawned an Android Activity to handle the searching and selecting via a device list. If the device had not been seen before and required a secure connection (PIN code), the user was prompted to input the information. Once a device has been selected from the list, the MAC address was passed to a Bluetooth service to handle the pairing and connection.

The Bluetooth service ran in the background and handled all of the pairing and connection tasks to set up the RFCOMM sockets. Once the sockets were established, the service used an SPP profile to listen for and receive the data from the RFCOMM socket. The bytes received were then parsed and stored into buffers for later processing. Once enough data had been collected, the buffers were passed to a Java class that handled processing the data using Dr. Myers' algorithm.

Processing: Data Processing

As data was sent via bluetooth and received by the Android device, it was placed in a buffer for processing. Once the buffer reached a specific number of elements, a thread was spawned and the buffer was passed to the thread for processing. Once the processing finished, the buffer is flushed to allow new data to be acquired. In order to process the data using the algorithm provided by Dr. Myers, several Java classes was created that mimic the Matlab procedures of the native algorithm. Special data structures were developed to help aid in the processing, including support for data sets that include complex numbers, filtering functions, and multidimensional array operations. Based on the algorithm, the final output can be transformed into a binary output by using a threshold that is set to a specific value by the health care provider (the threshold value is established for each patient through an external algorithm developed by Dr. Myers). Once a seizure prediction biomarker is detected, the Android application constructs and commits the relevant notifications. The notification types and destinations were all configured by the user through the main UI of the Android application. The user can choose to send notifications via email, SMS, or use Android's notification system (i.e. pop-ups, notification bar, sounds, etc.).

Notification: User Interface & Android Application Configuration

Figure 3

In Figure 3 above, the main settings window (right) shows the notification configurations available to the user. When a seizure prediction marker was detected, the application went through several conditional statements to determine how to send notifications. The user can select the type of notifications to use by activating or deactivating the radio buttons, which change flags in the background that affect the results of said conditional statements. The user could also modify who the notifications were sent to by using the appropriate buttons that are in the respective lists labeled “SMS settings” and “Email settings”. The “Add” button spawned a pop-up window to allow the user to manually type in a contact or go to the phone’s contacts to populate the lists. The user may remove recipients by using the appropriate “Del” buttons for each contact in their respective list. Once the settings are final and the connection to the EEG acquisition device was initiated, the application will send the notifications based on these settings.

Sustainability: Power

Various components in the design required a power supply. Since all the components were capable of operating on USB power, the battery needed to provide 5 VDC. Additionally, a modification was performed on the amplifier hardware which enabled it to use a mobile battery as its power source.

Test Process

Testing Environment

Testing Equipment:

HP 34401A Multimeter
Agilent 54622A Oscilloscope
Agilent E3620A Dual DC Power Supply
Weller Wes51 Soldering Iron
Samsung Galaxy S4 (Android OS)

A testing environment comprised of several components was necessary to conduct individual and multiple component testing. These components included an Arduino Uno, Power Supply, Breadboard, Multimeter, mobile phone, and various software. The particular environment will be discussed for each of the test configurations.

Individual Component Testing

EEG Amplifier

To test the ModularEEG SMT from Omilex, the device was be plugged into a computer host via a USB cable to determine if the power LED indicator turns on. This ensured that the SMT could be powered with a 5V USB power source.

Bluetooth Module

A breadboard, power supply, and Arduino was used to test the independent bluetooth module. The blinking LED on the bluetooth module signified that power was being supplied. Next the module was interfaced with an Arduino Uno. This allowed for a computer to be connected and monitoring the serial data from the module. The baud rate of the module was changed to match that of the EEG Amplifier. Then the baud rate was verified using AT commands within the Arduino software.

Battery

Independent testing of the battery consisted of verifying the battery rating. The battery chosen for this system was the *myCharge Amp4000*, a 4000 mAh Lithium-Polymer battery. This battery is rated for 5 V DC with an output current of 1 A. The system requires significantly lower current. Therefore, the battery voltage needed to be verified to be 5 V using a voltmeter.

Mobile Phone

The testing of the phone consisted of several parts: the Android application GUI, the notification system, and the data processing.

Android Application

The main testing of the android application involved ensuring that the GUI worked properly. All UI components functioned as intended, and the user interface included the following design components: device connection, signal acquisition, and notification settings. The GUI was tested by stepping through a workflow and ensuring that the functionality of every button, checkbox, listview, and image were working properly.

Notification System

The notification system involved taking user designated input to form local notifications (i.e. popups) and sending notifications to others via SMS or Email. The system was tested by traversing the GUI and selecting the desired notification settings, then creating pseudo-seizure events to trigger the notifications. The system passed this test when such seizure events triggered the correct notifications.

Algorithm

To verify the functionality of the algorithm in Java, the output of the algorithm was contrasted to the output of the original algorithm in Matlab. Due to the constraints and ongoing development of the algorithm, the test was conducted using a single data set.

Multiple Component Testing

Electrode + Amplifier

The simplest way to verify that the electrodes were acquiring EEG signals was to use the electrodes in conjunction with the amplifier and then monitor the signals using BrainBay software. BrainBay is a bio neurofeedback application designed to work with the OpenEEG-Hardware, ModularEEG, and MonolithEEG. BrainBay is part of the OpenEEG project and provides graphical feedback. In our design, we used BrainBay for bioelectrical signal processing and graphing.

The electrodes were connected to the amplifier and the amplifier into the USB port of a computer containing the BrainBay software. After the electrodes were placed on a subject's head, the EEG signals were viewed on the computer. To verify that the signals were not noise, the person could blink and the EEG signals on the computer spiked.

Cap + Electrode + Amplifier

After the functionality of the Electrode + Amplifier was confirmed, the positive channel electrodes were embedded into a cap at the appropriate locations. Then a similar test to the Electrode + Amplifier test was conducted in order to confirm these were the appropriate signals being acquired.

Bluetooth + Phone

After the bluetooth module was successfully powered by the battery, the orange LED on the module blinked. Then the user went to "Connection" tab and selected "Search For Device". Then the bluetooth module named *BCIsim Health Device* was selected. After the popup disappeared, "Connected to BCIsim Health Device" appeared on the phone, and the diagram displayed a valid connection. This means that the devices were paired. At this point, the orange LED stopped blinking and glowed steadily.

Phone + Algorithm

Using the test data set (provided by Dr. Myers), the data was processed on the mobile device and the results were passed to the notification system. When a seizure prediction biomarker was encountered, the notification system responded with the appropriate notifications based on the user specified settings (i.e. SMS, email, popup).

Cap + Electrode + Amplifier + Bluetooth

Once the Cap + Electrode + Amplifier three part system was confirmed to be working, the bluetooth module was added and verified using a computer. The system was powered by the computer during this testing. Electrodes were placed on a subject via the cap and the electrodes were connected to the appropriate channels on the amplifier. The amplifier was connected to the Bluetooth module and began sending data. The transmitted data was verified using a Bluetooth enabled device.

System Testing

Cap + Electrode + Amplifier + Bluetooth + Phone + Battery

To verify the functionality of the complete system, the amplifier and bluetooth was first powered by the battery. Also, the phone was paired with the bluetooth model. (See above to verify that the phone and bluetooth were paired.) The app was in the *Healthcare Config* window. Then after the electrodes were appropriately placed on a subject, the Chan. 1 and Chan. 2 graphs updated in real time with the EEG signals. A similar test to the Electrode + Amplifier test was conducted in order to confirm the appropriate signals were being acquired.

Size

Once the system was assembled, it was be weighed using a scale. Then the volume of the system was calculated by multiplying the measured length by width by height of the system. In order to meet the requirement, the system must have weigh less than 3 lbs and been smaller than 216 cubic inches (6x6x6 in).

Power Consumption

The power consumption of the system was analyzed in two parts: the power consumption of the external battery as well as the effect of the app on the phone battery. To calculate the power consumed by the electrodes, amplifier, and bluetooth module on the external battery, the voltage from the battery was measured using a voltmeter and the current from the battery to the components. In order to calculate the maximum power consumption, the measurements were taken when the system was acquiring and transmitting data. The power consumed by the components were then calculated using the following equation:

$$P = IV$$

It is difficult to quantitatively analyze the effect of the app on the phone battery. However, a general idea was gained by contrasting the battery life when the app was running as to when it is not. In addition, there are several diagnostic phone applications that estimate the power drain caused by a particular application, for example *Battery Stats Plus.* This information was also considered.

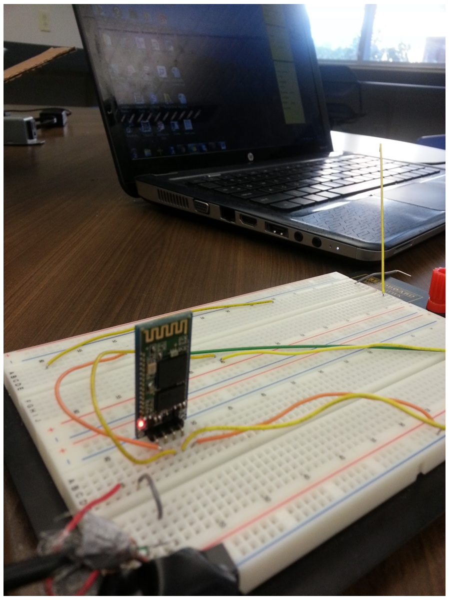
Lifetime

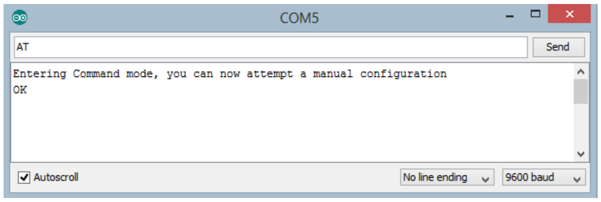
The system lifetime was evaluated by monitoring how long the system could continuously acquire, transmit, and process the EEG data. To test the system lifetime, a subject wore the electrodes, data was collected and then transmitted to the phone for a minimum of 3 hours. In order to meet the requirement, the system had to have a minimum lifetime of 3 hours.

Evaluation Results

Individual Testing

EEG Amplifier: Pass/Fail: Pass Tester’s Initials: LBH Date: 4/9/14 Notes: The EEG-SMT would successfully turn on usin the USB hub of a computer.	Results: 

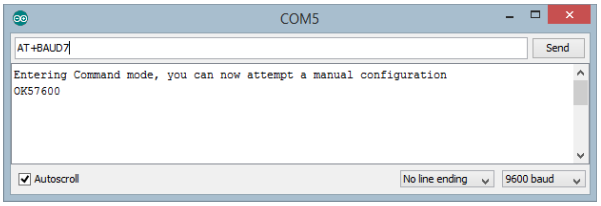
Bluetooth Module: Pass/Fail: Pass Tester’s Initials: MNT Date: 4/9/14 Notes: The Bluetooth Module would successfully turn using the USB hub of the computer. A breadboard was used to make the connection. The baud rate was verified using an Arduino Uno.	Results:  AT Commands



```
AT
```

```
Entering Command mode, you can now attempt a manual configuration
OK
```

☑ Autoscroll
No line ending
9600 baud



```
AT+BAUD7
```

```
Entering Command mode, you can now attempt a manual configuration
OK57600
```

☑ Autoscroll
No line ending
9600 baud

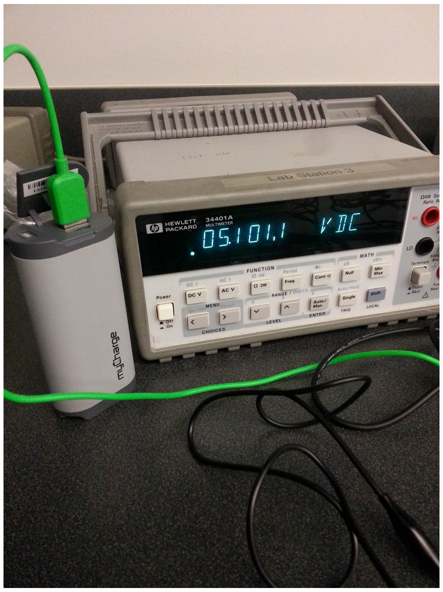
<u>Battery</u>:

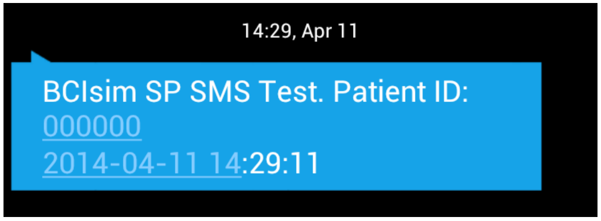
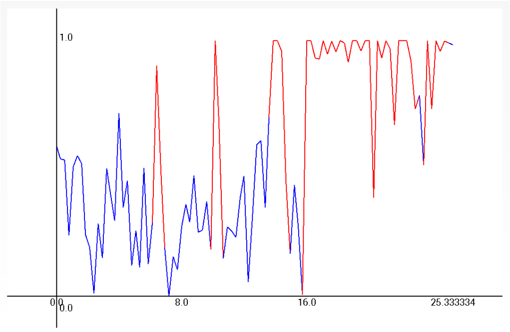
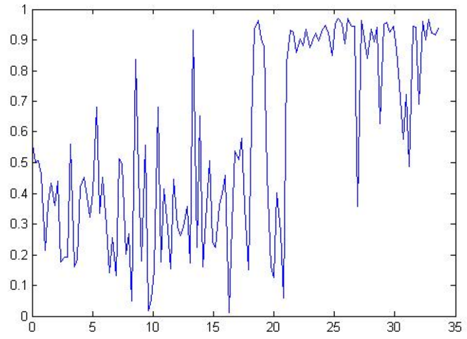
Pass/Fail: Pass
Tester’s Initials: DS
Date: 4/9/14

Notes:

The battery successfully produced 5.1 volts.

Results:



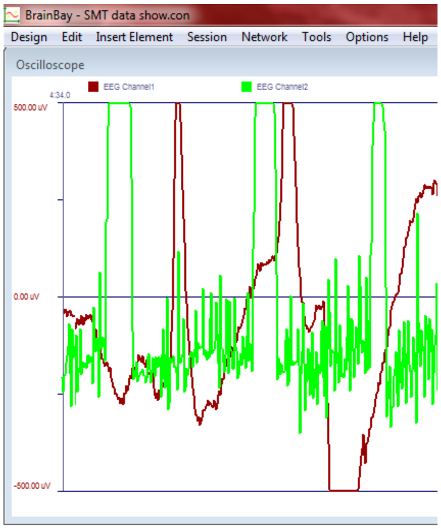
Mobile Phone: Pass/Fail: Pass Tester's Initials: BMM Date: 4/11/14 Notes:	Results: Notification System  14:29, Apr 11 BCIsim SP SMS Test. Patient ID: 000000 2014-04-11 14:29:11 Algorithm  Phone Output  Matlab Output

Electrode + Amplifier

Pass/Fail: Pass
Tester's Initials: KMS
Date: 4/9/14

Notes:

Results:

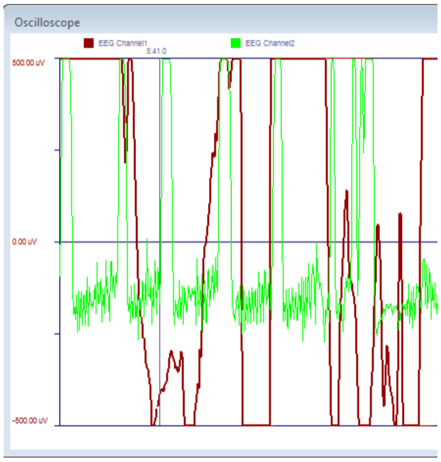


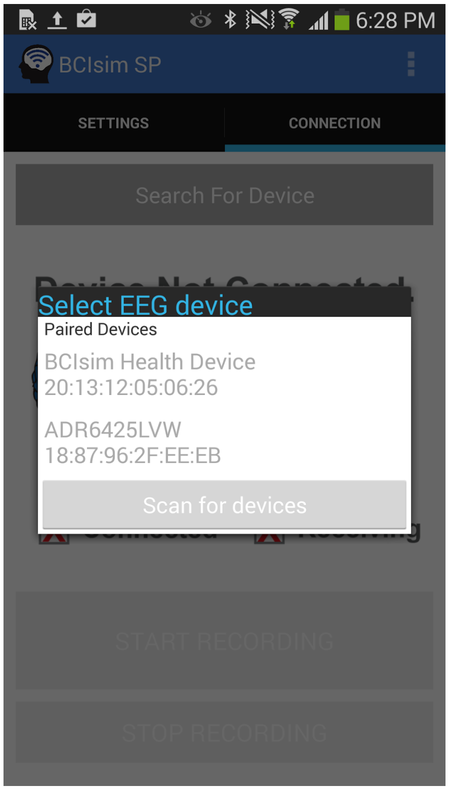
Cap + Electrode + Amplifier

Pass/Fail: Pass
Tester's Initials: KMS
Date: 4/9/14

Notes:

Results:



<u>Bluetooth + Phone</u> Pass/Fail: Pass Tester's Initials: MNT Date: 4/14/14 Notes:	Results:  Select EEG device Paired Devices BCIsim Health Device 20:13:12:05:06:26 ADR6425LVW 18:87:96:2F:EE:EB

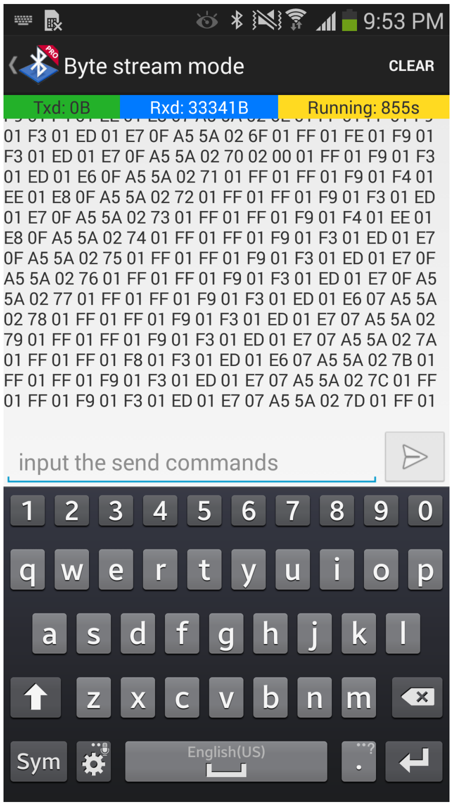
Cap + Electrode + Amplifier + Bluetooth

Pass/Fail: Pass
Tester's Initials: BMM
Date: 4/9/14

Notes:

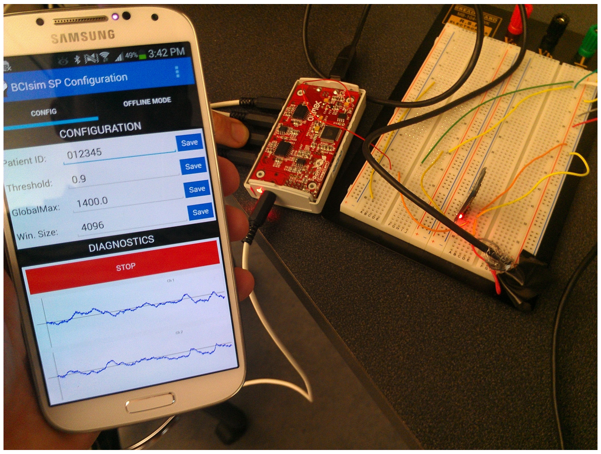
Raw data received over bluetooth.

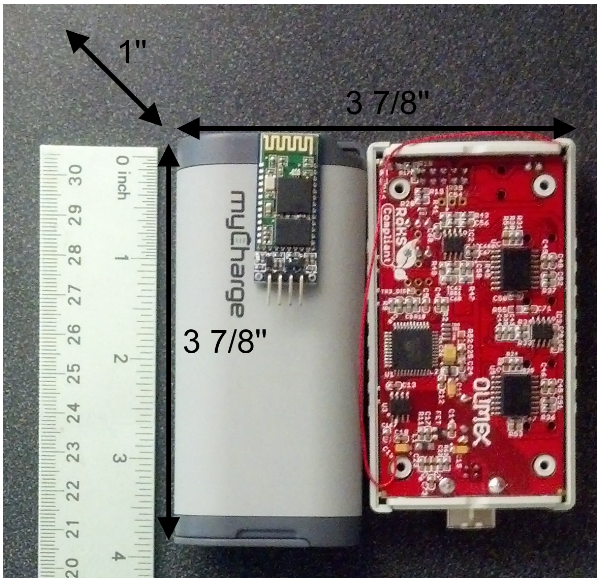
Results:



```
01 F3 01 ED 01 E7 0F A5 5A 02 6F 01 FF 01 FE 01 F9 01
F3 01 ED 01 E7 0F A5 5A 02 70 02 00 01 FF 01 F9 01 F3
01 ED 01 E6 0F A5 5A 02 71 01 FF 01 FF 01 F9 01 F4 01
EE 01 E8 0F A5 5A 02 72 01 FF 01 FF 01 F9 01 F3 01 ED
01 E7 0F A5 5A 02 73 01 FF 01 FF 01 F9 01 F4 01 EE 01
E8 0F A5 5A 02 74 01 FF 01 FF 01 F9 01 F3 01 ED 01 E7
0F A5 5A 02 75 01 FF 01 FF 01 F9 01 F3 01 ED 01 E7 0F
A5 5A 02 76 01 FF 01 FF 01 F9 01 F3 01 ED 01 E7 0F A5
5A 02 77 01 FF 01 FF 01 F9 01 F3 01 ED 01 E6 07 A5 5A
02 78 01 FF 01 FF 01 F9 01 F3 01 ED 01 E7 07 A5 5A 02
79 01 FF 01 FF 01 F9 01 F3 01 ED 01 E7 07 A5 5A 02 7A
01 FF 01 FF 01 F8 01 F3 01 ED 01 E6 07 A5 5A 02 7B 01
FF 01 FF 01 F9 01 F3 01 ED 01 E7 07 A5 5A 02 7C 01 FF
01 FF 01 F9 01 F3 01 ED 01 E7 07 A5 5A 02 7D 01 FF 01
```

System Testing

Cap + Electrode + Amplifier + Bluetooth + Phone + Battery Pass/Fail: Pass Tester’s Initials: LBH & BMM Date: 4/14/14 Notes:	Results:  Patient ID: 012345 Threshold: 0.9 GlobalMax: 1400.0 Win. Size: 4096

Size Pass/Fail: Pass Tester’s Initials: KMS Date: 4/21/14 Notes:	Results: 

Power Consumption Pass/Fail: Pass Tester’s Initials: LBH & MNT Date: 4/14/14 Notes:	Results: V = 5.049 V I = 99.077 mA P = IV = (5.049 V)(99.077 mA) P = 500.24 mW

Lifetime Pass/Fail: Pass Tester’s Initials: LBH & MNT Date: 4/16/14 Notes:	Results: The system ran for 12 hours with continuous acquisition and processing.

Conclusion

This document detailed the project requirements, solution investigation, prototyping, final design details, test process, and system evaluation of the WirelessEEG. After establishing project requirements, various solutions were investigated. The final design was then created and tested. After completion of the test plan, it was observed that the requirements were met by the results. The entire system worked seamlessly after a few modifications. The team considered the entire process a great success. They were able to use knowledge gained throughout their undergraduate curriculum along with valuable new found knowledge in the design process to see this project to its completion.

Team Contributions

Implementation
Hardware: David Platillero
Dylan Snowden
Karsten Solies
Software: Brent McFerrin
Madeline Threatt
Testing
Hardware: Lindsey Hopf
Dylan Snowden
Karsten Solies
Software: Brent McFerrin
Karsten Solies
Evaluation
Hardware: Lindsey Hopf
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