Brain Signal Operated
Technologies
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January 26, 2007

Dr. Andrew Rawicz
School of Engineering Science
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Burnaby, British Columbia
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Re: *ENSC 440 Post-Mortem Report for Brain Signal Controlled Devices*

Dear Dr. Rawicz:

The attached document, *Post-Mortem Report for Brain Signal Controlled Devices*, describes the activities of our group while we designed and implemented brain signal controlled devices. Our group overcame several devastating problems and built a prototype for monitoring brainwave signals

This document describes the current state of the project, the deviations from the original plan, the possible future work for this project, and the problems we encountered. In addition, each engineer in the group provides descriptions of individual contributions to the project and what was learned.

Brain Signal Operated Technologies is currently comprised of two enthusiastic engineering science students: Heng Wei Lan and Victor Yu. If you have any questions or concerns about our Post-Mortem Report, please contact us at ensc440-bso@sfu.ca.

Sincerely,

Victor Yu

Victor Yu
Chief Financial Officer
BSO Technologies

Enclosure: *Post-Mortem Report for Brain Signal Controlled Devices*

Post-Mortem Report for

Brain Signal Controlled Devices

BRAIN SIGNAL OPERATED TECHNOLOGIES

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Glossary

BCI	Brain Computer Interface
BSO	Brain Signal Operated
DAQ	Data Acquisition
EEG	Electroencephalography
LabVIEW	Laboratory Virtual Instrumentation Engineering Workbench
PCB	Printed Circuit Board
PCI	Peripheral Component Interconnect

1. Introduction

Many brain controlled products in the market are not very user-friendly. Consumers often have to spend a vast amount of time and effort before becoming familiar and comfortable using the devices. To solve this problem, Brain Signal Operated Technologies (BSO Technologies) developed a training system that will make learning to use a Brain Computer Interface (BCI) easy and entertaining. Our training device is easy to set-up, requiring just the placement of an electrode cap on the trainee's head.

During the past four months, the engineers at BSO Technologies have worked diligently to assemble a two-channel Modular Electroencephalography (EEG) System. The product was demonstrated on January 25, 2007 to showcase its capabilities and efficiency.

2. Current System

Figure 2-1 shows the overview of our current two-channel Modular EEG System.

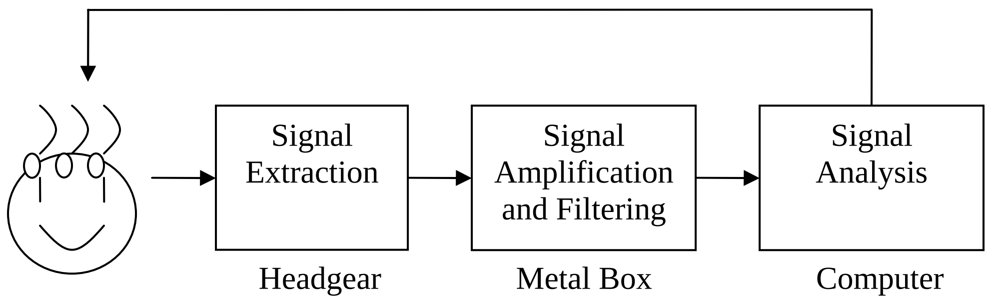

Figure 2-1: Modular EEG System Overview

The current device allows users to see brainwaves from two different areas of their brains: the left motor cortex and the right motor cortex. Thus, users will see two different waveforms on the computer screen. The system is designed to extract alpha waves (8-13 Hz) from the composite brain signals.

Our EEG system contains three main parts: signal extraction, signal amplification and filtering, and signal analysis. The functions of each component are discussed in the following sub-sections.

2.1 Signal Extraction

In order to extract brain signals, we use a total of four electrodes: three pin array electrodes and a clip electrode. The three pin electrodes are attached on the user's scalp at locations suggested by the standard 10-20 System. The clip electrode is attached on one of the user's ears as a reference.

The brain signals extracted by the electrodes are strengthened by an instrumentation amplifier chip by 100 times. The resulting signal is passed to the next stage via wires encapsulated in a cable.

All electrodes and electronic circuitry in this stage are located on a headgear, which users wear to interact with our system.

2.2 Signal Amplification and Filtering

This stage contains two second-order low-pass filters, an amplifier with a fixed gain of 100, another amplifier with a variable gain of 1-150, and a high-pass filter. The low-pass filters are designed to remove any noise outside the 6-15 Hz range. The high-pass filter is used to remove any DC offset. The electronic circuits in this stage and the previous stage are powered by batteries.

All electronic components in this stage are carefully soldered onto a pad board. The board is designed to fit into a metal box, which helps isolate the components from outside noise. However, sometimes the board is taken out of the box in order to apply batteries or adjust the gain of the variable gain amplifier.

The amplified signal from this stage is sent to the computer via a Peripheral Component Interconnect (PCI) 6024E Data Acquisition (DAQ) card.

2.3 Signal Analysis

The signal analysis of the amplified signal is done in commercial software called Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW).

After we receive the raw input from the amplification stage, we apply a software low-pass filter with cut-off at 45 Hz and a software notch filter with cut-off at 60 Hz. The purposes of these filters are to remove additional noises and the 60 Hz hum. Both the raw input and the clean input are displayed in LabVIEW for users to compare.

At last, the clean input is filtered into different frequency bands to display the presence of certain brainwave rhythms, such as alpha, beta, theta, and etc. Figure 2-2 below provides a snapshot of the user interface in LabVIEW.

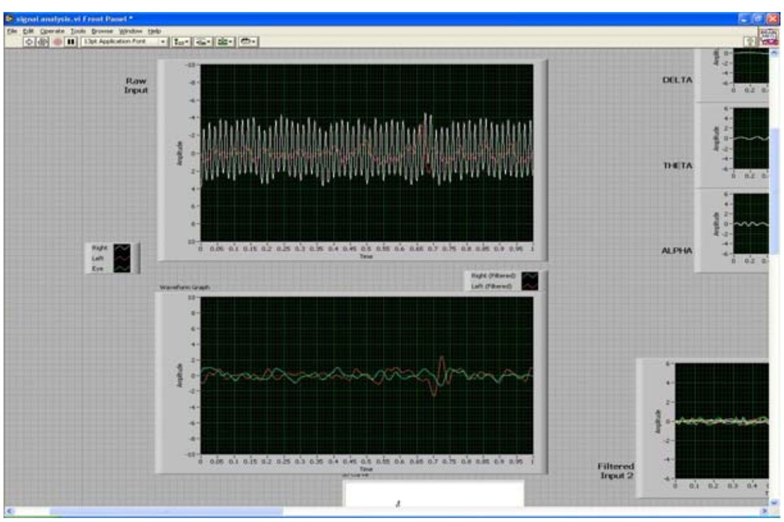

Figure 2-2: User Interface in LabVIEW

3. Device Deviations

3.1 Overall System

Our current system does not provide several of the proposed functionalities, most noticeably the PONG game. The main reasons behind the deviations are time and labor constraints.

The present system provides two channel displays, as opposed to the initial one-channel design. Moreover, the aim of our project changed from controlling beta waves to observing alpha waves. Such change affected the filter designs.

3.2 Pre-Amplification

In terms of functions, the pre-amplification part performs according to plans. Originally viewed as the most challenging aspect of the project, the active electrodes are well constructed. Brain signals are extracted and pre-amplified properly.

The key change in this area is the design. Since we are building two channels instead of one, additional electrodes have to be utilized. As a result, we figured out new electrode placements, as illustrated in Figure 3-2, to satisfy the two-channel criterion.

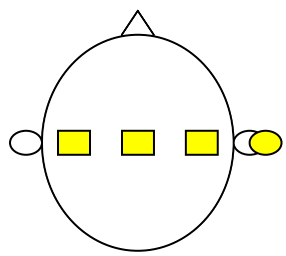

Figure 3-1: New Electrode Placements

The old design used AD625 as the instrumentation amplifier. However, we faced the low turn-on voltage problem in our operational amplifiers. After several weeks of trying to remedy this problem, the final solution was to use another instrumentation amplifier, INA128. Figure 3-2 shows the new schematic for the pre-amplification stage.

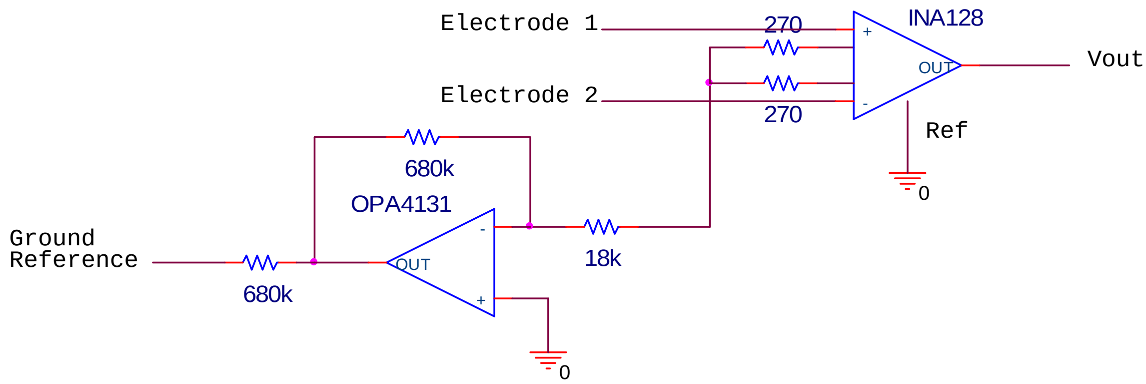

Figure 3-2: Modified Pre-amplification Schematic

3.3 Amplification and Filtering

The amplification stage provides most of the proposed functionalities. Brain signals are amplified and noise in irrelevant frequencies are filtered out.

Just like the original design, our current system has a fixed-gain amplifier and a variable-gain amplifier. The low pass filter had to be redesigned to pass alpha-wave frequencies (8-12 Hz) instead of beta-wave frequencies. Also, the hardware notch filter design was abandoned due to its complication. Instead, a software notch filter was added to remove the 60 Hz noise.

3.4 Software Analysis

As expected, the software analysis of brain signals is performed in LabVIEW. Although the current system does provide signal display and analysis, it lacks the PONG game interface. Nevertheless, we have created a PONG game playable by mouse. The only missing item is the bridge between a controllable brain signal and a brain signal game control.

The software design in LabVIEW was not provided in detail at the beginning. Hence, the current design, as described in section 2.3, is not considered as a deviation from the original design.

4. Future Plans

Our current EEG System has a great potential for future research and expansion. We have many suggestions for future development.

4.1 Overall System

The most obvious future work is providing better biofeedback training. Our results are inconsistent at times and subject to different user conditions. The future training environment should be more stable and reliable.

The next generation of our EEG System can fulfill our original goal of playing PONG via brainwaves. Future developers can use our mouse-controlled PONG game as the starting point and add brain-related controls.

4.2 Hardware

New techniques can be developed to hold the electrodes in place. Due to different head sizes, the middle electrode sometimes floats in air and does not contact the surface of the scalp.

All electronic circuitry should be mounted on Printed Circuit Boards (PCBs). This step was ignored to save project cost.

We recommend the construction of a hardware notch filter. We rejected our notch filter design because of its inefficiency, complexity, and difficulties to find perfectly matching components. The experimental result displayed a drop of -20 dB at 60 Hz instead of the theoretical -50 to -60 dB. Future work can examine the disadvantage of this filter and improve upon it. Ideally, the 60 Hz noise should be filtered out before much amplification is carried out.

4.3 Software

More signal processing and analysis can be done in LabVIEW. Future work includes figuring out how to remove more noise. Although the brain signals detected by the current system dominate the surrounding noise, a small amount of distortion can still be observed.

5. Buget and Time Constraints

5.1 Budget

Table 5-1 compares the estimated cost and the actual cost of the project.

Table 5-1: Estimated Cost vs. Actual Cost

Component	Estimated Cost	Actual Cost
Head Gear	$300.00	$20.00
Electrodes	$0.00	$14.82
Power Supply	$100.00	$9.01
Interface Box	$20.00	$9.14
Electronics	$50.00	$62.90
Connections	$0.00	$15.14
Tools	$0.00	$13.45
LabVIEW and DAQ (~$1,500)	$100.00	Borrowed
Miscellaneous	$0.00	$23.25
Unanticipated Materials	$0.00	$192.57
Total	**$570.00**	**$360.28**

Overall, the actual cost is much less than the estimated cost. The main reason is the cost of the head gear. Initially, we planned to acquire a commercial electrode cap, which costs around $300.00. In the end, we purchased a face shield for gardening for $20.00 and used it as the head gear.

The cost of components for the working prototype is only $167.71. However, another $192.57 was spent on broken and unused components, useless parts, and the non-working prototype with AD625 as the instrumentation amplifier.

5.2 Time

Table 5-1 compares the estimated time schedule for six people and the actual time schedule for two people.

Table 5-2: Estimated Schedule (6 People) vs. Actual Schedule (2 People)

Task	Estimated Completion Time	Actual Completion Time
Components Purchasing	September 23, 2006	January 4, 2007
Soldering	October 7, 2006	January 9, 2007
LabVIEW Design	October 7, 2006	January 12, 2007
Game Integration	October 14, 2006	N/A
Testing	October 21, 2006	January 17, 2007
Game Training	November 4, 2006	N/A

The actual completion time for the project was much longer than what we had planned for six people. In the original schedule, tasks were supposedly done in parallel by groups of three. When the group size was finally locked to two people, the group excelled.

Most of 2006 (September to November) was wasted on figuring out who were or were not in the group. December was spent on the non-working prototype. The low turn-on voltage problem lasted for a few weeks. Many analog circuitry tricks were used to try to solve the problem. After that, the current prototype was assembled and tested in just a few weeks.

6. Group Dynamics

6.1 The Problem

Group dynamics was a fatal problem that this project team faced. The group was formed by five people in summer of 2006, before the start of the course. We shared project ideas and distributed tasks to everyone. Everything seemed organized. At the start of the fall semester, we added another person. As a group of six, we discussed the proposal. An ambitious project was decided since we had many people.

Soon after that, we had people not attending meetings, not doing individual tasks, and not answering e-mails. Before the proposal was due, one left the group without telling others, one had registration problems and soon left, and one was discouraged by losing members. Before the functional specification was due, the discourage person left the group without notifying other members. As a result, the group was down to three people.

To make things worse, the third member constantly claimed that s/he had already finished his/her tasks or that s/he would finish certain things by certain time. (All) The claims and the promises never come true. Then, the third member took an extended leave without informing the team. The remaining two students were dejected and hopeless.

6.2 The Solution

Several preliminary steps were taken to avoid things like this from happening. A caucus conference was set-up for group members to share ideas. However, only the two remaining students visited there regularly. Since the idea of caucus did not work, a group mailing-list was set-up. Nevertheless, many members would not respond to e-mails. Hence, phone numbers were exchanged to provide instant communications. However, most phone calls were not answered.

A meeting with the course instructor was conducted to discuss the problems with group dynamics. A possible new project with two students was mentioned. However, our love and passion for the field of BCIs kept us in this project.

6.3 The Outcome

In the end, only two students remain in the group. Although the selfish decisions made by others once forced us into difficult academic and family situations, we have learned many technical and soft skills and progressed both as engineers and as team players.

7. Individual Experience

7.1 Heng Wei Lan (COO, CTO)

During the project progression, I experienced many difficult situations. I was frustrated to see group members leaving one bye one and face many undone tasks. I became more confident as our group overcame these issues and completed the project. In the end, I have learned the basic knowledge of EEG and other technical problem-solving skills.

Group dynamics is always the most important factor to determine the success of a group. Obviously, there was a very serious problem in our group, which lacked strong leadership. Our group was formed with different people who did not know each other well. We tried to be nice to each other and avoid any conflicts, but I think there were many decisions and negotiations that had to be done without too much hesitation. We lost much time dealing with individual tasks and were afraid of pushing each other to keep the project on track. As each member lost his/her faith of the group, no tasks were done. If there was an ambitious leader in our group to push each individual and tie the team together, our project might come out with a different result.

From building up the hardware, I have learned much technical knowledge and improved my problem-solving skills. In school, I have learned the technical knowledge for the ideal case; however, I realized there are more realistic facts I have to be aware at the design stage. As for the software part, I obtained more experiences with LabVIEW, a powerful system design tool. There are more capabilities and applications of LabVIEW I have not explored yet. To improve our project and reach our original goals, I had to learn and research more on related technical knowledge. Our active electrodes once had conducting problems and could not receive proper brainwave signals. I researched on electrode technology to solve the exact problems we had encountered. To improve noise rejection, we added all sorts of filters in the amplification stage. I was not comfortable with filter designs prior to the project, but now I am.

Working in this group project, I obtained a very special experience. Now, I have more confident to face difficult group problems that I cannot expect. It is very grateful to have my good friend, Victor Yu, who helped and supported me when I lost my faith to accomplish the project. I believe our friendship did help us pass many challenges and achieve a successful result.

7.2 Victor Yu (CEO, CFO)

At the start of the project, I was assigned the role of a CFO. I had the responsibility to keep track of the budget. I was also in charge of the business component of the project. After the former CEO left, I took over the leadership role and tried to save this catastrophic group from the arms of the “F” devil. How I managed to do it became the Ninth Wonder of the World (the Eighth being how the group size shrunk from six to two).

Since the project was only done by two people, my partner and I were involved in all phases of the implementation. Lester and I both participated in hardware design, software design, integration, and testing phases of the development.

Previously, my experience with analog circuit designs was focused on building and testing on a breadboard. In this project, I did use the breadboard to perform the initial design and testing. After that, I was exposed to a lot of soldering, something I was not good at before this course. In addition, I learned a lot about wire engineering. I became skilled at using different types of cables and connectors. I became aware of the influence of the length and the number of wires on the noise level of the circuit. Our pre-amplification circuit had to be as close to the electrodes as possible so the tiny brain signals would not be interfered by noise. Also, I gained valuable knowledge in working with small signals, particularly those from the human brains. I constructed different types of filters with different orders. Prior to the project, I had never worked with LabVIEW. Now, I have grasped the basic design methodology of the application. I can perform simple signal analysis and processing using LabVIEW.

The project gave me a good introduction to the field of biomedical engineering. I was not familiar with the biological structure of the brain. I did not know about the different rhythms of the brainwave. In addition, the project taught me about the EEG mechanism. The ability for electrodes to pick up brain signals from the human scalp was very cool. Now I have a good understanding of different types of electrodes and how each reacts when contacting the human body.

Working on this project gave me many insights into group dynamics. I had the pleasure to work in groups of two to six. In large groups, more ideas are thrown around and more work (usually) can be done. However, group communication becomes a problem because finding a meeting schedule that suits everyone is difficult. Furthermore, there are usually conflicts among team members. On the other hand, working in small groups has the advantage of getting to know everyone very well. A drawback is that the number of human brains is limited. When this project group was down to two people, I felt that sometimes the group ran out of ideas, which was never the case when the group had five or six people. I always wished that we had at least a third member (Brad was usually the victim of this).

If I am to undertake a similar project again, I will address the group dynamics problem immediately. Getting the team sorted out is the first priority because it puts everyone on the same page and it allows the group to know the proper time and labour constraints. Also, I will come up with better contingency plans, which will cover the unexpected emergencies. For this project, although I had anticipated a group member or two becoming sick, I did not expect the possibility of having four group members leave. As a result, I was fully unprepared for such crisis.

Overall, I acquired many valuable technical and soft skills from this project. I was able to apply the knowledge learned from my first, second and third year courses. To look back, this 440 nightmare will be one of the most thrilling rides of my undergraduate career.

8. Conclusion

Despite experiencing numerous difficulties, the two students in the group worked well together and achieved as much as possible during the limited time frame. We are pleased with the outcome of the project. We hope one day our device can help the disabled by allowing their brains to perform many activities which their physical attributes would not permit. We would like to thank Brad Oldham, Andrew Rawicz, and Steve Whitmore for their guidance during the course of the project.