Safer Driving System

EE 175AB Final Report

Department of Electrical Engineering, UC Riverside

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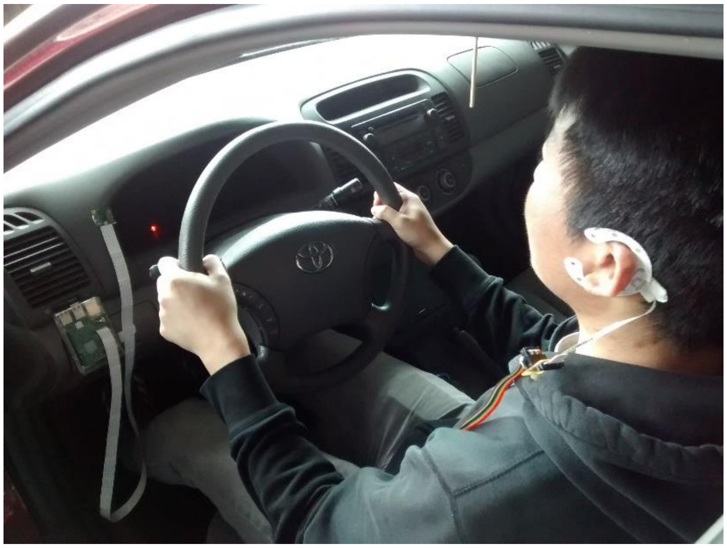

Summary

This project aims at creating a safer driving experience for all motor vehicle operators. The safer driving system goals are; provide data that could prevent and reduce motor vehicle accidents, due to driver drowsiness, sudden sleep, distraction or loss of attention while they operate a vehicle. This system is based on EEG signal analysis and camera assisted eye and head tracking.

Revisions

Version	Description of Version	Author(s)	Date Completed	Approval
1.5	First Version	Andrew Kwon, Aberto Arriaga Felix, Kai Wen	3/08/2017	
1.6	First Draft Submitted	Andrew Kwon, Aberto Arriaga Felix, Kai Wen	3/10/2017	
1.7	Last Version Submited	Andrew Kwon, Aberto Arriaga Felix, Kai Wen	3/21/2017	
2.0	Last Version Edited	Alberto Arriaga Felix	6/13/2017	

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1 Executive Summary

In a study conducted by the AAA Foundation for Traffic Safety, an estimated 21, 292 crashes were recorded in 2009-2013. Approximately 10% of those crashes involved distracted or sleepy drivers. 21% of those crashes involving a drowsy driver were fatal. Currently even the most expensive vehicles available are not equipped with any type of system that detects when a driver falls asleep. Some modern vehicles detect obstacles on the road and employ autonomous driving to avoid accidents, but there are currently no cars with systems that detect the activity of the driver.

The main goal of this senior design project is to provide a driver monitoring system that can detect when a driver is falling asleep, and an alarm system to wake the driver up before an accident occurs. The title of the project is the Safe Driving System and it is a two-part device. The first part is an Electroencephalogram (EEG) system that analyzes the electrical activity of the brain as the drivers operate a vehicle. The second is a camera system aimed at tracking the eyes of the driver. The EEG system serves to identify brain signals that are related to sleep or drowsiness. The Eye tracker system serves to identify driver distraction, such as not looking at the road, or symptoms of sleep, such as closing eyes for extensive periods. The design created is cost efficient and compatible with all vehicles.

Testing was conducted on a person in a closed environment. The camera system accurately located the face and eyes of the driver in real time with little delay. As the subject closed his eyes, an alarm sounded and stopped as soon as the subject reopened his eyes. The EEG system was tested in an electromagnetic interference shielded room, and collected brain activity from a subject. An important achievement that was accomplished includes the electrodes in the EEG system being portable and requiring little effort to setup. As well as data analysis being conducted in almost real time on a portable computer.

2 . Introduction

2.1 Design Objectives and System Overview

The Safe Driving System (SDS) is a portable driver safety system. The system operates by looking at the eyes and brain signals of a person driving, and detects if the driver is falling asleep. If the system detects the driver to be falling asleep, an alarm sounds to wake the driver. The system involves four components; a camera eye tracking component, and brain signal detection component, a portable processing component, and an alarm system. The system works in close to real-time. It takes information from the camera and brain signal detection parts into the portable processing component, the data is analyzed, and feedback is given shortly after.

The objective of this project is to design a brain signal detection system and an eye tracking system. Another objective is to find a portable processing solution. The brain signal system is comprised of Electroencephalogram (EEG) electrodes, an EEG amplifier, and a filtering system for the brain signals. An analog to digital converter transfers the analog brain signals to a portable computer for signal analysis. The EEG system is self-contained and battery operated, in a small package that allows for portability. The eye tracker system has the following characteristics. It is mounted inside a motor vehicle with a clear view of the driver's eyes, it tracks the eyes of the driver, and detects when the driver closes their eyes for an extended period.

The project's objective is to prevent the problem of drivers that fall asleep and cause accidents. It is meaningful because currently there exists no comparable systems on the market, which can both track a driver's eyes and their EEG signals simultaneously. The applications of the SDS are diverse. It can be used by individuals that drive for long hours or those that have medical conditions related to sleep.

The SDS solves several problems from the standpoint of motor vehicle safety engineering. There is a space here to apply knowledge of Electrical Engineering and brain science, to help prevent unnecessary accidents from driver error. Signal processing and modern computer vision techniques are used to complete the objective. Currently there are smarter, more efficient, and structurally safer cars being designed and build. But the key component in most motor vehicle accidents is still the driver. Understating the physiological and behavioral aspects of driver distraction or incapacitation that lead to accidents, is an important aspect of safety engineering.

The overall goals for the project include designing a brain signal detection component and an eye tracking component. Finding a solution for portable analysis of the signals. And finally, designing an alarm system that wakes the driver.

2.2 Backgrounds and Prior Art

EMOTIV EEG

Figure 2.1 – Emotive EPOC+ wireless EEG system.

Emotiv has several systems for mobile EEG brain signal analysis applications. The Emotive EPOC+ is a wireless 14 channel EEG reading device. The price of this device is $800, and it's available to all consumers.

Emotive EGG –

Advantages:

- Wireless connectivity.
- 14 channels for EEG signals.
- Extended software support and tutorials.
- Small form factor.

Disadvantages:

- The cheaper emotive systems operate for up to 6 hours on battery, and have long recharging time of 2-3 hours.
- Expensive for regular consumers, $800 entry point, including software subscription.
- Difficult to use software libraries.
- Must connect to external PC for analysis

The SDS –

Advantages:

- The Safe Driving System is designed to be operational for up to 9 hours.
- Designed with minimum number of features for device operation.
- Cheaper overall cost of system, under $200.
- Analysis Computer included

Disadvantages:

- Wired connectivity
- 2 channels for EEG signals
- Bulky design for first iteration.
- No support for custom data files, all data is raw data.

THE EYE TRIBE and Tobii Eye Trackers

Figure 2.2 – The Eye Tribe (on left) and
Tobii (on right) eye trackers.

These companies have devices for eye tracking like what the SDS accomplishes. Tobbitech and The Eye Tribe offer individual eye tracking, head position tracking, face recognition, and facial feature tracking.

- **Advantages of the SDS:** These products are not commercially available or are very expensive for consumers. These two companies offer too many features that are not user friendly or accessible by the driver. Tobbitech and The Eye Tribe camera devices are geared towards industry applications and not the average consumer. These cameras also require more power consumption. The Eye Tribe tracker needs a separate power source to be fully functional. The SDS camera operates off the 1.1 amps supplied by RaspberryPi's Universal Serial Bus (USB) ports.
- **Disadvantages of the SDS:** The systems available by these companies do have more features than the SDS could ever possible have. Another advantage of competitors is in the form factor. Cameras used by these companies are smaller and faster than the ones implemented in the SDS system.

2.3 Development Environment and Tools

Software:

The eye tracker and EEG analog to digital converter parts of the SDS are develop usng a Linux based operating system Raspbian running on a Raspberry Pi Model 3. The SDS uses Atmel Studio 7, a C/C++ editor and compiler to write C code that is programmed into an ATMEGA1284-PU Microcontroller. This microcontroller is the central component of the alarm system. Printed Circuit Boards (PCBs) are needed for the electrodes. The software used to generate the PCB is DesignSpark PCB 7.2. The files output from this PCB software were used on a PCB Prototyping Machine.

Hardware:

Testing of hardware components was done on a digital multimeter, a waveform generator, an oscilloscope with 2 channels, and a power supply. These measurement devices were provided by the school's laboratory. Manufacturing of PCB boards for custom components not available on the market was accomplished through PCB Prototyping Machine. Two PCB boards were designed and created. These boards are used in the electrode cables that attach to the driver's head. An IDC crimp tool was used to make the ribbon cables for the electrodes. Lastly, an Olimex AVR ISP mkII programmer was used for writing code to the ATMEGA1284 Microcontroller.

2.4 Related Documents and Supporting Materials

- Raspberry Pi Foundation (2017, April 21). *Raspberry Pi Documentation* [Online]. Available: https://www.raspberrypi.org/documentation/
- Atmel Corporation (2017, April 21). *Atmel Studio Documentation* [Online]. Available:http://www.atmel.com/webdoc/GUID-ECD8A826-B1DA-44FC-BE0B-5A53418A47BD/index.html
- SPI Communication Protocol

2.5 Definitions and Acronyms

- SDS – Safe Driving System
- PCB – Printed Circuit Board
- RPi – Raspberry Pi portable computer
- EEG – Electroencephalogram
- ADC – Analog to Digital Converter
- DRL -Right Leg Driver Circuit
- USB - Universal Serial Bus

3 Design Considerations

3.1 Realistic Constraints

The SDS has these project constraints:

Power:

- A realistic battery life should last 4 hours.

Processor:

- Due to budget constraints, the processing computer chosen is the Raspberry Pi 3 Model B.

Frequency/Sample:

- Realistically the processor on the RPi computer is not fast enough for real time analysis. The system samples signals at a rate of 1 sample per 5 second period, do analysis and provide results based on that sample.
- Processing time is 2 to 3 seconds.

Weight/Size:

- Weight under 1 lbs.
- Portable size, about 4 x 3 x 2 inches (Length x Width x Height).
- The EEG electrodes attached behind the ears of the subject are flexible and easy to and lightweight, less than 2 ounces.

Interference:

- To make accurate EEG readings, isolation from noise signals such as wireless networks, radios, microwaves, and light signals is required. These exterior signals cause interference on the EEG readings. The SDS is tested inside a room shielded from Electromagnetic interference. This room is provided by the psychology department.

Camera:

- The camera for eye tracking, is placed inside the vehicle with a clear view of the driver's eyes.

Budget:

- The budget for the SDS is $200.

Time:

- A deadline of 20 weeks to complete this project.

3.2 System Environment and External Interfaces

The main control and analysis functions of the SDS operate on a Raspberry Pi 3 Model B (RPi) computer hardware. This includes control of the eye tracker camera and analysis of the EEG signals and eye tracker camera video feed. The RPi PC runs on a custom Linux operating system distribution called Raspbian. The main programming language for all the scripts that run on the RPi computer is Python.

The connection between the eye tracker camera and the RPi computer is made through the Camera Serial Interface (CSI) port on the RPi motherboard. This interface facilitates the fast exchange of data between the camera and the RPi processor.

The analogue to digital converter component (ADC) allows us to convert the analog data received from the EEG amplifier into digital data that can be analyzed by the RPi computer. The ADC connection to the RPi computer is done via the General Purpose Input/Output (GPIO) pins. The main communication protocol between these two devices is the Serial Peripheral Interface (SPI) protocol.

The alarm component of the SDS is also controlled via the GPIO pins on the RPi computer. The alarm system uses Pulse Width Modulation technique to create the sound that alerts the driver.

3.3 Knowledge and Skills

Alberto Arriaga Felix

Knowledge and Skills

- EE100B – Understanding of operational and instrumentation amplifiers, and filter networks.
- EE120B – State machines, microcontrollers, designing hardware that is software controlled, and interfacing embedded systems.
- EE116 – Electromagnetic waves and applied physics.
- EE 132 – Designing control systems with feedback loops.
- EE141 – Digital signal processing.
- CS12 – Programming in C++.

New Skills

- Programming in Python.
- Linux Operating System knowledge.
- Raspberry Pi hardware knowledge.
- PCB Design.
- EEG signal analysis.

Andrew Kwon

Knowledge and Skills

- EE152 - Understanding of image processing techniques
- EE146 - Using computer vision and morphology to detect face.
- EE141 - Digital signal processing
- CS10/CS13 - Programming in C++
- EE120B - Combining hardware and software through microcontrollers

New Skills

- Programming in Python
- Becoming familiar with Raspberry Pi
- PCB Design

3.4 Budget and Cost Analysis

The system cost should be under $200. Overall, the parts selected meet this requirement as shown in Table 3.1.

Table 3.1 - Budget for Project

Item	Cost ($)
Raspberry Pi 3 Model B Motherboard	35.70
RPi 3 Case	7.50
Raspberry Pi Camera Module V2	23.41
Raspberry Pi Camera Module Mount	8.45
Battery High Capacity 13000 mAh	18.99
AD620ANZ-ND Instrumentational Amplifier	9.03
2 x TL084CN OpAmp	1.26
MCP3008 - 8-Channel 10-Bit ADC With SPI Interface	3.75
6 x Silver Pins Back with Foam Adhesive	2.70
Capacitor Kit	6.95
Resistor Kit	7.95
Ribbon Cable 10 Wire	4.95
2 x 5 Connector Pins and Sockets	5.00
Jumper Wires M/M and F/F	9.90
IDC Crimp Tool	19.95
cEEGrids ear electrodes	Free / Borrowed
ATMEGA1284-PU Microcontroller	Free / Borrowed
Olimex AVR ISP mkII programmer	Free / Borrowed
Piezo Speaker - PC Mount 12mm 2.048 kHz	Free / Borrowed
2 x 20 kOhm Potentiometers	Free / Borrowed
Total cost	165.49

3.5 Safety

There are risks involved with the operation of the EEG system in the SDS. The EEG amplifier device in the SDS has been designed with the intention of providing electrical isolation barriers between the user and the EEG system and the EEG system and the analysis computer. However, there are still risks involved as there can be interaction with the environment of operation by the subject connected which may cause short circuits and unwanted currents to be transferred to the subject or EEG system. As a precaution for the safety of the subject connected to the SDS and the analysis computer, all testing is done by having the subject connected avoid touching exterior objects while the system is operational. Finally, the EEG device should never be used during a lightning storm or very humid environments, as static electricity in the air could cause complications with the EEG amplifier.

In this design, the voltages in EEG circuit part of the internal system are very low, and not dangerous. There has also been precaution taken in the power supply of the system, and this is why the design is meant be battery operated. This limits the chances of there being voltages of dangerous levels, such as from a wall AC connection, from entering the system.

Safety Standards that apply to the SDS include; IEC 60601-2-26:2012, this standard applies to basic safety and essential performance of electroencephalographs used in a clinical environment.

However, none of the devices built by this team have been tested according to the standard because of the costs involved. Therefore, this EEG device is merely for theoretical purpose and proof of concept, and should never be used in real medical application

3.6 Performance, Security, Quality, Reliability, Aesthetics etc.

Numerous tests were conducted to make sure the SDS system is sturdy and the internal circuits inaccessible to the user. A special case specifically designed for the Raspberry Pi was constructed so that the user does not accidentally interact with hardware components.

Many considerations on aesthetic design were made. However, because the system is quite small a simple color coating on the case made it blend well with the dashboard or behind the rear-view mirror.

3.7 3.8 Documentation

Alberto Arriaga Felix

Kept track of the circuits used in the EEG system by drawing detailed diagrams. This includes keeping a precise record of parts that were used. Kept track of how the design progressed from one implementation to another, depending on what designs worked and which failed. Keep track of progress of individual components of the project. Kept track of parts and inventory used in the project.

Andrew Kwon

Researched methods to monitor face detection as well as eye detection. The most robust method was to use the Haar Cascade classifier. This classifier was developed by Intel and can be used with proper acknowledgement. This method detects the eyes very well but the only limitation is the lighting. If it is too dark the eyes won’t be able to be seen. That is why an infrared LED system for extra night time vision was attached to the system. To ensure that the driver is always protected especially during the night time when illumination is dark. Infrared LED is not visible by human sight, but with special cameras the driver is able to be seen.

4 Experiment Design and Feasibility Study

4.1 Experiment Design

This section outlines the experiment design and testing procedures for modules of the SDS.

8.1.1 Experiment Design for EEG Electrodes

Alberto Arriaga Felix and Kai Wen were responsible for this part.

Test of EEG Electrodes.
Objective: To verify that the cEEgrid electrodes detect signals greater than 100 μV. Any signal below 100μV is considered noise. Testing is done on an Emotiv EEG system, not the SDS system. The Emotiv EEG system is a commercial 14 channel headset that reads voltages as sensitive as 0.51 μV. The aftermarket system is used to eliminate the potential of errors coming from the SDS EEG amplifier. Test is done to determine if connectivity on the skin of the subject is stable and consistent with expected EEG signals coming for these electrodes.

Setup and procedure:
1. Attach cEEgrids to the Emotiv hardware with the PCB connectors and cables.
2. Check Emotiv software's built in connectivity measurements to determine whether signal connection is stable.
3. Observe EEG signals received by Emotiv hardware module.
4. Decide if signals are consistent with EEG signal parameters.

Expected result: To observe signals greater than 100 μV from the cEEgrid electrodes on the Emotiv EEG device.

8.1.1 Experiment Design for Analog to Digital converter

Alberto Arriaga Felix and Andrew Kwon were responsible for this part.

Test of Analog to Digital converter.
Objective: Test the analog to digital chip with an analog signal given by a photoresistor. This is to verify connectivity and consistency in signal transfer from ADC to analysis computer.

Setup and procedure:
1. Connect Photoresistor to ADC.
2. Shine a light from an LED on Photoresistor.
3. Vary the LED light intensity over time.
4. Use RPi software to measure the analog signal coming from the ADC and store the digital signal in a file.
5. Display a graph with the digital data measured from the photoresistor.

Expected result: Obtain a digital signal on the RPi from the ADC chip that varies over time.

8.1.1 Experiment Design for eye tracking with Raspberry Pi Camera

Andrew Kwon, Kai Wen, and Alberto Arriaga Felix were responsible for this part.

Test of Eye tracking with Raspberry Pi Camera.
Objective: Test the consistency of the eye tracker camera, and its connection to the alarm system.
Setup and procedure:

1. Verify that the driver is looking at the camera.
2. Determine if the driver's eyes are closed.
3. Sound alarm system if the subject's eyes remain closed for over 3 seconds.
4. Stop alarm system when the eyes of the driver are opened.

Expected result: Tell when a subject has his eyes closed for a long period of time, and sound the alarm if sleep is detected.

8.1.1 Experiment Design for eye tracker glasses

Kai Wen was responsible for this part.

Test of -Eye-tracker glasses.
Objective: To test the eye tracker glasses. Have the pupil camera tracking eye movements and obtain real-time streaming from eye-tracker cameras to computer.

Setup and procedure:

- Install Pupil dependencies and lab streaming layer on Mac OS system.
- Fix IP config file written in Python language.
- Install Raspberry Pi operating system.
- Run Pupil software on Windows with labstreamer enabled.
- Put on eye tracker glasses and run calibration test.
- Check with software if eye tracker glasses are able to keep track of subject's eyes.

Expected result: Have real time streaming signal on windows PC, with eye-tracker camera tracking subject's eye.

8.1.1 Experiment Design for EEG signal analysis with test data

Kai Wen was responsible for this part.

EEG Signal Analysis.

Objective: To use the EEG data files supplied by the Mednick Sleep and Cognition Lab and UCR Brain Game Center and analyze EEG data signals. In this experiment, analysis is conducted on Matlab. The EEG signals are read from file and functions are performed on them. First are the suppressing frequencies higher than 60 Hz. Afterwards Delta, Theta, and Alpha waves from one of the recording channels are identified. Use several band-pass filters designed to suppress EEG signals from noise. The following experiment would analyze 2000 samples from channel 5 of the EEG data file.

Setup and procedure:

- Read European Data File (EDF) using 'edfread' function from EEG signal recording with sampling rate of 128 Hz
- Truncate 2000 samples from the EEG signal recording channel 5.
- Design 0.5 Hz to 60 Hz filter to suppress high frequency noise due to constraints of sampling frequency.
- Design 0.5 Hz to 3 Hz (Delta Wave) band-pass filter.
- Design 3 Hz to 8 Hz (Theta Wave) band-pass filter.
- Design 8 Hz to 12 Hz (Alpha Wave) band-pass filter.
- Plot frequency response in magnitude of each filter.
- Implement the band-pass filters and evaluate signal noise suppression and window the signals using Hamming Window of window length 200 to minimize Gibbs effect.
- Perform frequency domain analysis of filter output by taking Fast Fourier Transform (FFT) and compare with original signals in frequency domain.

The Matlab code files can be found in Appendix D.

Expected result: High frequency larger than 60 Hz should be suppressed by filtering. Delta, Theta and Alpha waves should be identified.

4.2 Experiment Results, Data Analysis and Feasibility

8.1.1 Experiment results for EEG electrodes

Alberto Arriaga Felix and Kai Wen were responsible for this part.

Test of EEG Electrodes.

Results: The cEEgrid electrodes were attached to a team member using the adhesive on the electrodes as shown in figure 4.1. A conductive gel was placed on each electrode contact before attaching the electrode to the back of the ear. Custom cable and connectors were used to connect the cEEgrid electrodes to the Emotiv hardware EEG device. Afterwards, the Emotiv software was opened on the mac computer and data recording began. All the testing was done inside an electromagnetic shielded room in the psychology building lab. This is to prevent interference on the signal readings from Wi-Fi, radio, and microwave signals. Figures 4.1 and 4.2 show how the cEEgrids were connected to the Emotiv hardware and subject.

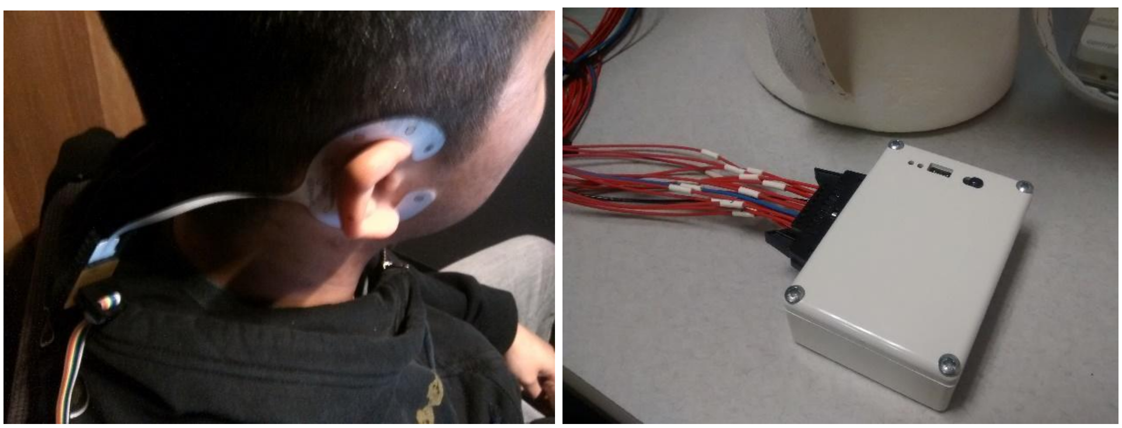

Figure 4.1– Left - cEEgrids v3 ear EEG electrodes connected to team member.
Right- Emotiv EEG Hardware connections.

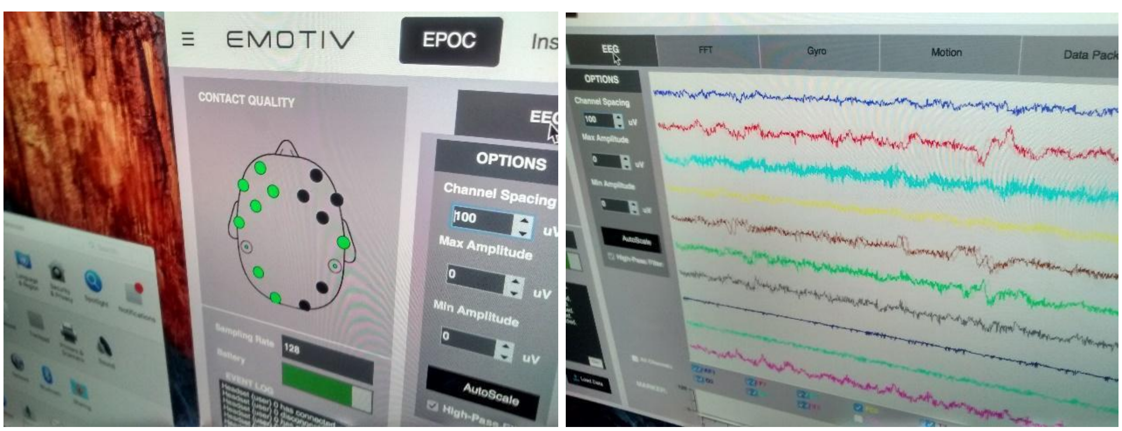

Figure 4.2 – Left - Emotiv software signal strength.
Right- Emotiv software EEG signals detected.

A total of 8 electrodes were connected to the Emotiv software with two electrodes acting as Reference and DRL/ground. Table 4.1 shows the connection pins between Emotiv and cEEgrid electrodes.

Table 4.1 – Emotiv to cEEgrid connection pins.

Electrode	**Emotiv Pin #**	**Emotiv Software Signal**
R1	1	O1
R2	2	P7
R3	3	T7
R4	4	F7
R4a	12	DRL Ground
R4b	5	CMS Reference
R5	6	AF3
R6	7	FC5
R7	8	F3
R8	11	O2

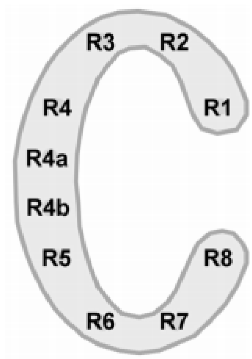

Figure 4.3 – EEG electrodes reference pins.

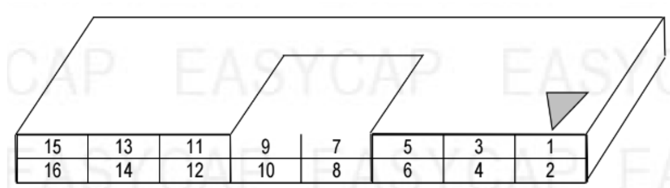

Figure 4.4 – Emotiv connector hardware box reference pins.

The emotive software showed excellent connectivity for the electrodes connected to the subject. As shown in Figure 4.2, the signals recorded by the emotive software ranged from 100 µV to 400 mV. This test showed that the electrodes can read the desired EEG signals into the SDS system.

Videos of test in **Appendix E**.

8.1.1 Experiment results for Analog to Digital converter

Alberto Arriaga Felix and Andrew Kwon were responsible for this part.

Test of Analog to Digital converter.

Results: The ADC was connected to the RPi. The Photoresistor is connected to Channel 1 of the ADC as shown in figure 4.5.

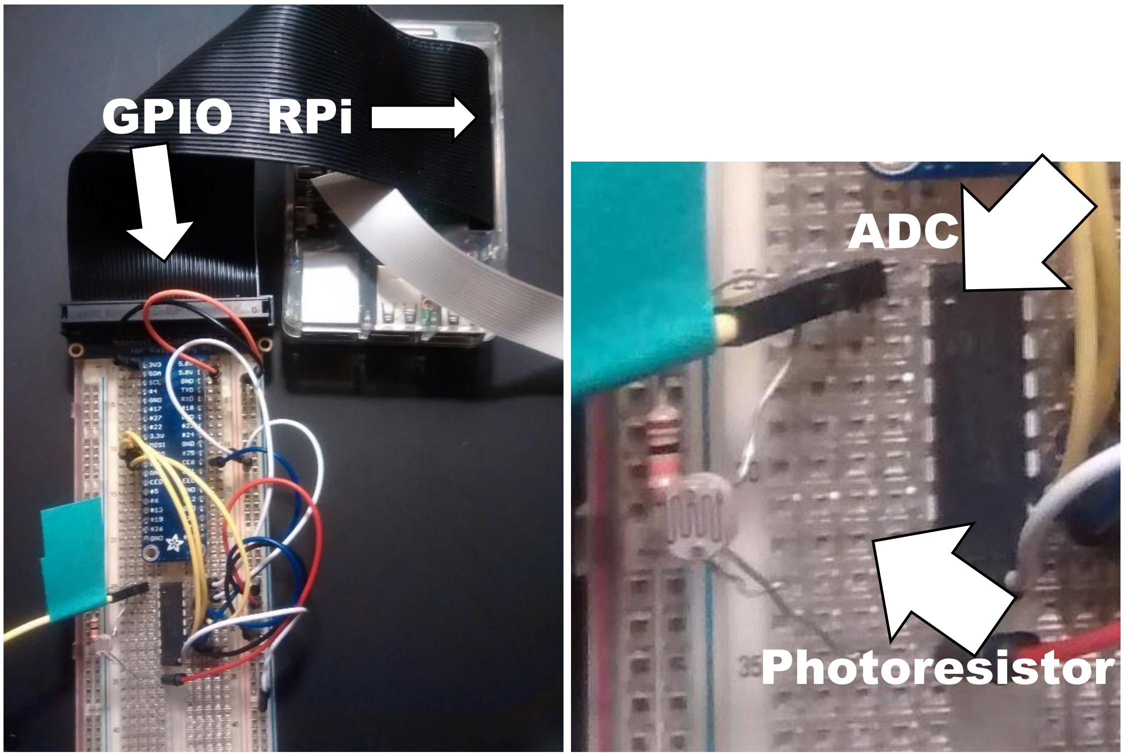

Figure 4.5 – ADC connections

The test was run from a Python script on the RPi. This script reads the analog signal from the photoresistor and converts it to a digital voltage. This digital voltage was plotted as shown in Figure 4.6.
The python script can be found on **Appendix D**.

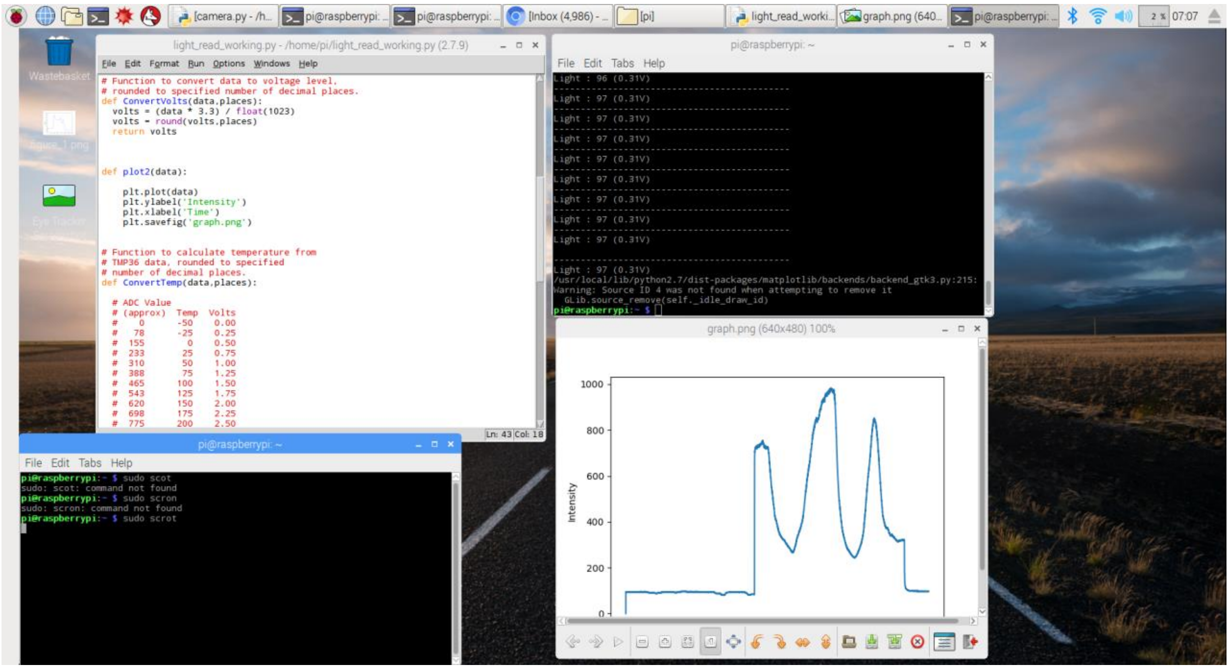

Figure 4.6 – Python script for ADC running on RPi, Graph of test run data is shown

Conclusion: The ADC worked as expected. Using a reference voltage of 5 V and an 8-bit resolution, the ADC could read accurate data when shined with light of various intensity levels. When the resistor was completely exposed to light, the resulting digital value was 999 ADU (analog-to-digital units) as seen in Figure 4.6. When the resistor had no exposure to light, the digital value was close to 88 ADU. Based on these results, the ADC works as intended for the analog EEG signal. The figure shows the code, the Python script running, and the resulting graph from the digital data obtained during the test video below.

Video of test in **Appendix E**.

8.1.1 Experiment results for eye tracking with Raspberry Pi Camera

All team members were responsible for this part.

Test of eye tracking with RPi Camera.

Results: The eye tracker was tested using the RPi Camera module. A team members was used as a subject in this test. The camera was pointed at the subject, and when he closed his eyes for more than 3 seconds, the python script responded by enabling the alarm system. The alarm was triggered approximately 0.54 ms after the system determined the subject to be sleeping. The alarm continued to make a sound until the subject opened his eyes again. This test shows the feasibility of using the RPi camera module to work in eye tracking. This is shown in figure 4.7.

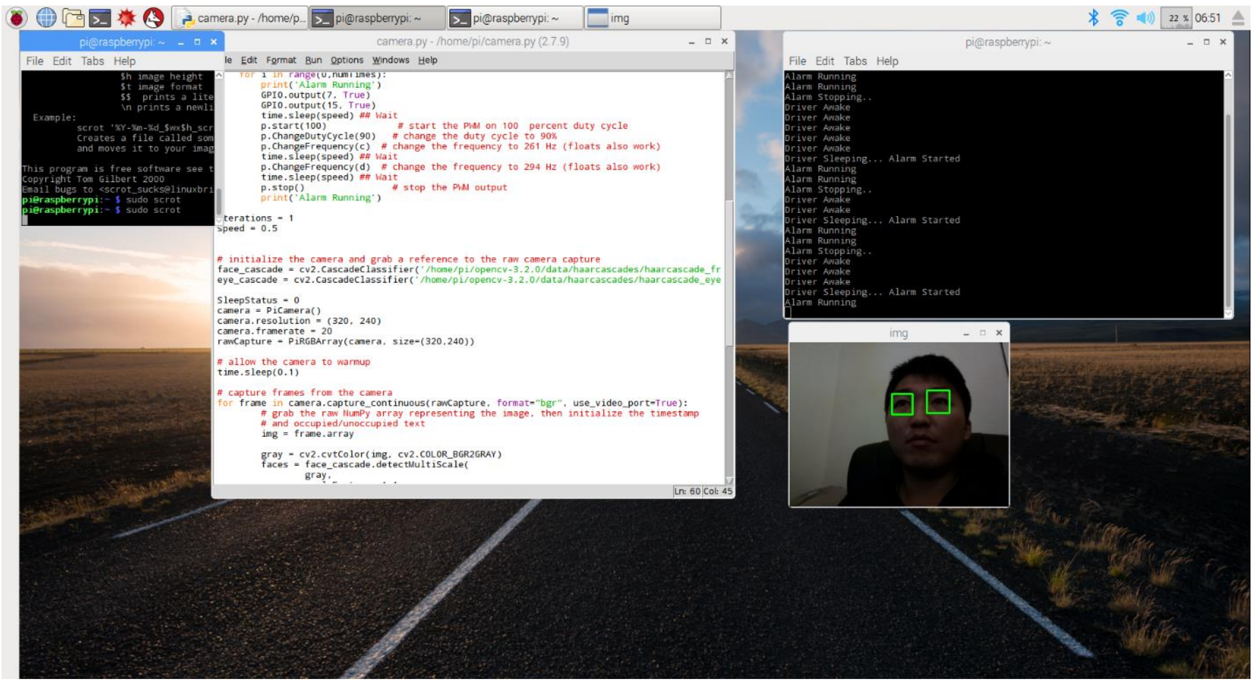

Figure 4.7 – Python script for eye tracker camera running on RPi. Picture shows subject with eye tracker markers on his eyes.

Video of test in **Appendix E**.

8.1.1 Experiment results for eye tracker glasses

All team members were responsible for this part.

Test of Eye-tracker glasses.

Results: Figure 4.8 shows that the eye-tracker camera worked as expected and accurately tracking eye movement. The Raspberry Pi 3 was used to stream the camera feed from the glasses to the computer.

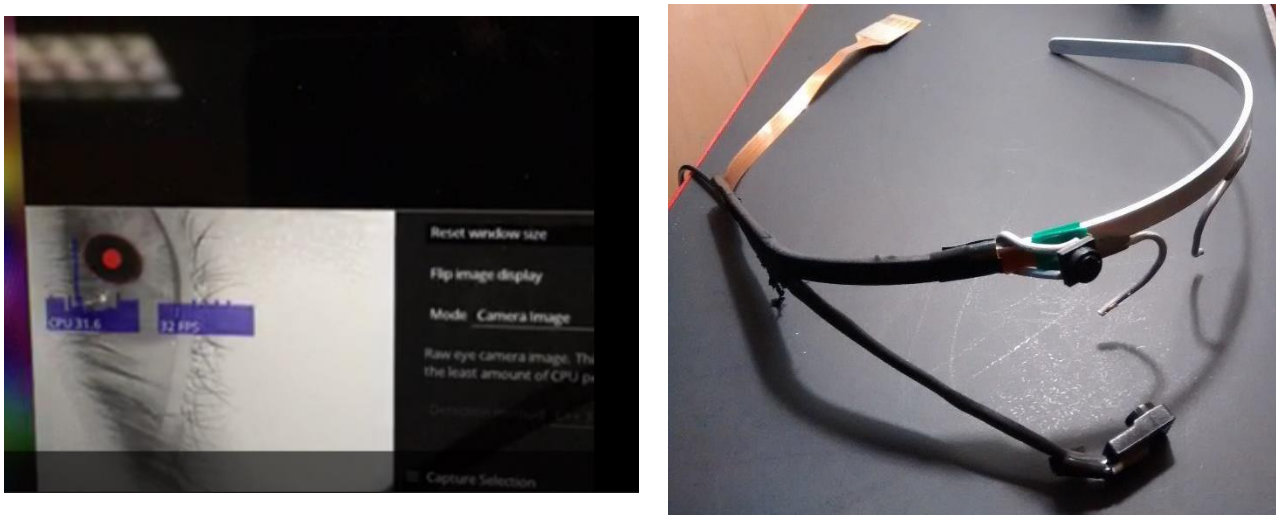

Figure 4.8 – Eye-tracker real-time streaming using Raspberry Pi. The pupil is being tracked by the software. The eye tracker glasses on the right.

Conclusion: Due to instability of wi-fi connection, and the limitation of processing power using Raspberry Pi. The real-time streaming had a few seconds of delay. The next step was to implement eye detection algorithm that detected whether the driver's eye were open or closed. However, there were many problems with the pupil software. The software would crash unexpectedly and was not stable enough to continue testing. Unfortunately, a lot of time in the first quarter was spent attempting to make this work. A decision to move on to the one camera approach was made after this test failed. Overall the eye tracker glasses were not successful in accomplishing the task for this design.

Video of test in **Appendix E**.

8.1.1 Experiment results for EEG data analysis with test data

EEG Signal Analysis

Experimental Result:

Figure 4.9 shows the 1 Hz to 60 Hz Filter magnitude response in decibel with filter order 650.

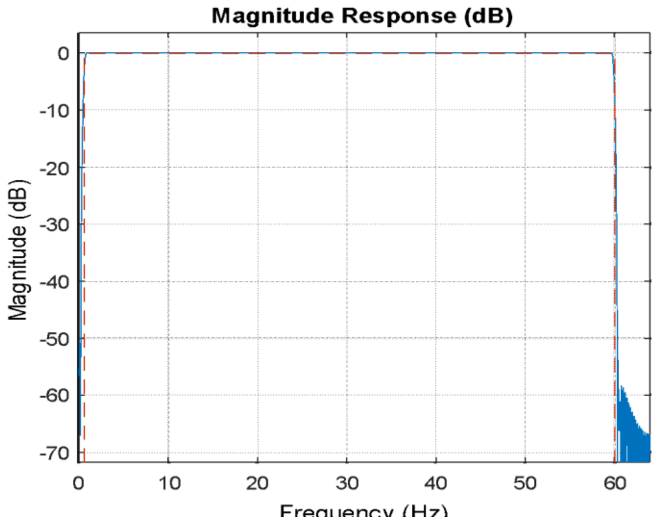

Figure 4.9 – 1 Hz to 60 Hz Band-pass filter

Figure 4.10 shows 0.5 Hz to 3 Hz Filter magnitude response in decibel with filter order 650.

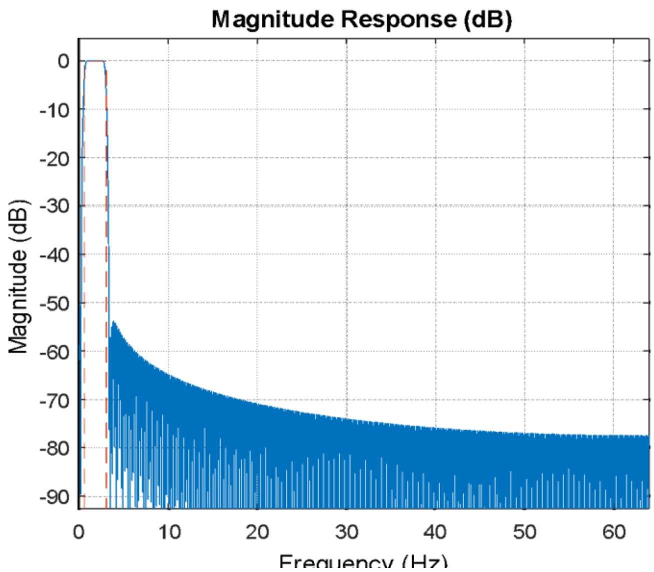

Figure 4.10 – 0.5 Hz to 3 Hz Band-pass filter

Figure 4.11 shows 3 Hz to 8 Hz Filter magnitude response in decibel with filter order 650.

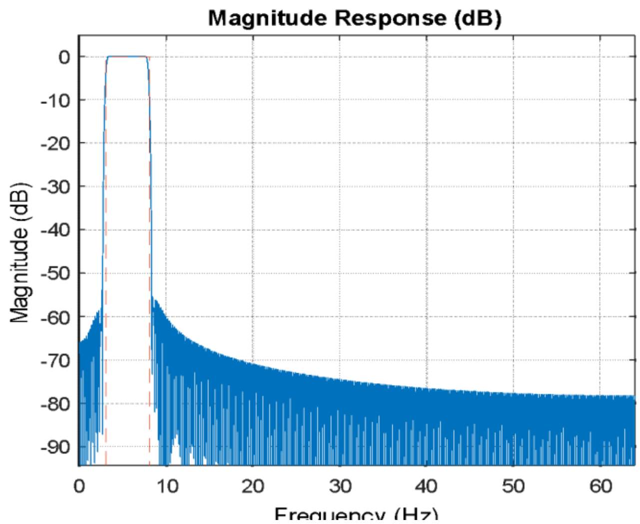

Figure 4.11 – 3 Hz to 8 Hz Band-pass filter

Figure 4.12 shows 8 Hz to 12 Hz Filter magnitude response in decibel with filter order 650.

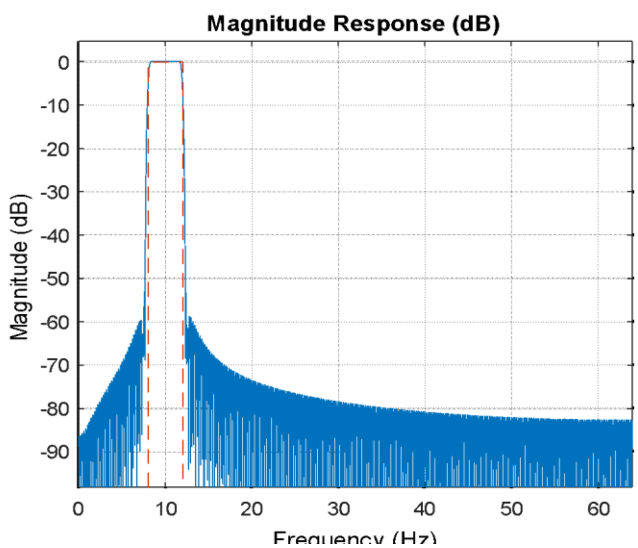

Figure 4.12 – 8 Hz to 12 Hz Band-pass filter

Figure 4.13 shows Original input EEG signals in time domain. Figure 4.14 shows EEG signals between 1 Hz to 60 Hz in time domain. Figure 4.15 shows 0.5 Hz to 3 Hz EEG signals between in time domain. Figure 4.16 shows EEG signals between 3 Hz to 8 Hz in time domain and Figure 4.17 shows EEG signals between 1 Hz to 60 Hz in time domain. The time domain sampling rate of the signals are all 128 Hz recording from EEG.

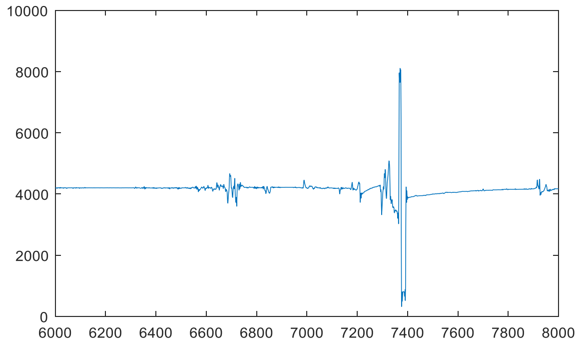

Figure 4.13 – 8 Hz to 12 Hz Band-pass filter

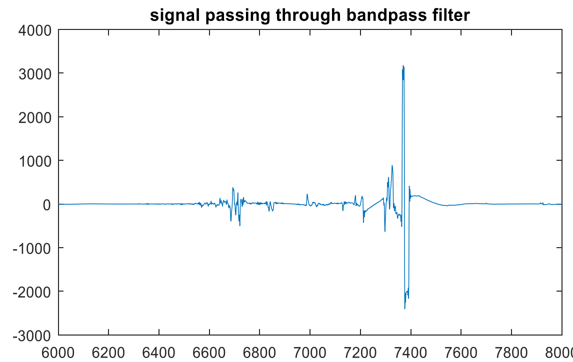

Figure 4.14 – 1 Hz to 60 Hz band-pass

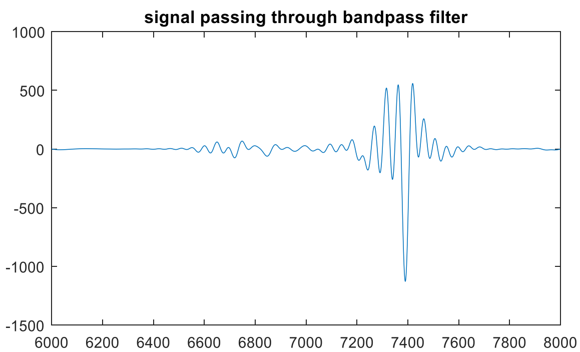

Figure 4.15– 0.5 Hz to 3 Hz Band-pass filter

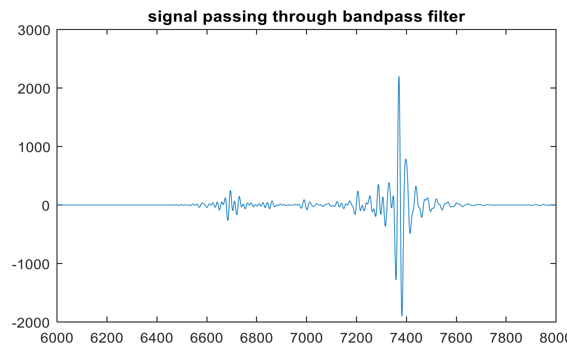

Figure 4.16 – 3 Hz to 8 Hz Band-pass filter

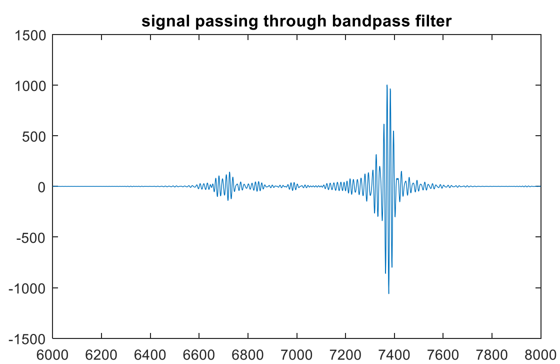

Figure 4.17– 8 Hz to 12 Hz Band-pass filter

FFT of EEG signals:

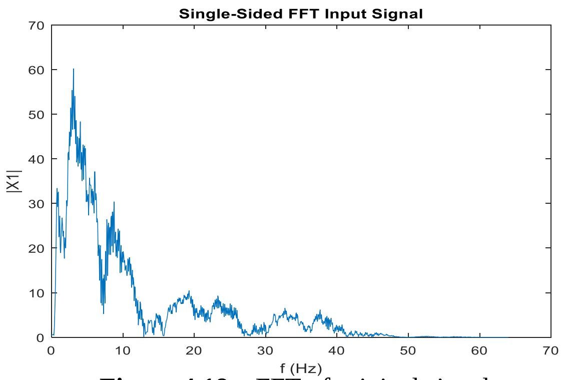

Figure 4.18 – FFT of original signal

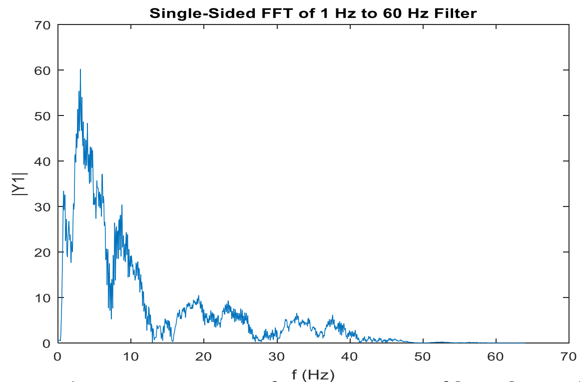

Figure 4.19– FFT of 1 Hz to 60 Hz filtered signal

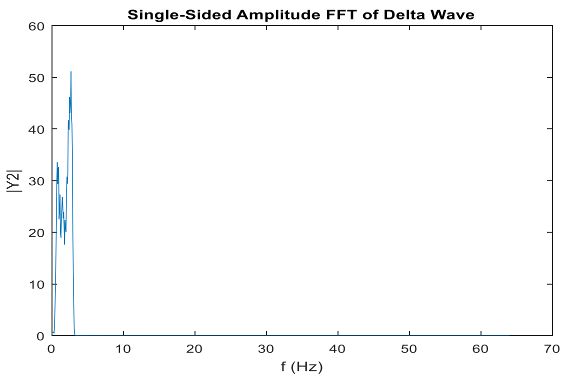

Figure 4.20– FFT of 0.5 Hz to 3 Hz filtered signal

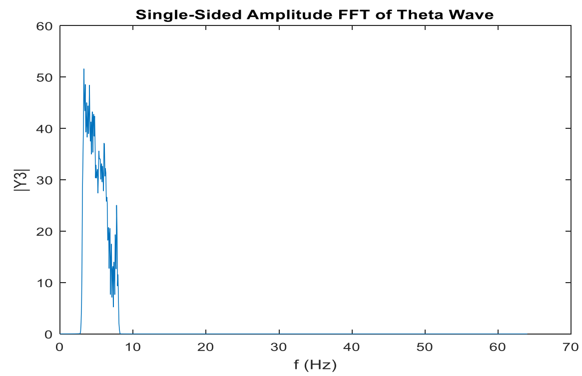

Figure 4.21– FFT of 3 Hz to 8 Hz filtered signal

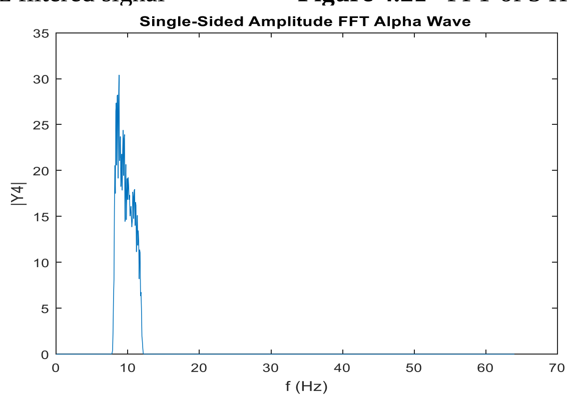

Figure 4.22– FFT of 8 Hz to 12 Hz filtered signal

Analysis and Conclusion:

By comparing Figures 4.18-22, which is frequency domain analysis of output with input EEG signals, noise has been removed by band-pass filter and the designed band-pass filters worked as expected. Delta Wave, Theta Wave as well as Alpha Wave were easily extracted through filtering. However, this analysis was done using MALAB. The 1-60 Hz filter was implemented using hard ware and other band-pass filters. These are also implemented using Python on Raspberry Pi.

5 Architecture and High Level Design

The architecture provides the top-level design view of a system and a basis for more detailed design work.

5.1 System Architecture and Design

The feedback loop architecture of the SDS is shown in Figure 5.1. This figure also shows the basic working principle of the Safe Driving System. In part 1, data is acquired via EEG and camera monitoring of the driver. That data is send to the analysis computer in part 2. That data is analyzed through software inside the computer on part 3. The software detects the state of the driver, how long eyes have remained close or EEG data related to sleep. If sleep patterns are detected in the analysis, a signal is send to part 4. The alarm system in part 4 uses sound to alert the driver. In part 5 the driver is alerted. After the driver physically re-sets the alarm, the system returns to part 1.

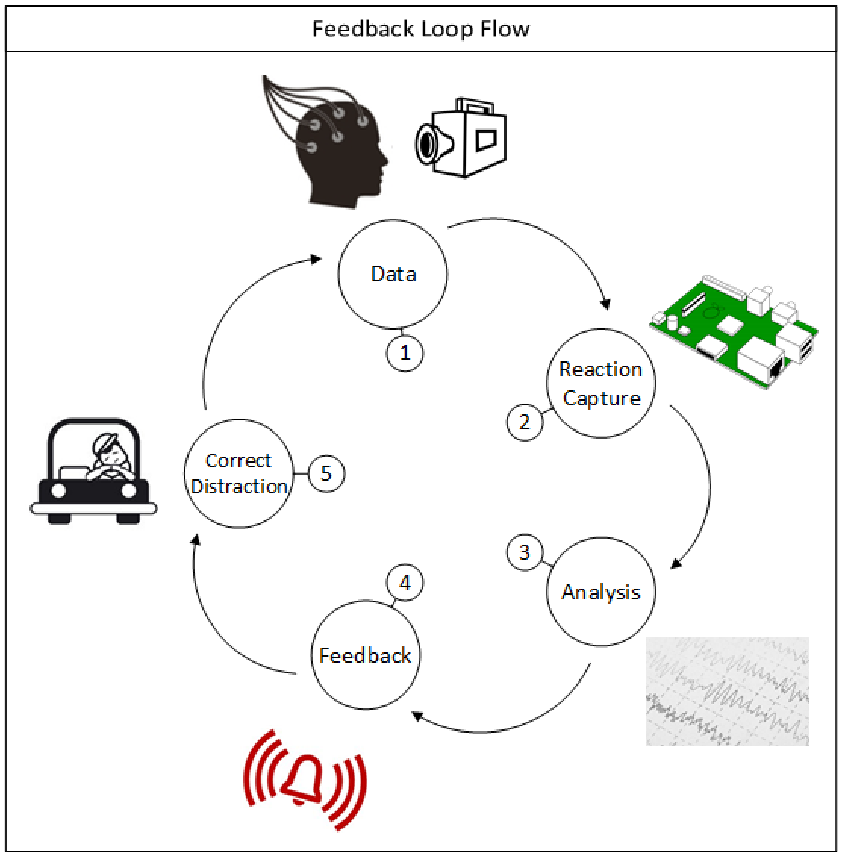

Figure 5.1 – The system loop.

Division of Responsibilities:

Alberto Arriaga Felix oversaw the EEG system and analysis computer:

1. Research Electrodes and find a portable electrode system that is lightweight and simple to use.
2. Design and test an analog amplifier system used to acquire the EEG signal from the electrodes and send it to the digital system.
3. Find a way to convert the analog electrode signal into a digital signal that can be analyzed on the computer.

Kai Wen oversaw signal analysis and EEG circuit.

4. Research human brain wave frequencies and sleep patterns in EEG signals.
5. Design band-pass filters for Delta, Theta and Alpha EEG waves. Used frequency domain analysis on EEG signals.
6. Worked on eye-tracker with both front and back cameras and how to work with Pupil and Lab Streaming Layer software on Mac OS computer.
7. Designed 16-bit mux circuit with Arduino for EEG device.

Andrew Kwon oversaw the eye tracking system.

- Configure and install RaspberryPi dependencies to work with RaspCam V2. Installed OpenCV and used some functions to detect faces.
- Applied Haar Cascade to video frames to locate and box out the driver's eyes.
- Created infrared led system for camera's night vision.
- Studied Machine learning for classification of eyes and face used in eye tracking component.

5.2 Hardware Architecture

The system block diagram is shown in Figure 5.2. This figure shows the interaction of the different modules in the Safe Driving System. The physical system connections are shown in Figure 5.3.

The modules of the Safe Driving System are:

1. Module 1a - EEG ear electrodes.
2. Module 1b - eye tracking camera.
3. Module 2a - EEG signal amplifier.
4. Module 2b - analog to digital converter.
5. Module 3 - analysis computer.
6. Module 4 - alarm system.

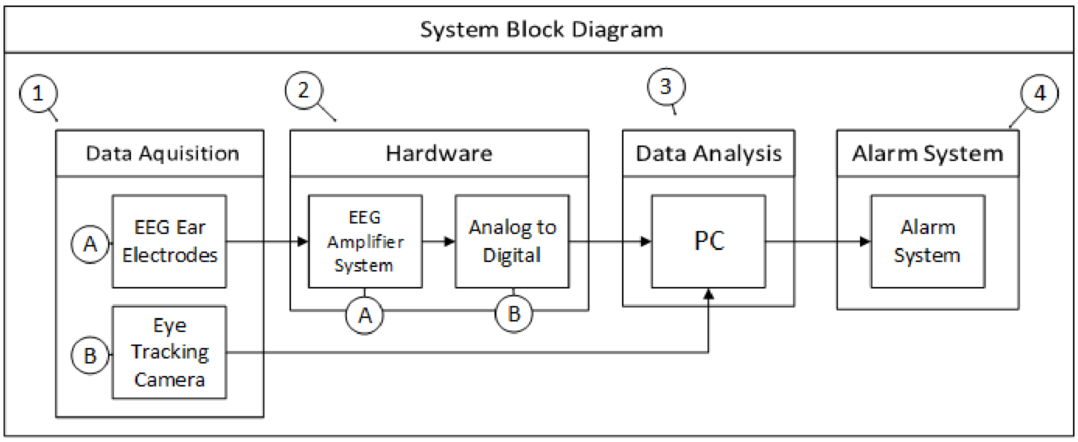

Figure 5.2 – The block diagram of the entire SDS.

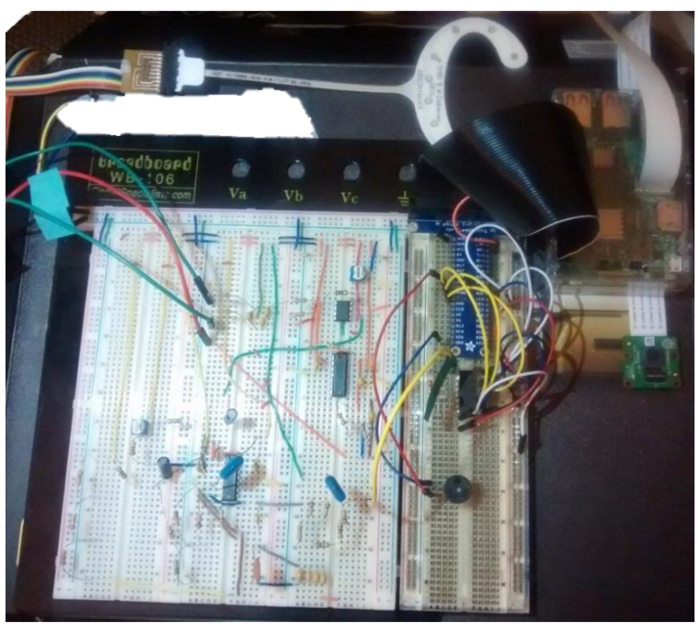

Figure 5.3 – The SDS physical hardware, pictured as connected during operation.

Description of system modules:

1. Module 1a – Figure 5.4
   The EEG electrodes cEEgrids attach to the driver around the ears and provides EEG signals to the EEG amplifier in Module 2a.

2. Module 1b – Figure 5.4
   The eye tracker camera monitors the eyes of the driver and connects to the analysis computer in Module 3.

3. Module 2a – Figure 5.5
   The EEG amplifier circuit takes an input signal from EEG electrodes. The output signal from this module is an analog signal that is send to the analog to digital converter in Module 2b.

4. Module 2b – Figure 5.5
   The analog to digital converter chip takes the analog signal from the amplifier as input. This module converts the analog signal into a digital signal. The output of this module is send to the analysis computer in Module 3.

5. Module 3 – Figure 5.5
   The main analysis computer is a Raspberry Pi 3. It links the ADC of Module 2b, the Eye tracker of Module 1b, and Alarm system of Module 4.

6. Module 4 – Figure 5.6
   The alarm system is a speaker that is connected to the RPi via the GPIO pins. It is activated by a signal from Module 3.

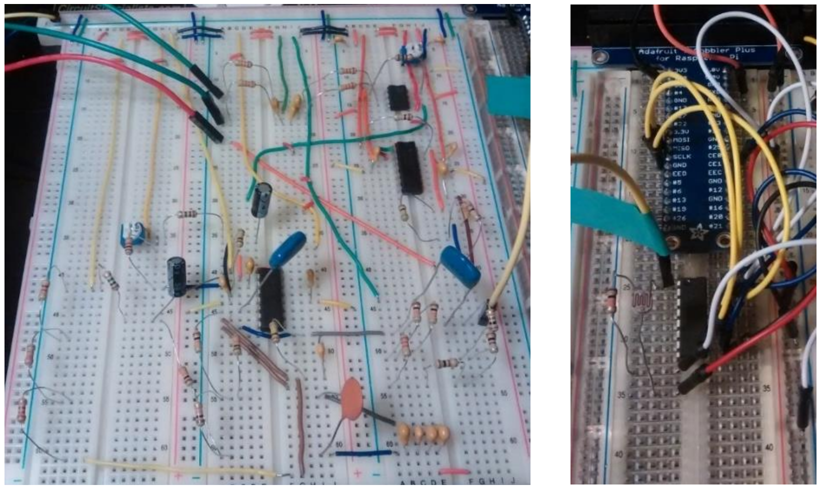

Figure 5.4 – The EEG amplifier in the left image (Module 2a), and the ADC in the right image (Module 2b).

Figure 5.5 – Analysis Computer in left image (Module 3), below that in the same image is the eye tracker camera (Module 1b). The EEG electrodes shown in image below (Module 1a).

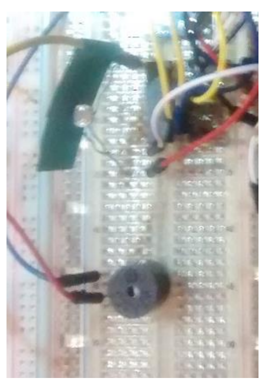

Figure 5.6 – Alarm system (Module 4).

5.3 Software Architecture

Andrew Kwon was responsible for this part.

The diagram in Figure 5.7 shows the top-level design of the eye tracker software. The steps are described below:

- **Import libraries –** This allows OpenCV cascade to be used by the script.
- **Face detection –** This is completed using a Haar Casacde technique to detect the face of driver.
- **Eye detection –** The eye tracking begins.
- **Decision –** The system is monitoring the eyes of the driver. If eyes are closed for over 3 seconds, a signal is send to the alarm system.

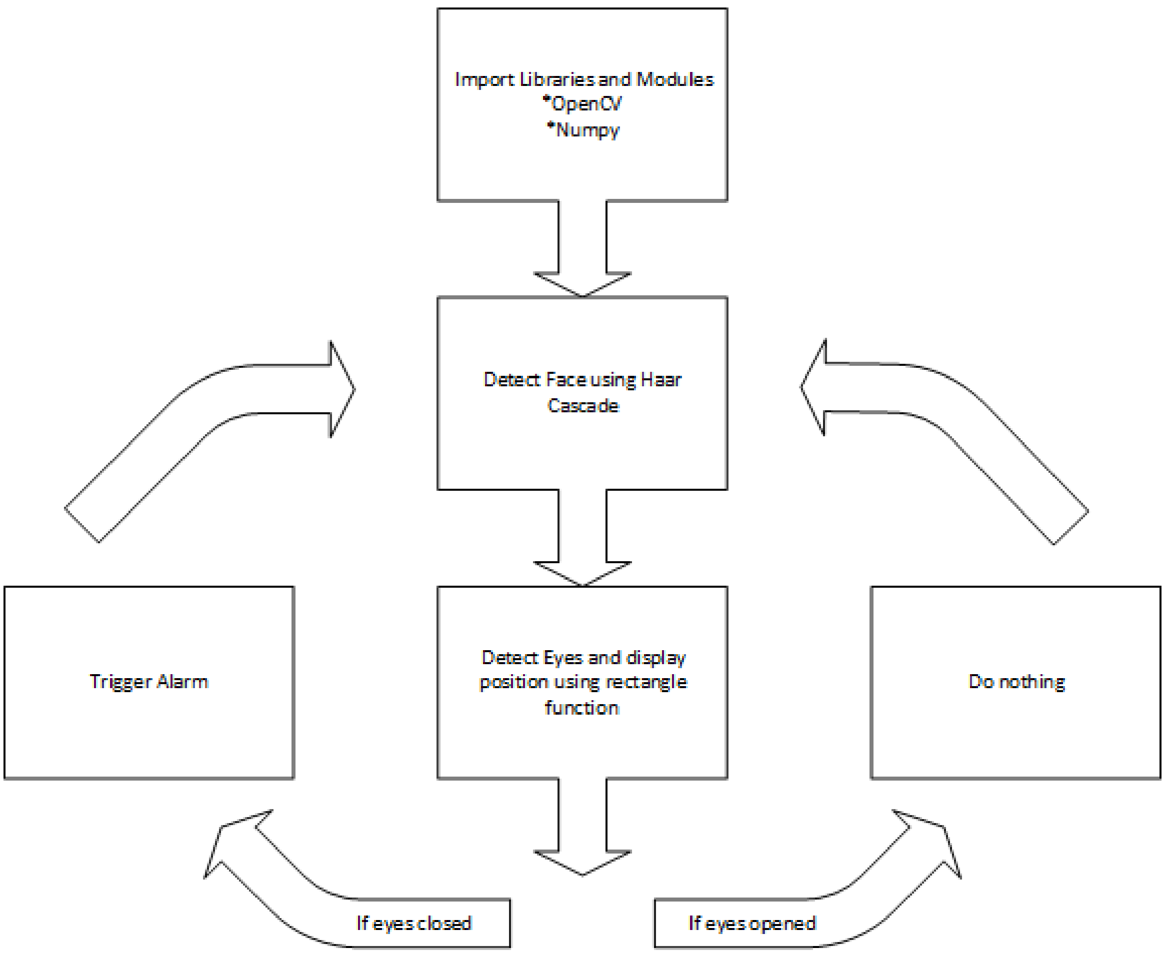

Figure 5.7 – Top level eye detection software diagram.

The diagram in Figure 5.8 shows the top-level design of the ADC software. The steps are described below:

4 **SPI** – The SPI protocol is initialized on analysis computer. This allows communication to ADC chip.

5 **Read data –** Begin reading analog signal from ADC.

6 **Convert data –** The analog signal is compared to a reference voltage with 10-bit precision and converted to digital data that is stored on analysis computer.

7 **Cycle is repeated**.

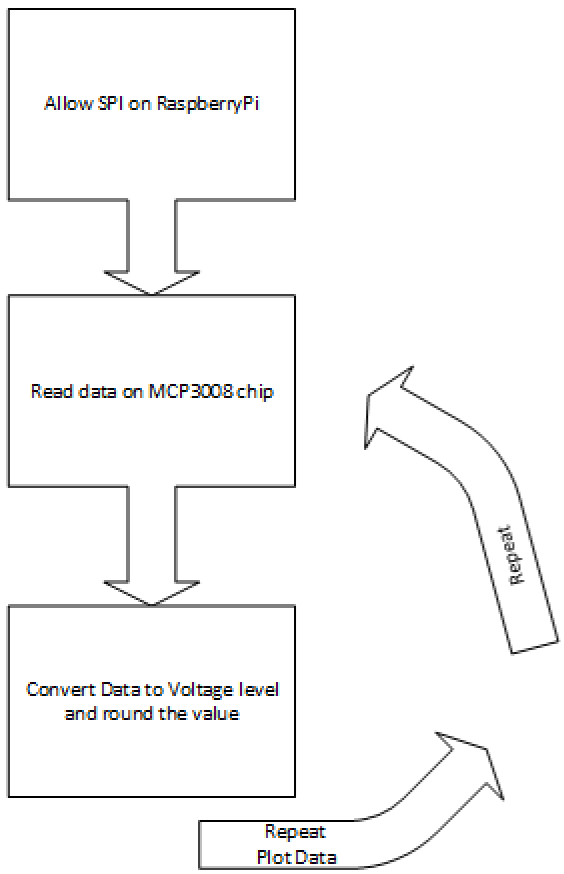

Figure 5.8 – Top level ADC software diagram.

5.4 Rationale and Alternatives

Alberto Arriaga Felix was responsible for this part.

EEG System alternatives:

For the EEG system, cap systems that use various types of EEG electrodes were considered. The most used electrodes in EEG systems are silver-chloride electrodes, that are placed inside a cap systems that is worn over the entire head. The major drawback is that these electrodes require the application of a conductive gel, that bridges the gap between the electrode and the skin of the subject. Figure 5.9 shows a picture of this type of system.

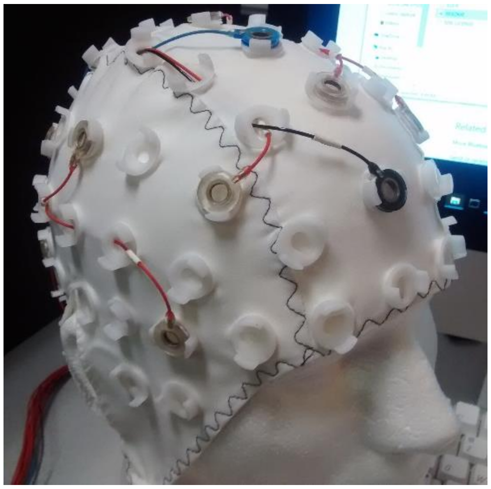

Figure 5.9 – EEG headset with electrodes example.

Ultimately, this type of EEG electrode system was not considered because it would be too expensive to build. Each individual electrode would be around $10, and 10 of them are required. Another reason for rejecting this design was because the set-up time for this type of cap is about 20-30 minutes, which is too long for the system's purpose.

The team also considered dry electrode of the type in Figure 5.10. This type of electrode did not meet the specifications because of its price. They are also cumbersome for someone to wear while driving, and can fall off and lose signal if they are not secured tightly against the skin.

Figure 5.10 – Dry Electrodes example.

Andrew Kwon was responsible for this part.

Eye tracker Alternatives:

Initially the eye tracker design would use two cameras. One camera to monitor the pupil and another to monitor the environment in front of driver. Through calibration and image processing techniques a mapping correlating pupil movements could be displayed on the outer surrounding view. The team tested the eye tracker glasses as shown in Figure 5.11, that are made by a company called Pupil Labs. However, due to the team's limited knowledge in Python and the complicated internal systems of the device. The team was unable to get pupil tracking working with the two cameras.

Figure 5.11 – Eye tracker glasses examples.

6 Data Structures

Not Used

7 Low Level Design

This section describes the Low-Level design of all the modules in the Safe Driving System.

7.1 Module 1a – The EEG Electrodes

Alberto Arriaga Felix and **Kai Wen** were responsible for this module.

The EEG electrodes are the cEEgrids v3, which are shown in Figure 7.1. These electrodes are placed around the ear with an adhesive as shown in Figure 7.2. They have 10 channel sensors, and are flex printed on a thin plastic which makes them light weight and unobtrusive. They use silver ink for the conductive parts that attach to the skin, thewiring, and the connectors to reduce impedance. These electrodes are preferable for the SDS because they pick up EEG Alpha signals related to eye movements from the Occipital lobe at the back of the head.

Figure 7.1 – Left - cEEgrids v3 ear EEG electrodes front and back.

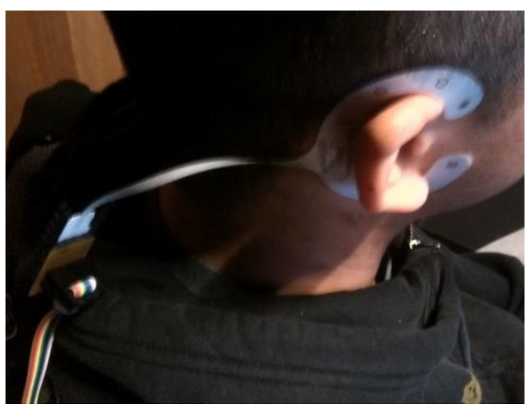

Figure 7.2 – Electrodes connected to team member.

These are experimental electrodes not available commercially, they were obtained through the Psychology Department at UCR. The team designed and build the connectors for them using Printed Circuit Board (PCB) design. There are two types of connectors.

1. Type 1 connects the cEEgrids electrodes to a ribbon cable, shown in Figure 7.3.
2. Type 2 connects the ribbon cable to jumper cables, shown in Figure 7.4.

The connector cables have the following components:

1. The Type 1 Connector uses a SAMTEC (MB1-120-01-L-S-01-SL-N) mini edge card socket soldered to the PCB.
2. Two 10-wire ribbon cables, part no. HFR-28R3HF.
3. Two 2x5 Pin Shrouded Headers, part no. PRT-08506. Soldered on PCB.
4. Two 2x5 Pin Female Crimp Connectors, part no. PRT-10650.
5. Twenty F/F 6” Jumper Wires 20 AWG, part no. PRT-11710

Both PCBs for the connectors shown in Figure 7.5 were designed using DesignSpark PCB 7.2 software, and manufactured using a PCB Prototyping Machine available at the EE Shop on campus.

Video of PCB manufacturing in **Appendix E**.
The files for this PCB are included in **Appendix D**.

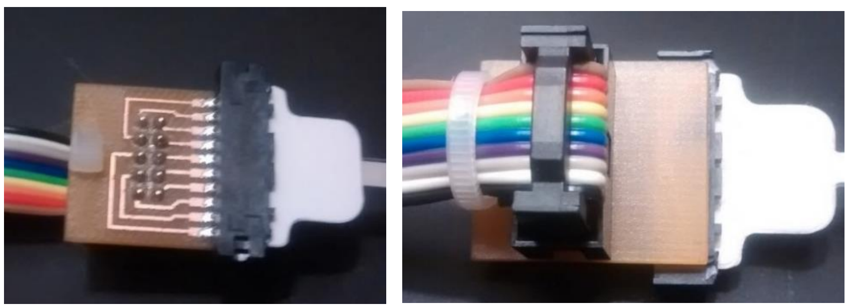

Figure 7.3 – Type 1 connector, electrode to ribbon cable

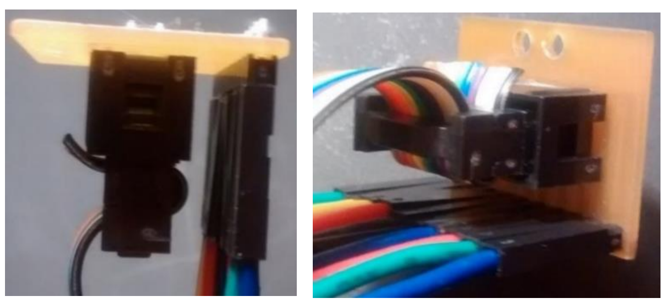

Figure 7.4– Type 2 connector

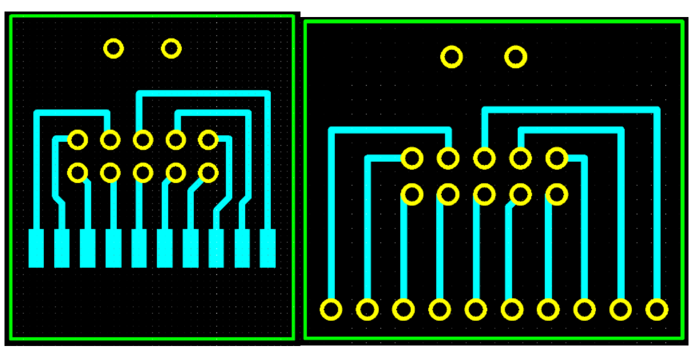

Figure 7.5 – PCB designs.

8.1.1 Module 1a Processing Narrative – the EEG Electrodes

The cEEGrid electrodes are passive electrodes. This means they have no inbuilt circuitry, and are always ON. Each electrode contact sends a signal through the 10-channel ribbon cable, when it is attached to the skin around the ear.

8.1.1 Module 1a Interface Description – the EEG Electrodes

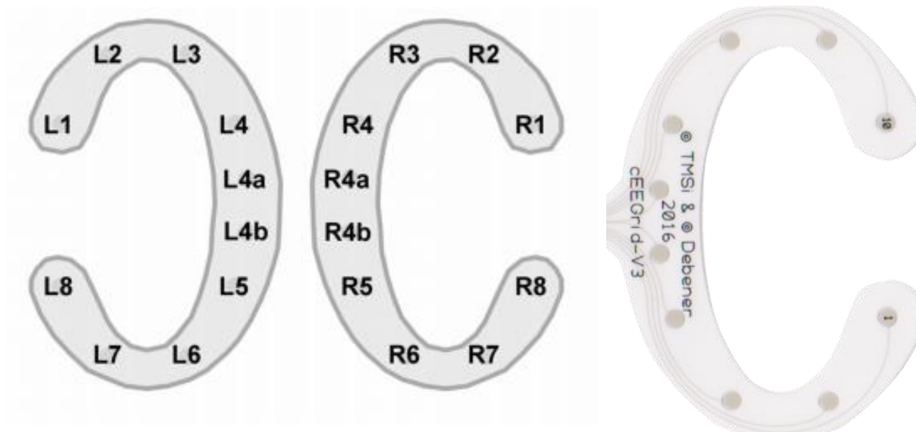

Figure 7.6– Electrode Channels.

Each cEEGrid consists of 10 electrodes as shown in Figure 7.6. Electrodes R1-R4 and R5-R8 measure the voltage between the respective electrode and a reference electrode. Electrode R4b is designated as the reference electrode (REF/CMS). Electrode R4a is the ground electrode (DRL/GND). All electrodes send a signal from the subject to the EEG amplifier. Except for the Driven Right Leg (DRL) electrode, which receives a signal from the EEG amplifier directed to the subject.

The brain activity region that is monitored by the electrodes is shown in Figure 7.7. From this monitoring position, the electrodes sense signals from the Occipital lobe, which produces Alpha waves in the range of 8-12 Hz. These waves are produced by the brain just before sleep or when the eyes are closed in a wakeful relaxed state. The eye activity of the driver is determined by measuring the intensity of the Alpha waves.

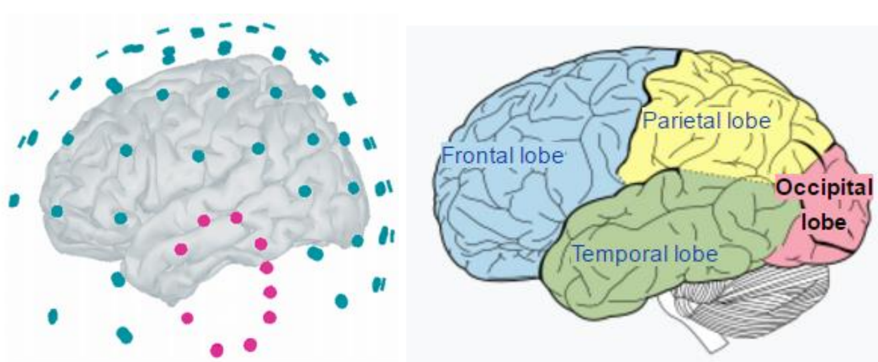

Figure 7.7– Left – Region of brain monitored by Electrodes.

Right – Lobes of the human brain. Occipital lobe shown in red.

The front of the brain points towards the left.

7.2 Module 1b – The Eye Tracker Camera

Andrew Kwon was responsible for this module.

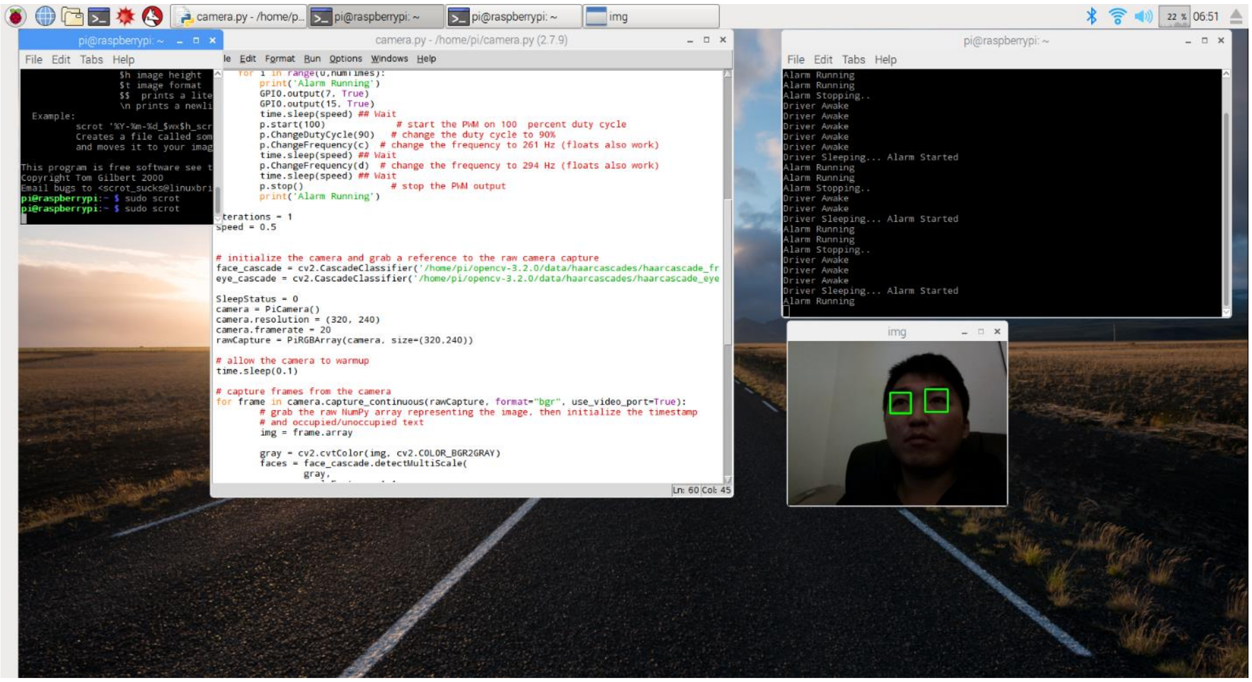

Figure 7.8 – The eyetracker software working in RPi

The techniques used for eye detection were based on the Haar Cascade classifier. This technique is quite easy to use because it can recognize virtually any object. For this project, it is desired to monitor the drivers face and eyes and detect if the subject's eyes are closed for a long period of time. Detecting the driver's eyes using the Raspberry Pi Camera is shown in Figure 7.8.

8.1.1 Module 1b Processing Narrative – the Eye Tracker Camera

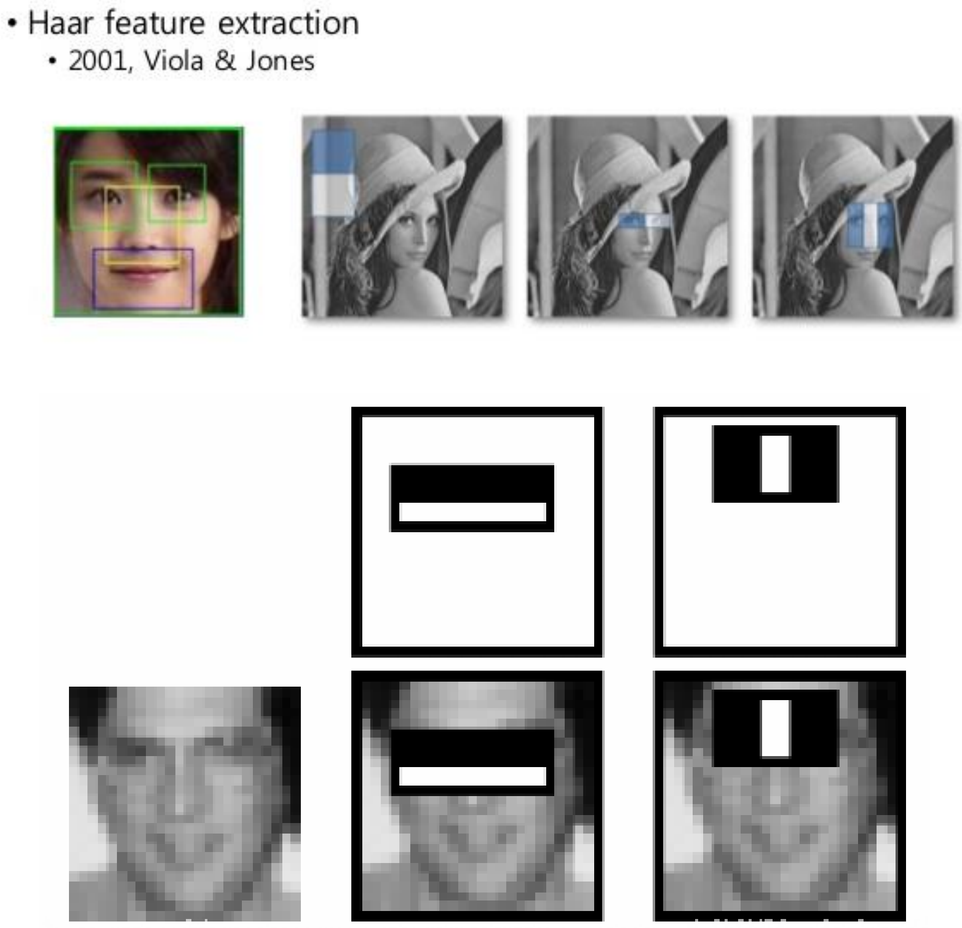

Figure 7.9– Haar Cascade Classifier

The Haar Cascade technique works by training the computer to put together thousands of positive and negative images and taking a least squared error approximation. Intel's face and eye classifier are robust and can detect the face and eyes from far and close distances. The sampling rate is at 20 frames a second although the video feed obtained has some lag. Sleep detection is recognized within 500 milliseconds. If the eyes of the driver remain sleepy or drowsy the alarm continues to ring until the driver is awake through the opening of his/her eyes.

8.1.1 Module 1b Interface Description – the Eye Tracker Camera

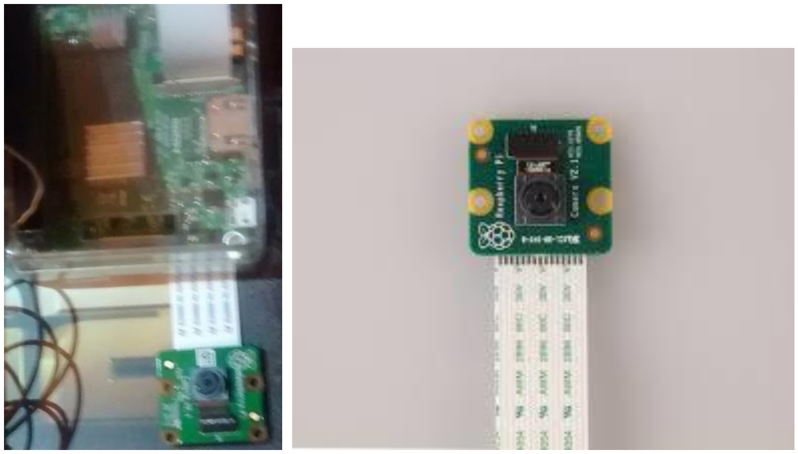

Figure 7.10 – Camera Connection on left, Camera module below

The camera module connects to the RPi via a ribbon cable to the Camera Serial Interface (CSI) connector on the RPi main board as shown if Figure 7.10. The pin layout is according to Table 7.1.

To setup the camera to be recognized by the RPi:

- Ensure camera is connected with a ribbon cable to CSI port.
- Enable Camera in Raspberry Pi Configuration → Interfaces→ Camera → Enable

Table 7.1 – CSI Port pin configuration.

S5 Pin	Name	Purpose	S5 Pin	Name	Purpose
1	Ground	Ground	9	CAM1_CP	
2	CAM1_DN0	Data Lane 0	10	Ground	Ground
3	CAM1_DP0		11	CAM_GPIO	
4	Ground	Ground	12	CAM_CLK	
5	CAM1_DN1	Data Lane 1	13	SCL0	I²C Bus
6	CAM1_DP1		14	SDA0	
7	Ground	Ground	15	+3.3 V	Power Supply
8	CAM1_CN	MIPI Clock			

8.1.1 Module 1b Processing Details – the Eye Tracker Camera

All the processing for the eye tracker camera is controlled Python script 'camera.py'. The logic flow of the python script is shown in Figure 7.11.

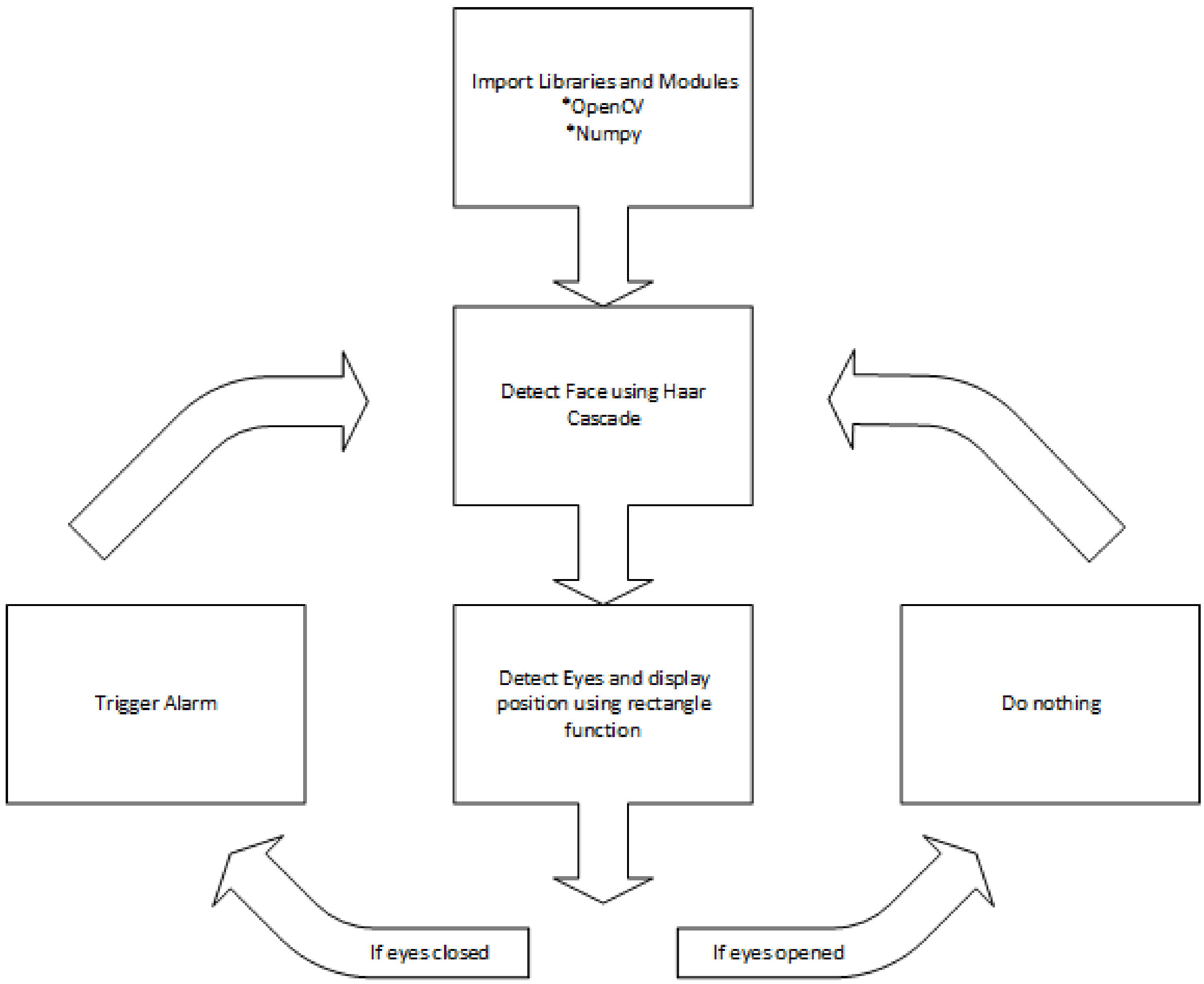

Figure 7.11 – Eye Tracker Code Flow

The code flow is shown in Figure 7.2.3, the code to run the Camera Eye detection is in **Appendix D,** titled camera.py.

7.3 Module 2a – The EEG Amplifier

Alberto Arriaga Felix was responsible for this module.

The EEG amplifier bridges the connection between the EEG electrodes and the ADC device. The EEG amplifier circuit is composed of 5 different sections:

- Protection Circuit, Figure 7.12.
- Electrode Comparison Stage, Figure 7.12.
- Right Leg Driver Circuit (DRL), Figure 7.14.
- Signal Amplifying Circuit, Figure 7.3.4.
- Filter Network, Figure 7.3.5.

8.1.1 Module 2a Processing Narrative – the EEG Amplifier

A description of each part of the EEG amplifier:

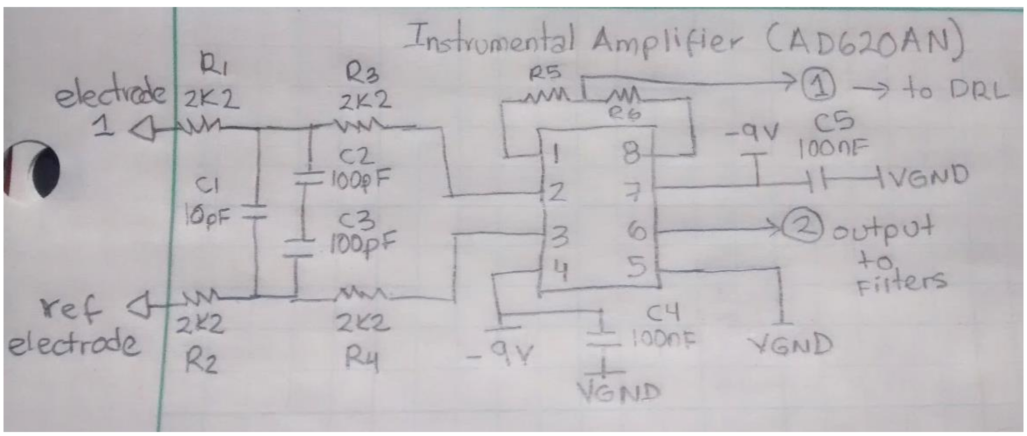

Figure 7.12 – Instrumentation Amplifier AD620AN chip pin configuration.

Protection circuit:

The first part of the circuit as shown in figure 7.12. The EEG electrodes connect here, electrode 1 and a reference electrode both selected from the cEEGrid. The capacitor and resistor network that follows is used to suppress radio frequency signals entering the system via the ribbon cable connected to the electrodes. This network also limits the current coming from the user to the circuit.

Electrode Comparison Stage:

The instrumentation amplifier AD620AN shown in figure 7.12 is the first amplification stage. It reads and EEG signal by measuring the voltage difference between the two electrodes. The output at node 2 is the voltage difference between electrode 1 and reference electrode. This stage also lowers the impedance, which makes the rest of the circuit less sensitive to noise. The gain of the instrumental amplifier is set by the resistors R5 and R6, according to Eq. 1. In between R5 and R6 at node 1 is where the common mode voltage is measured. The signal from this junction is passed to the DRL circuit in figure 7.14.

$$\text{Gain1} = (4.49\ \text{k}\Omega)/(R5+56) + 1 \qquad \textbf{(Eq. 1)}$$

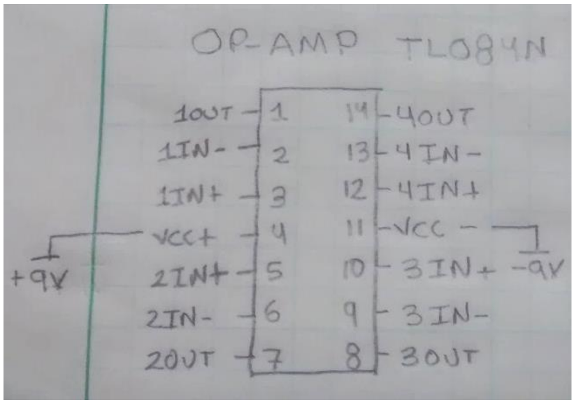

Figure 7.13 – TL084 Operational Amplifier chip pin configuration.

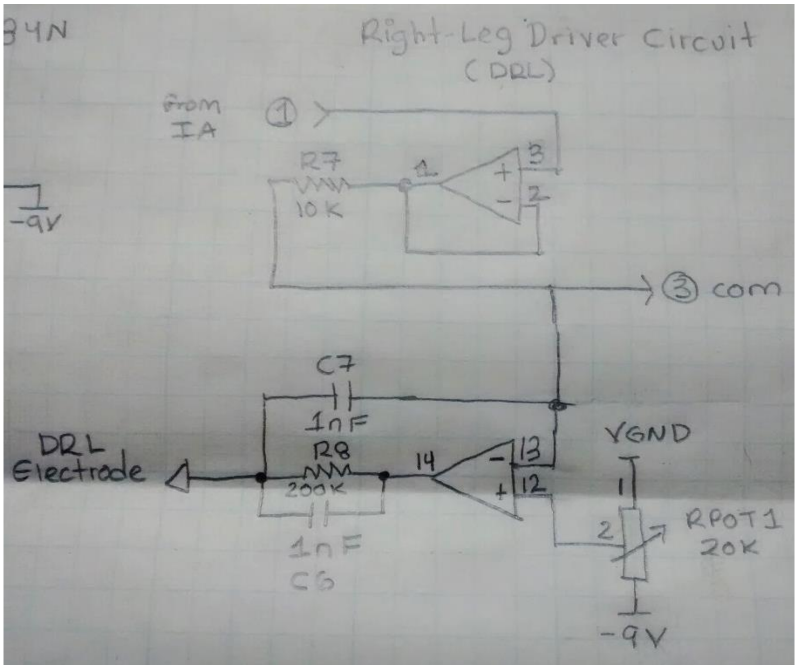

Figure 7.14 – Right Leg Driver Circuit (DRL).

Right Leg Driver:

The Right Leg Driver (DRL) receives a common mode voltage signal from node 1 and sends a signal back to the DRL electrode. The need for this circuit exists because the user's body can act as an antenna, and picks up electromagnetic interference from the environment through the skin. This interference in the 50/60 Hz range can make it difficult to detect small signals from the skin, such as EEG signals. The purpose of this circuit is to reduce or eliminate that interference, also called common-mode interference, that is noise in the 50/60 Hz range. The DRL inverts and amplifies the average common mode signal back into the patient's skin. This action cancels the 50/60hz noise, and brings out a cleaner EEG output signal.

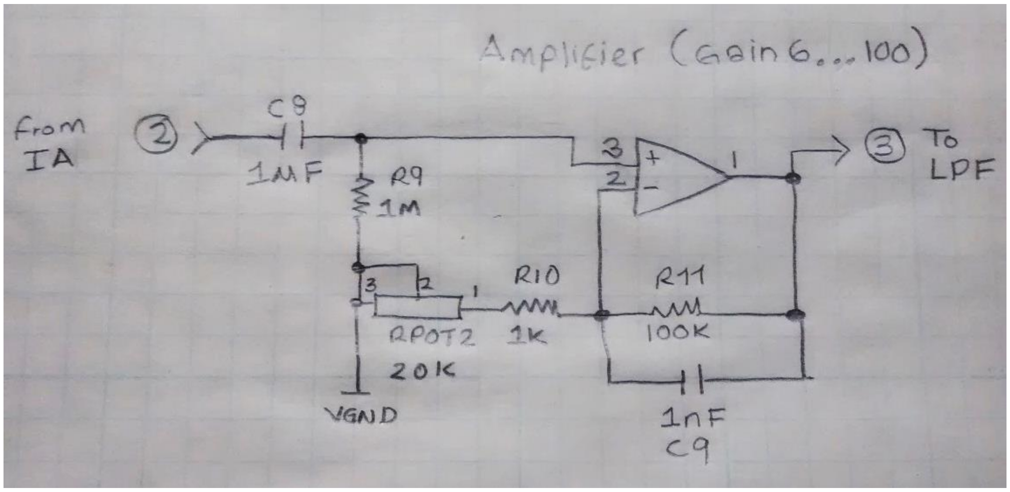

Figure 7.15 – Signal Amplifying Circuit.

Signal Amplifying Circuit:

Right after node 2 is a High-Pass Filter composed of capacitor C8 and resistor R9 as shown in figure 7.15. This filter is designed to remove DC offsets in the incoming signal. The cutoff frequency of this filter is fc = ~0.16Hz.

Following in figure 7.15 is a standard non-inverting amplifier circuit that uses the TL084 Operational Amplifier of figure 7.13. The purpose of this stage is to amplify the signal from node 2 to the output node 3. The gain is determined by Eq.2 and can be set between 6 to 100 with the help of the potentiometer.

$$\text{Gain2} = (\text{Ra} + \text{Rb})/\text{Ra}$$
$$\text{where Ra} = \text{Rpot2} + \text{R10},\ \text{Rb} = \text{R11} \qquad \textbf{(Eq. 2)}$$

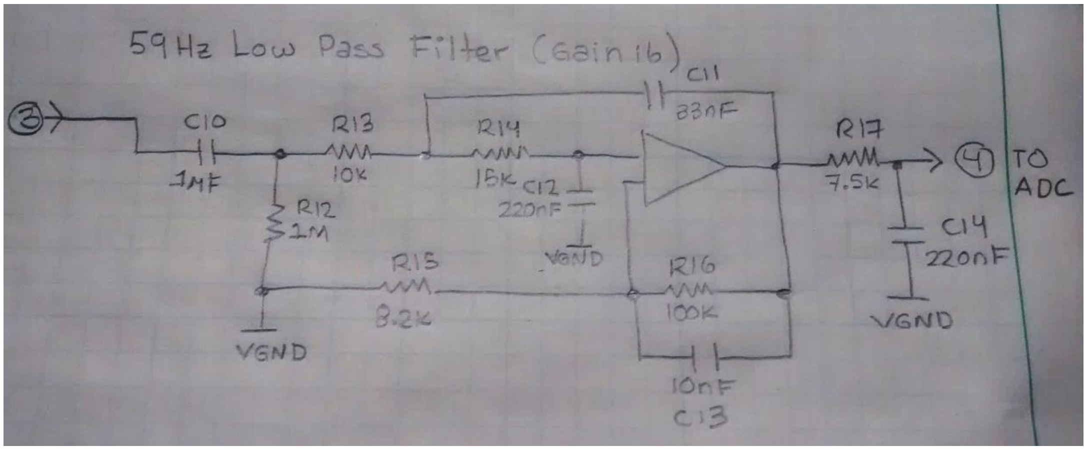

Figure 7.16 – Filter Network.

Filter Network:

At the beginning of this circuit in node 3 is second high-pass filter stage, with C10 and R12 as shown in figure7.16. The rest of the circuit is called a besselworth filter and its purpose is preventing aliasing artifacts in the signal that is sent to the 10-bit analog to digital converter from node 4. Figure 7.17shows the gain of this filter in dB across frequencies.

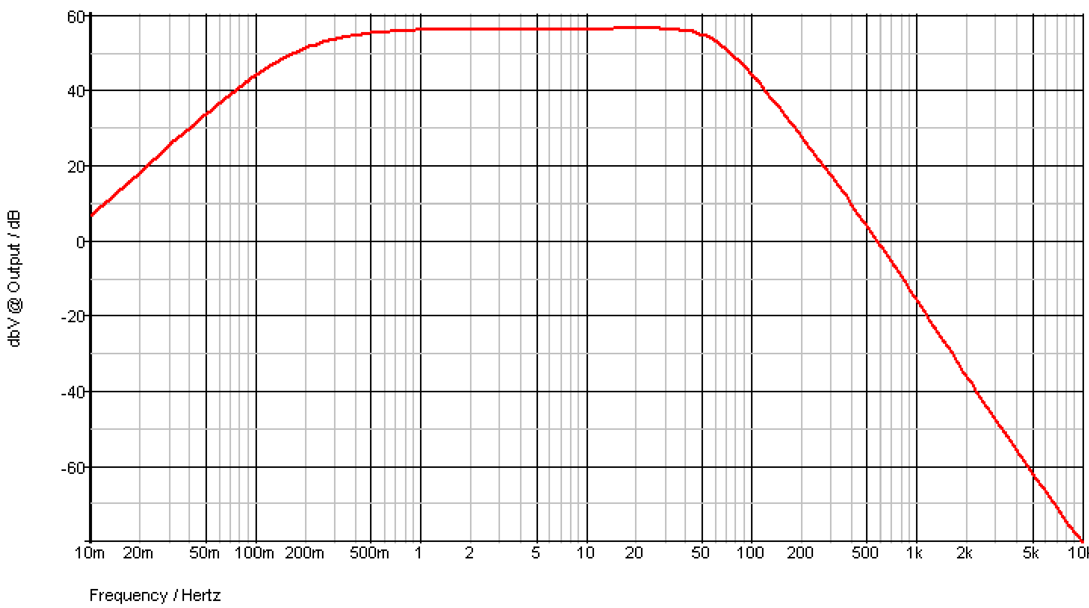

Figure 7.17–Filter Network Gain

8.1.1 Module 2a Interface Description – the EEG Amplifier

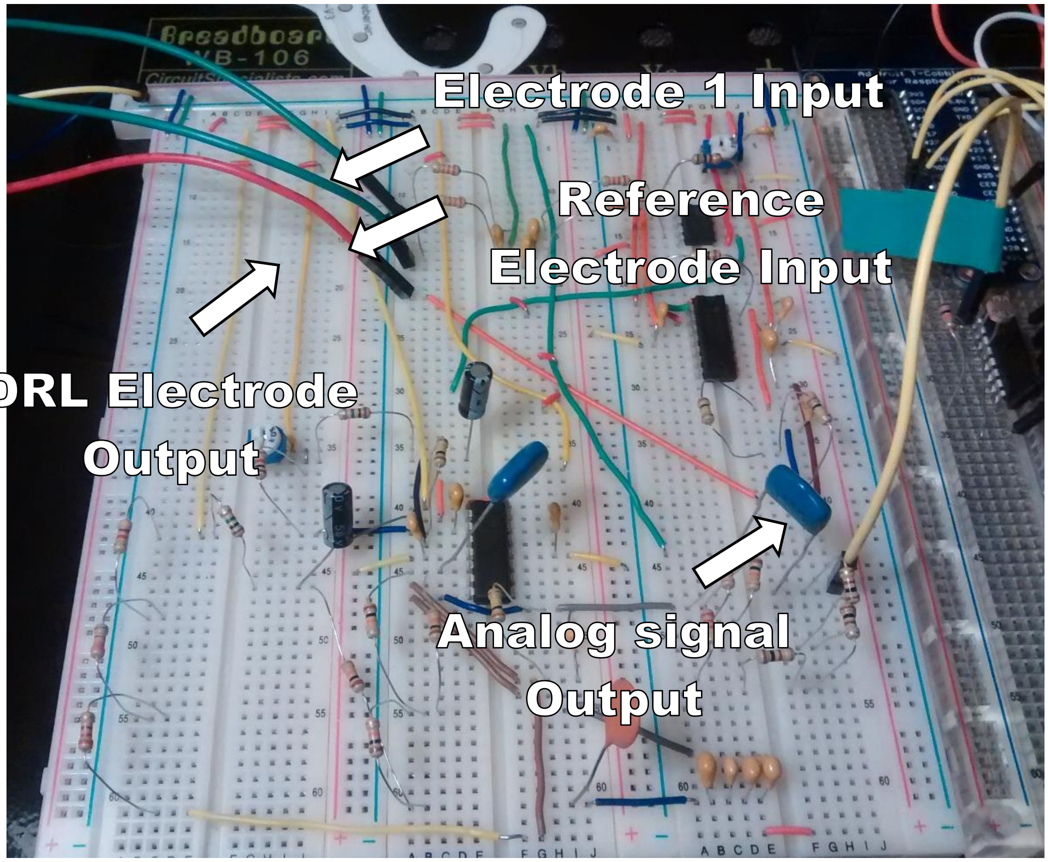

Figure 7.18 – EEG Amplifier
Interface

The physical interface of the amplifier is shown in figure 7.18, and the inputs and outputs of this module are shown in Table 7.2.

Table 7.2 – EEG Amplifier Input/Output Channels	
Input	Output
Electrode 1	DRL Electrode
Reference Electrode	Analog Signal

7.4 Module 2b – The Analog to Digital Converter

Alberto Arriaga Felix and **Andrew Kwon** were responsible for this part.

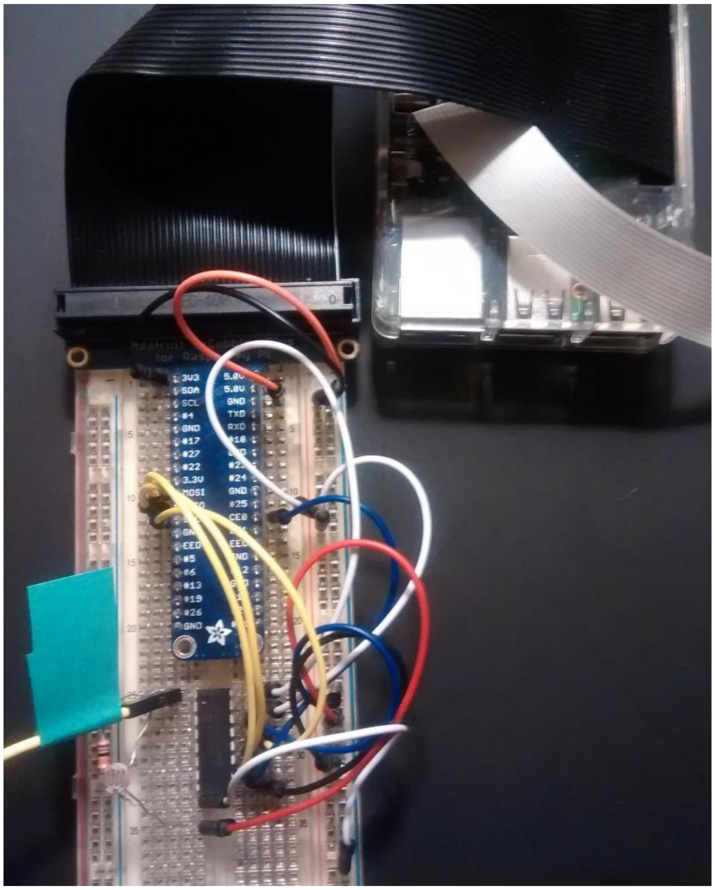

Figure 7.19 – Complete ADC Module

Figure 7.19 shows the Analog to Digital Converter Module, the MCP3008 ADC IC, and a Raspberry Pi 3 Model B.

8.1.1 Module 2b Processing Narrative – the Analog to Digital Converter

The Analog to Digital Converter (ADC) chip is the MCP 3008. It is a 10bit 8-channel ADC that uses SPI bus protocol to communicate with other devices. The analog signal from the EEG amplifier is received into channel 1 of the ADC chip, and a digital signal is send via the ribbon cable to the processing computer (RPi).

8.1.1 Module 2b Interface Description – the Analog to Digital Converter

As shown in Table 7.3, the analog signal is connected to the ADC at pin 1 (CH0) via a single channel originating from the EEG amplifier. The ADC connects via SPI protocol to the RPI on the GPIO pins as shown in the table. Figure 7.20 gives visual reference to the pins.

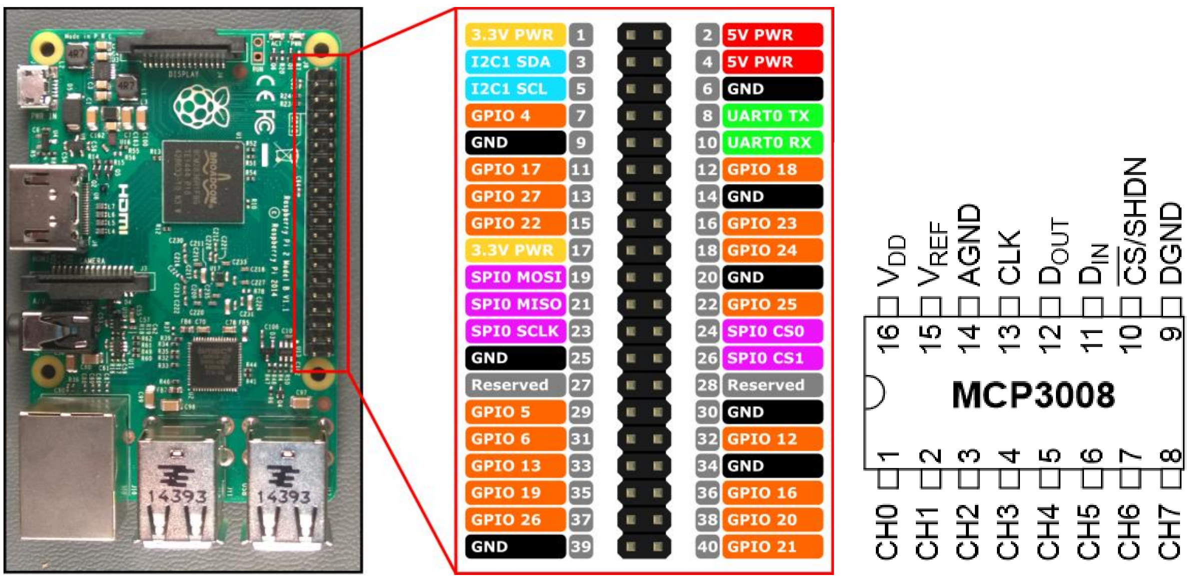

Figure 7.20 – Left - GPIO Pin Layout on the Raspberry Pi 3 Model B motherboard.
Right – ADC MCP3008 Pin Layout.

Table 7.3 – ADC and Raspberry Pi GPIO connections.

ADC MCP3008 Pin #	ADC Pin Symbol	RPI GPIO Pin #	RPI GPIO Pin Symbol	Description
1	CH0			Analog Input to ADC
2-8	CH1-CH7			No Connection
9	DGND	06	GND	Digital Ground
10	CS	24	CS0	Chip Select
11	DIN	19	MOSI	Serial Data In
12	DOUT	21	MISO	Serial Data Out
13	CLK	23	SCLK	Serial Clock
14	AGND	06	GND	Analog Ground
15	VREF	01	3.3V	Reference Voltage Input
16	VDD	01	3.3V	Power Supply

8.1.1 Module 2b Processing Details – the Analog to Digital Converter

All the processing in the ADC is done via the Python script ‘light_read_working.py’. The logic flow of the python script is shown in figure 7.21.

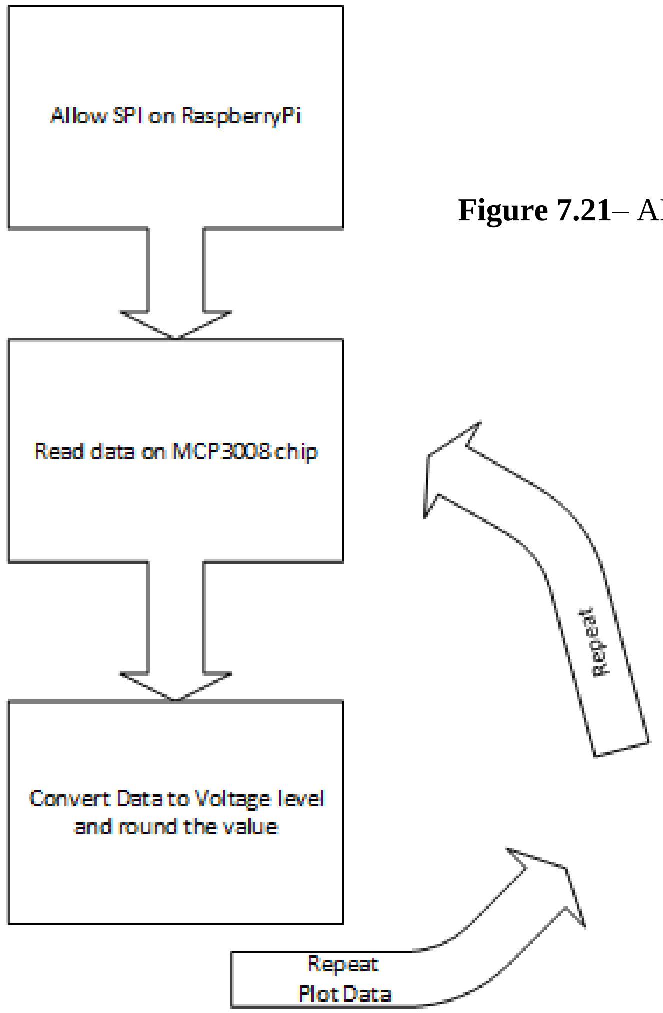

Figure 7.21– ADC Software Flow

The code is in **Appendix D**, title light_read_working.py.

8 Technical Problem Solving

Alberto Arriaga Felix and **Kai Wen** were responsible for this part.

8.1.1 The EEG Amplifier #1 Problem

A problem that prevented the team from finishing the project was in the design of the EEG amplifier. The Amplifier #1 design uses as reference the DIY EEG Circuit design shown in figure 8.1.

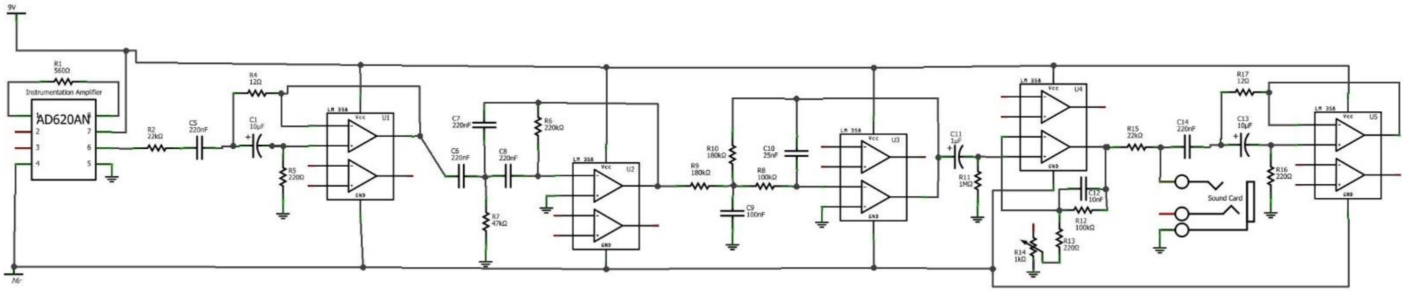

Figure 8.1 – DIY EEG Amplifier Design.

The Problem: After the team finished constructing the Amplifier #1 circuit, no identifiable EEG signal was observed at the output.

8.1.2 The EEG Amplifier #2 Problem

After the Amplifier #1 design didn't work, the team moved on to another amplifier design. The Amplifier #2 design uses as reference the EEG BCI design shown in figure 8.2.

The Problem: The signal at the output had noise artifacts, and was too weak to be read by the Analog to Digital converter.

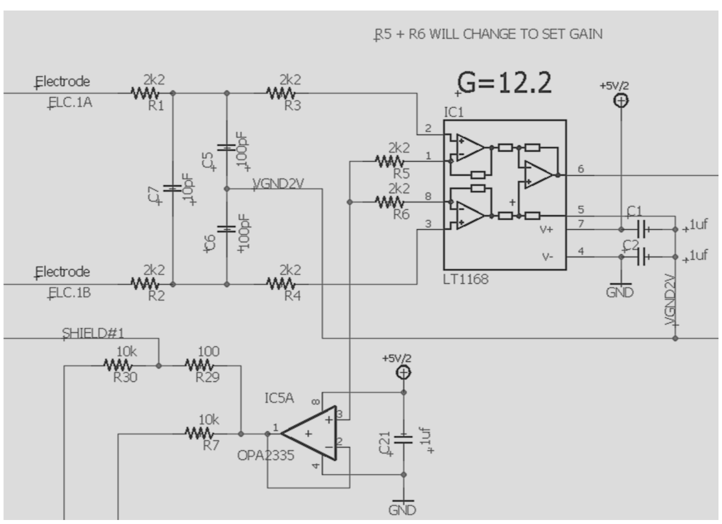

Figure 8.2 – EEG BCI Amplifier Design.

8.2.1 Solving the EEG Amplifier #1 Problem

The Amplifier #1 design is based on the DIY EEG Circuit of Figure 8.1.

The parts used for Amplifier #1 design were:

- Instrumentation Amplifier (AD620AN).
- Op-Amp (TL084CN).
- Capacitors: 1x 10 nF, 1x 20 nF, (ceramic), 1x 100nF, 5x 220nF (tantalum), 1x 1µF, 2x 10µF (electrolytic).
- Resistors: 1x 1kΩ Potentiometer, 2x 12Ω, 1x 220Ω, 1x 560Ω, 2x 22kΩ, 1x 47k, 2x 100kΩ, 2x 180kΩ, 1x 220kΩ, 2x 270kΩ, 1x 1MΩ

Figure 8.3 – Representation of brain waves Beta, Alpha, Theta, Delta.

The problem: After the Amplifier #1 circuit was build, no identifiable EEG signal was observed at the output. The signal that was expected at the output should have been like the Alpha signal shown in Figure 8.3. But the signal obtained in testing from Amplifier #1 was random noise.

How the team attempted to solve the problem:

The first approach to find the source of the problem was in identifying defective components in the circuit. With the help of the EE shop, the team replaced one by one each capacitor and resistor in the circuit. Then retested the amplifier using the oscilloscope. No discernable signal was observed at the output after components were replaced. The ICs couldn’t be replaced as easily, as they were custom ordered.

The second approach to solve the problem was to simplify the design. Remove all the filters and just have the ICs and the electrode system. After trying this, the problem persisted, and it was concluded that the source of the problem was with the ICs that were selected.

Conclusion: The problem could not be solved without rebuying the ICs used in this design. The team moved on to create the Amplifier #2 design.

Skills or lessons learned: The team learned how to test an EEG circuit using the Oscilloscope and Signal Generator tools available in the Senior Design lab.

8.2.2 Solving the EEG Amplifier #2 Problem

The Amplifier #2 design is based on the EEG BCI Amplifier shown in Figure 8.2. Amplifier #2 was an attempt to solve the problem encountered with Amplifier #1, by trying different ICs.

The parts use for Amplifier #2 design were:

- Instrumentation Amplifier (LT1168)
- Op-Amp (OPA2335)
- Reused Resistors and Capacitors from Amplifier #1.

The problem: After Amplifier #2 was build, two problems were observed in testing with the Oscilloscope.

- There was noise and interference in the output signal.
- The EEG output signal was too weak to be detected by the Analog to Digital converter.

How the team attempted to solve the problem:

The first approach to solve the problem was to add filters and add an additional amplifying stage after the instrumentation amplifier. The team worked with the reference Modular EEG amplifier shown in Figure 8.4 to create the circuit for Amplifier #3. The Modular EEG is a more advanced form of the EEG BCI design of Figure 8.2, and it includes an additional amplifying stage and additional filters.

The team tested the circuit after building each stage in the Amplifier #3 design, making sure a correct output was observed after each new part that was added.

Conclusion: The Amplifier #3 design worked as intended. The two major problems with Amplifier #2 were solved. There is less noise and interference in the output signal, and the EEG signal is now strong enough to be read by the Analog to Digital converter.

Skills or lessons learned: The team learned how to distinguish the components of an EEG circuit. How to construct and analyze an amplifying circuit, and a high pass filter. Finally, how to prevent aliasing artifacts in the output signal.

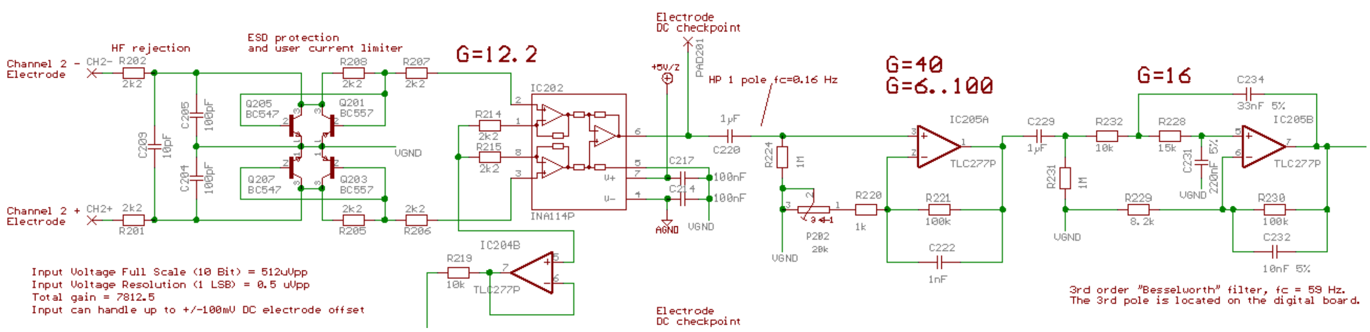

Figure 8.4 – The Modular EEG Amplifier.

9 User Interface Design

Not Used.

10 Test Plan

10.1 Test Design

Tests and expected responses

Test Case 1:

1. To record voltages above 100 μV.
2. Tests the functionality of the brain signal detection.
3. This measures the design objective of accurate and precise EEG signal detection.
4. 1. Place electrodes behind the ears of the driver
   2. Hook up electrodes to the amplifier
   3. Connect amplifier to the Raspberry Pi 3
   4. Use SPI to change the analog signal to a digital signal.
   5. Read the digital signal and store the data for analyzing.
5. Data is collected through the Raspberry Pi 3
6. **Expected results:** Signals above 100 μV are recorded and analyzed on the Raspberry Pi 3.

10.2 Bug Tracking

One significant bug in the design of the SDS is the filtering of noise signals. When the signal is read, the noise often gets amplified as well. This causes readings of the actual signal to become distorted. Thus, the readings aren't as precise. To fix this, the signal processing engineer of the Safe Driving System.

10.3 Quality Control

EEG signal detection: PASS

Sleep detection: PASS

Alarm system: PASS

Signal Analysis: PASS

10.4 Identification of critical components

The most important part of the design resides with the signal detection of the brain. The design of the Safe Driving System relies on two methods of detecting for a sleepy driver. The eye camera works with no problems, but for a more robust detection of sleep, the activity of the brain must be monitored.

11 Test Report

Not Used.

12 Conclusion and Future Work

12.1 Conclusion

Alberto Arriaga Felix

The team worked hard on this project and overall, I think we came very close to achieving all the goals we set up at the beginning. For my part, I spend most of the first quarter just doing research on various components we could use for this project. I had no prior knowledge of how EEG systems worked, or of the theory behind an EEG amplifier. This was a challenge that I believe has taught me interesting new subjects and the technical knowledge to work with EEG systems. The EEG amplifier I designed we got to work on the final week, when I tested each part with a function generator and oscilloscope. But there were errors in the logic and circuit design I needed more research to solve. I went through several iterations of the amplifier, and it was difficult to stay on track in our time schedule, as each iteration meant I had to order new parts, and wait several weeks for the new parts to arrive. I tested about 3 different instrumentation amplifiers, and several operational amplifiers in the design of the filters and amplification systems. The goal by week 9 of having a functional EEG amplifier I don't believe was met, even if we do obtain a signal from the amplifier into the raspberry pi in the latest version. It is currently not clear if the signal is accurate for an EEG signal, and more testing is required. But the system we designed should work given more time to troubleshoot the problems.

The team experience was good. We met weekly, sometimes two times a week. There was good communication between the 3 members. We sought help from people more familiar with EEG and eye tracker systems, with the Psychology department, the Mednick sleep lab and the Brain Game Center at UCR. We met with Benjamin Yetton of the Phycology EEG labs almost every other week. He kept track of work we did and helped us with components and ideas for the project where we lacked experience.

Kai Wen

We all worked on eye-tracker during the first quarter and we have spent significant amount of time on eye-tracking part. We have meeting every Friday during the lab time and after the lab working on this project and keeping the work updated. There were difficulties when setting up the pupil software and lab streaming layer for eye-tracker and unfortunately, our software crashed during the second when we tried to modify the program files. We therefore, switched eye cameras with a single Raspberry Pi camera.

I learned a lot during the two quarters' design. Since this project required not only engineering knowledges, but required some knowledges for image processing, computer software as well as psychological concepts. Therefore, significant effort has been put for studying and researching brain wave signals, and EEG circuit design etc. Even though we could only have a final prototype of EEG circuit, we did learn a lot. Time management and budget management were two important issued we encountered during the two quarter. It's is important to keep track of the progress and minimize the cost for this project. Communication is also an important aspect though out the project. We regularly communicated with psychology lab and UCR Brain Game Center for learning EEG device set up and lab procedures.

12.2 Future Work

Alberto Arriaga Felix

There are many things that can be improved on this project. But the basic system loop is good the way it is. The technology we used could be implemented better to achieve more accurate results, with just more time to learn the details required for each module. The EEG electrode solution we found is great for the task. It wouldn't need to be changed, I think other electrode systems are too expensive or difficult to use. The eye tracker systems were the most difficult part of the project, we tested a device for a large part of the project, the Eye Tracker Glasses, that we couldn't make work by week 15. The software was too complex for us to use, and there were bugs we couldn't solve. We made the right decision to change to the RPi Camera module towards the end, as it gave us results we could use.

We also learned about PCB design during this project, and we made a design for our amplifier PCB. This PCB design uses different surface mounted chips, but they have similar functions to the ones in our testing board. They are the LT1168ACS8 instrumental amplifier, and a OPA2604AP operational amplifier. In this design, the PCB does not include the filters and additional amplification system I included in the latest design tested, but it would be easy to add those parts.

In concept, there should be one PCB for the EEG amplifier system, and that should be placed inside a shielded box to prevent signal interference. There should be a separate PCB for the ADC and alarm circuit that connect to the Raspberry Pi.

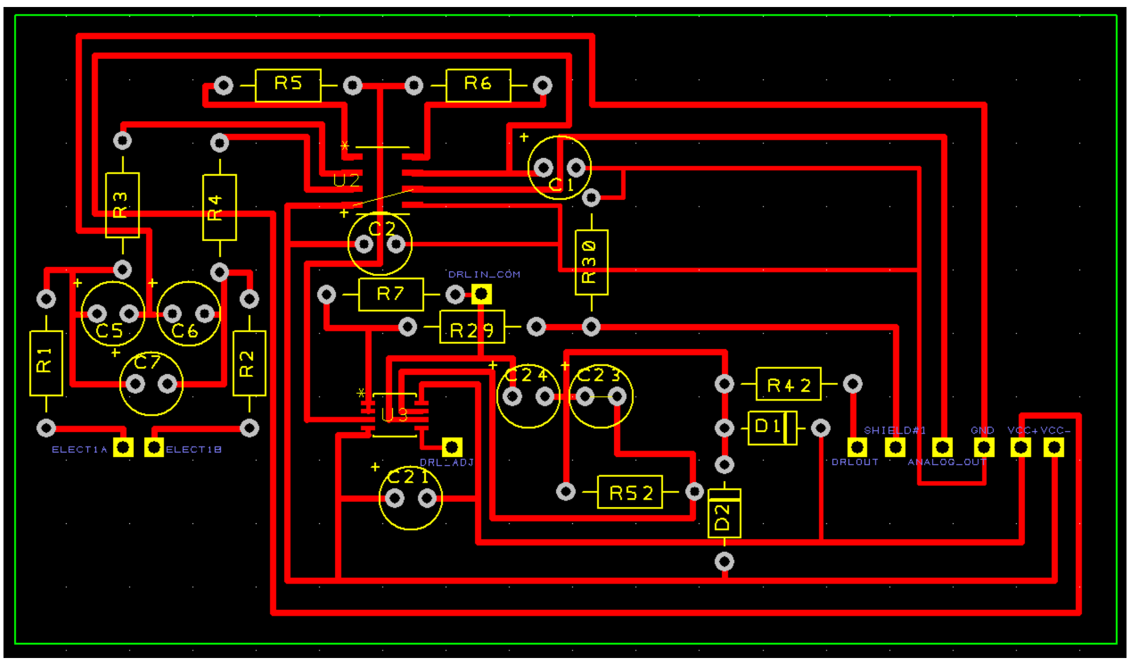

Figure 12.2.1 – EEG Amplifier PCB.

The files for this PCB are included in Appendix D.

Another improvement would be to make the signal between the ADC and the RPi wireless, to make the system easier to carry and operate.

12.3 Acknowledgement

We want to thank sincerely:

Gang Chen – Our advisor, for ideas and solutions to problems we encountered.

Pavle Kirilov – For helping us with fabrication of parts, soldering, and giving us some free components.

Benjamin Yetton – Graduate Student of Mednick Sleep Lab. For helping us with ideas for the design and answering question about EEG systems and data.

Dr Seitz – The Brain Game Center, for allowing us to use the Psychology Department's equipment and facilities.

13 References

List the references used in the design, including books, data sheets, technical documents, industry standard documents. References can be printed documents or online.

Section 1

http://www.nsc.org/DistractedDrivingDocuments/Cognitive-Distraction-White-Paper.pdf

http://drowsydriving.org/about/facts-and-stats/

Section 2.2

Emotive Devices:

https://www.emotiv.com/product/emotiv-epoc-14-channel-mobile-eeg/

https://www.emotiv.com/product/emotiv-insight-5-channel-mobile-eeg/

Eyetracker Devices

http://www.tobii.com/tech/products/platforms/

https://s3.eu-central-1.amazonaws.com/theeyetribe.com/theeyetribe.com/dev/general/index.html

Section 2.3 Development Tools

Raspian

https://www.raspberrypi.org/downloads/raspbian/

Atmel

http://www.atmel.com/microsite/atmel-studio/

PCB prototype machine

http://www.lpkf.com/products/rapid-pcb-prototyping/circuit-board-plotter/index.htm

IDC Crimp Tool

https://www.amazon.com/gp/product/B007R2JEM4/ref=oh_aui_detailpage_o00_s00?ie=UTF8&psc=1

Section 4.1

Pupil labs

https://pupil-labs.com/

EDF file reader function

https://www.mathworks.com/matlabcentral/fileexchange/31900-edfread

14 Appendices

14.1 Appendix A: Parts List

- Raspberry Pi 3 Model B Motherboard
- RPi 3 Case
- Raspberry Pi Camera Module V2
- Raspberry Pi Camera Module Mount
- Battery High Capacity 13000mAh for Raspberry Pi Power
- AD620ANZ-ND Instrumentational Amplifier
- 2x TL084CN OpAmp
- MCP3008 - 8-Channel 10-Bit ADC With SPI Interface
- 6 x Silver Pins Back with Foam Adhesive
- Capacitor Kit
- Resistor Kit
- Ribbon Cable 10 Wire
- 2x5 Connector Pins and Sockets
- Jumper Wires M/M and F/F
- IDC Crimp Tool
- cEEGrids ear electrodes
- ATMEGA1284-PU Microcontroller
- Olimex AVR ISP mkII programmer
- Piezo Speaker - PC Mount 12mm 2.048kHz
- 2x20kOhm Potentiometers
- Assorted Pins for PCB connectors
- Various Breadboards

All of these parts were obtained or can be obtained from the following places:

- Amazon.com
- Sparkfun.com
- Adafruit.com
- Digikey.com
- Mouser.com

14.2 Appendix B: Equipment List

- USB cable for battery connection to RPi
- VGA to HDMI adapter for RPi connection to Monitor
- Multimeter
- Oscilloscope with 2-Channels
- Waveform Generator

14.3 Appendix C: Software List

- DesignSpark PCB for PCB design
- Atmel Studio for ATMEGA microcontroller
- VNC Viewer for accessing the RPi remotely
- VirtualBox for using linux on a virtual desktop on Windows
- Notepad++ for editing code
- Microsoft Visio for making block diagrams
- MATHLAB for signal analysis
- OrCad PSpice for testing circuits

14.4 Appendix D: Code and Files

- Google Drive Folder with Codes and Files

  https://drive.google.com/drive/folders/0B5KgttTfriNsMkw3cU0yVTNHdmM

14.5 Appendix E: Videos

- Test of EEG Electrodes.

https://www.youtube.com/watch?v=1l8gK4smX5o
https://www.youtube.com/watch?v=-_v8I10HXWo

- Test of ADC.

https://www.youtube.com/watch?v=zwg6CYPtTBc

- Test of eye tracking with Raspberry Pi Camera**.**

https://www.youtube.com/watch?v=KZKmKMHsYqE

- Test of eye-tracker glasses.

https://youtu.be/shH9HFxkUMA

- PCB Manufacturing.

https://youtu.be/kESSE6B-UX4

Essay 1 - Understading of Professional and Ethical Responsibility and Global, Economic, Environmental and Societal Impact of the Safer Driving System

Alberto Arriaga Felix
UCR: Bourns College of Engineering

***Abstract*— The Safer Driving System is a device that aims to prevent accidents due to drowsy drivers. The problem that exists is that in 2009-13 an estimated 21% of fatal crashes involved a drowsy driver [1]. The SDS solves this problem by detecting when a driver is falling asleep, and sounding an alarm to wake the driver. The SDS could potentially reduce the number of drowsy driver involved fatal accidents. Recent studies have shown there is a willingness by the public to trust these types of technologies. The low cost of the system will enable more people to have access to this type of technology. The SDS treats the data being collected with careful security considerations to maintain the privacy of the user.**

I. Introduction

The Safer Driving System device has the following components; an eye tracking camera, an electroencephalogram (EEG) system, a processing computer, and an alarm system. The system takes data through the camera and EEG components, and that data is analyzed by the processing computer. If the computer detects the driver is falling asleep, it activates the alarm system to wake the driver. The driver must demonstrate that it is fully awake and manually reset the alarm.

The team researched other similar existing technology. Currently even the most expensive vehicles available are not equipped with any type of system that can detect when a driver is falling asleep. Some modern vehicles, such as those offered by Toyota [2], can detect obstacles on the road and employ autonomous driving to avoid accidents. But there are currently no vehicles that monitor and detect the activity of the driver

The team also researched similar technology to the one used by the SDS. For EEG headsets, there exist products such as the emotiv EPOC+ EEG headset [3]. The disadvantages of the emotiv are that it is expensive, $800, and it is not easy to use. For eye tracking there exists the Pupil Labs Eye Tracker [4]. The disadvantages of Pupil are that it is very expensive, $1500, and it's not portable. The advantages of the SDS compared to similar technologies: It is affordable, under $200. It is easy to use, it will offer a simple user interface. It is portable, and it can be integrated into all existing motor vehicles with minimal modification to those vehicles.

II. Ethical Implications

A. Health

In a study by the AAA Foundation for Traffic Safety [1]. It was revealed that more than a third of drivers reported having fallen asleep behind the wheel at some point in their lives. More than one in ten also reported having fallen asleep behind the wheel in the past year. Drowsy drivers are involved in an estimated 21% of fatal crashes. Out of 21,292 crashes recorded in 2009-13, approximately 10% involved distracted or sleepy drivers.

The SDS provides a solution to this problem, and could potentially reduce the number of drowsy drivers involved in crashes, including reducing the number of casualties, repair expenses, and health care bills. Currently there are no numbers for this type of system, but it can be compared to other vehicles safety systems. The Insurance Institute for Highway Safety (IIHS) reports that vehicles equipped with a simple forward-collision warning and automatic braking system have seen incidents of rear-end collisions reduced by 40 percent, with bodily injury claims cut by 30 percent [5].

B. Privacy

The Safe Driving System uses components which monitor the physical and mental states of a driver. These monitoring techniques can invade the privacy of the individual that uses the SDS. The two types of data collected by the SDS are EEG data, and eye tracking data.

The SDS uses an electroencephalogram (EEG) component that detects and analyzes brain signals related to cognitive processes. Many people perceive these brain processes to be bound to personal identity. The SDS reveals and identifies neural processes, and then correlates those processes with a specific individual's actions. Some may feel uncomfortable with this type of data being stored, or archived and kept for later analysis. As it could be used or exploited for purposes which could cause discrimination in areas of work or social life [6]. The SDS also uses a camera component to keep track of the driver's eyes. This type of eye movement data can provide a measure of visual and cognitive information processing, and can be used to determine aspects of the driver outside the scope of our project.

C. Public Safety

The purpose of the SDS is to improve public safety, but for this purpose to be met, public trust of this type of technology is important. A report by the IIHS found that trust may affect real-world use of driver assistance technologies and thereby limit the opportunity for systems to provide their intended benefits. The same report found that after people were allowed to use driver assistance technologies for a period of time, 72 percent of people who tried crash-avoidance technologies said they would want them in their personal vehicle [7]. It can be determined that there is a willingness by the public to trust these type of technologies, and the only existing barrier is the affordability of the technology.

III. Addressing Ethical Issues

To solve the perceived problem of data being collected and archived. The SDS must treat the data being collected with careful security considerations and maintain the privacy of the user. The SDS takes additional steps in security to keep the data safe. The system operates always offline and with wired connections, with no internet or other outside processing. This prevents intruders from using Wi-Fi or Bluetooth networks to intercept and obtain data from the system. The team also considered a secured enclosure to protect the processing component and prevent intruders from physically connecting and modifying the software in any way that could allow for the exploitation of the data within. The Safe Driving System protects all the data obtained, as it's a part of a person with rights and privacy. [6]

To address the issue of public safety and affordability of the technology. The SDS is designed to keep low cost as a priority. Each component of the SDS was carefully selected by the team to meet minimal functional specifications and keep the cost per component low. The low cost of the system, under $200, will allow more people to have access to this type of technology. This will enable more people to try it and therefore improve public trust in these types of driver safety systems.

IV. Professional and Ethical Responsibility

In the design of this project our team learned about many techniques for monitoring and extracting brain signals. While the team understands the physical and scientific processes for how these techniques work. The team is not fully aware of the social implications of using this type of brain data to make conclusions on an individual's actions [8]. Therefore, it is important for this team to be upfront about the significance of the project, and how the use of this data relates to the problem that is being solved.

V. Potential Impact of the Project

The goal of this project is to improve the quality of life for everyone that drives a car. There is a trend currently in improving car safety through the research of autonomous systems. Autonomous driving technology has the potential to save many lives, as it allows for less human errors in the process of driving. If a system like the SDS becomes a commercial product. It will likely be an integrated component of an autonomous vehicle system.

Conclusion

While existing crash prevention technology monitors the outside of a vehicle, through sensors and cameras. The SDS takes a different approach, and looks inside the vehicle at the driver. It monitors the behavior of the driver to prevent accidents due to drowsiness or distraction. This team believes that future research in car safety will take this type of inside the vehicle monitoring into greater consideration. The health, privacy, and public safety ethical implications of the SDS are carefully examined. The SDS could reduce the number of drowsy drivers involved in accidents. The SDS treats the data being collected with careful security considerations and maintain the privacy of the user. The low-cost entry of the system will allow for more people to try it, and therefore improve public trust in these types of technology. A device like the Safer Driving System uses emerging technology in eye tracking and EEG signal analysis to improve driver safety.

References

[1] "Prevalence of Motor Vehicle Crashes Involving Drowsy Drivers, United States, 2009 – 2013." Aaafoundation.org. AAA Foundation for Traffic Safety, Nov. 2014. Web. 2 June 2017. https://www.aaafoundation.org/sites/default/files/AAAFoundation-DrowsyDriving-Nov2014.pdf

[2] "Toyota Global Site | Toyota Safety Sense." TOYOTA MOTOR CORPORATION GLOBAL WEBSITE. N.p., n.d. Web. 21 May 2017. <http://www.toyota-global.com/innovation/safety_technology/toyota-safety-sense/>.

[3] "EMOTIV Epoc - 14 Channel Wireless EEG Headset." *Emotiv*. N.p., n.d. Web. 08 June 2017. <https://www.emotiv.com/epoc/>.

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[7] "Driver Trust in Five Driver Assistance Technologies Following Real-World Use in Four Production Vehicles." IHSS. N.p., Dec. 2016. Web. <http://www.iihs.org/frontend/iihs/documents/masterfiledocs.ashx?id=2131>.

[8] SENTENTIA, W. (2004), Neuroethical Considerations: Cognitive Liberty and Converging Technologies for Improving Human Cognition. Annals of the New York Academy of Sciences, 1013: 221–228. doi:10.1196/annals.1305.014 Link:http://dx.doi.org/10.1196/annals.1305.014

Essay 3 - Project Management and Importance of Team Work

Alberto Arriaga Felix
UCR: Bourns College of Engineering

Abstract—

I. Project Management

A. Task Distribution

The SDS project management was handled by all team members. From the beginning, it was agreed that one team member would monitor and keep track on the progress of the project. But tasks could be selected or assigned by all team members. These tasks would be assigned weekly during the scheduled meeting time. One different task could be selected by or given to each team member. Two team members could work on a task that was more difficult, but never all three team members on one task. This was done to make sure enough different work was being done each week. If work for a task that was assigned a week was not completed at the next Friday meeting. All team members would work on that task during the Friday meeting time.

The division of responsibilities for this project were selected by each team member according to their skills and knowledge of each subject matter. Each team member selected the following tasks:

Alberto Arriaga Felix:

- Oversaw the EEG system and hardware parts of the project.
- Research Electrodes and find a portable electrode system that is lightweight and simple to use.
- Design and test an analog amplifier system used to acquire the EEG signal from the electrodes and send it to the digital system.
- Find a way to convert the analog electrode signal into a digital signal that can be analyzed on the computer.

Kai Wen:

- Oversaw signal analysis and EEG circuit.
- Research human brain wave frequencies and sleep patterns in EEG signals.
- Design digital band-pass filters to distinguish Alpha EEG waves and used frequency domain analysis on EEG signals.

Andrew Kwon:

- Oversaw the eye tracking system.
- Research eye and head tracking techniques, such as Haar Cascade, to detect driver's eyes.
- Created infrared led system for camera's night vision.
- Studied Machine learning for classification of eyes and face used in eye tracking component.

B. Schedule

The SDS team met weekly on Friday during the pre-assigned lab schedule for the EE 175 class, and worked on the project exclusively all Friday after lab. Additionally, the team met on another day of the week, depending on the weekly schedule of the team members. This second meeting took place in the Psychology building, were a Graduate Student of the Mednick Sleep Lab would help the team with answering question about EEG and brain analysis. The team would meet additional times if there was an important task that needed more attention in each week.

C. Project management software/methods

The main project management software that was used was Google Docs. The team kept a weekly list of tasks that were agreed to be completed by each member and were written on the online document. Tasks could be marked as completed or needing attention by all team members. This was an easy way to see what work was being completed and what needed the attention of other team members.

The main form of communication during the project was in person. Because of the other school responsibilities of the team members, the team couldn't meet in person that often. It was decided that it was important that the team met in person to discuss over important ideas or key aspects of the project. This would leave online or phone communication for smaller needs.

II. What you learned from this Project

A. Teamwork

Team work is an important aspect of a project. An important aspect of team work is communication. The more the team communicated about tasks, the easier it was to find solutions to problems. A study done by the Harvard Business Review found that, patterns of communication to be the most important predictor of a team's success [1]. This was true for this team, and in weeks were the team had less communication, it was observed that less work was completed. The weeks were the team met in person, more work was completed. Online communication did not have the same impact as in person communication.

B. Time Management

This project gave an insight into the importance of meeting deadlines. The overall project management was difficult. The problems the team ran into were mainly due to poor time management. While the team set out tasks for each member, many times deadlines had to be pushed back for tasks. Task often took longer to complete that what was originally estimated. A cause for this was in the fact that the team members were often overloaded with work from their regular class work responsibilities. Often team members decided to take time to complete their respective class responsibilities over completing project tasks. This pushed back deadlines, and in the end the project was not completed on time.

III. UNDERSTAND THE IMPORTANCE OF TEAMWORK.

This project required different skill sets and knowledge to be accomplished. The team had sufficient knowledge to complete certain parts, including knowledge of low-level circuits, programming, computer vision, and signal analysis. The areas of the project were the team had no knowledge, this included eye tracking, EEG signals, and Linux interfaces. The team sought help from people that worked in these areas. The team particularly got help from the Psychology Department at UCR in this project. They helped explain how EEG signals work and how to design experiments that involve EEG devices. The team also received help for the computer vision part, from the Brain Game Center, which supplied the team with a working eye tracker. From this the team could experiment with the equipment and understand the basics of eye tracking.

Overall the composition of the team was all Electrical Engineering majors. Within that the team had a broad enough range of skills to understand all aspects of the project Alberto had a deeper knowledge of programming and circuit design. While Kai had more knowledge of signal analysis and Andrew had more knowledge of computer vision. These skills combined was sufficient knowledge for this team to understand and attempt most aspects of this project.

REFERENCES

Pentland, Alex "Sandy", and Anita Woolley and Thomas W. Malone. "The New Science of Building Great Teams." Harvard Business Review. N.p., 15 July 2015. Web. 14 June 2017. <https://hbr.org/2012/04/the-new-science-of-building-great-teams>.