Electrooculography Virtual Reality Headset: Final Report

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Executive Summary

Electrooculography (EOG) uses electrodes placed at locations around the eyes to measure eye movement. Horizontal and vertical movements can be measured by having pairs of electrodes above and below the eye and to the left and right of the eye. These measurements can in theory be translated to a control scheme similar to a mouse or joystick. The goal for this project is to use EOG as a control scheme in a Virtual Reality (VR) game. The VR environment is used to test the usability of EOG as a control scheme, and explore potential use cases for EOG in the real world.

Some potential use cases for EOG are:

- Allow disabled individuals to perform tasks that would typically be accomplished with hand-guided mechanisms (mouse or joystick)
- An additional control mechanism with low cognitive load for tasks that require multiple sources of input

The project consists of a custom-built VR headset which can incorporate the EOG hardware in streamlined fashion. The signal from the electrodes is amplified, processed with a microcontroller to output a digital signal that is sent to a computer, and then interpreted with a driver. The VR game is used to evaluate performance and usability compared to traditional control mechanisms.

The estimated budget for this project was $460. The final expenditures for the prototype were $329.40. We have a working prototype as of May 4, 2020.

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Project Description

Background and Motivation

The ability to properly control or aim a system is an important aspect of virtual reality (VR) interactions. The use of a traditional hand controller is one that is widely accepted and leaves much room for growth. Gaze aiming in particular has shown to have a lower cognitive load in comparison to a traditional controller. Yet, gaze aiming did produce lower accuracy in most conditions (Luro and Sundstedt 1).

The lower cognitive load of gaze aiming demonstrates its potential for use in VR. This document aims to create a gaze aiming system that is comparable to a traditional controller in accuracy. To capture eye movement, an electro-oculography (EOG) system will be implemented. An EOG uses multiple electrodes to measure the potential difference between the cornea and retina. It is considered “the most stable physiological signal in the development of human–computer interface (HCI) for detecting eye-movement variations” (Lin 96166).

EOG systems have been explored previously, but with a lack of focus on a non-intrusive setup. They are typically not mobile, and require a plethora of wires to be connected on an individual’s face. This leads to a lack of desire for an EOG controller to be used. The goal is to remedy this through a portable headset that makes for a simple and easy user experience.

Project Goal

The project's main goal is to build an ocular controller for a VR simulation. The simulation will be used as a verification of a working system and a proof of concept of controller usability.

Project Requirements

ID	Project Requirement	Description
1.0	Production Cost	**Primary Functional Requirement:** Dependent on limited resources available
2.0	Supply Output: 12V to Monitor -USB Powered Circuit -Circuit functional at 5V	**Primary Functional Requirement:** Output Specification of power supply
3.0	Mouse Control	**Primary Functional Requirement:** Control the mouse movement through EOG signal input.
4.0	Signal Range: .1 - 20 Hz	**Constraint:** The applicable range of an EOG. Need to remove excess noise
5.0	Gain Stage: 30 - 40dB	**Constraint:** Amplify the signal to be readable
6.0	Latency: The time between signal acquisition and control output	**Objective:** Keep latency below 150ms
7.0	Headset “Experience”	**Objective:** A comfortable and non-intrusive headset for acquiring EOG signal

Validation and Acceptance Tests

- Supply Output
    - Use voltmeter to measure voltage output of battery and arduino
        - Reading will match determined Voltage Supply
- Signal Range
    - Plot Frequency Response of the circuit
    - Output filtered signal to microcontroller and create a frequency response of the plot
        - Apply Frequencies from 0 - 100 Hz to input of circuit
        - Use AD2/Waveform Generator to apply signal
            - Create schematic to demonstrate where it is applied
- Gain Stage
    - Use oscilloscope to plot signal waveform at output of amplifier to stage
- Cursor Accuracy
    - In the VR environment, a minigame is used to test the abilities of the headset and the user. This minigame uses asteroids as targets, the more asteroids destroyed, the higher the score.
- Latency
    - Measuring the time between signal acquisition and control output
        - Ideal: Latency < 150 ms
        - Functional: Latency < 350 ms
- Headset "Experience"
    - Qualitative Analysis
        - Ease of Setup
        - Structural Soundness, doesn't break easily
        - Comfortability
        - Weight
        - Style/Looks

Validation and Acceptance Test Summary

The Supply Output, Signal Range, and Gain Stage tests were evaluated during development of their module. The completion of the project was dependent on the validation of those tests. The Cursor Accuracy, Latency and Headset Experience tests were conducted in the post-development phase of the project to determine usability.

Technical Design

Design Alternatives

Image based eye-tracking:

- This technique uses cameras and advanced algorithms to determine a person's gaze. This solution could potentially yield increased accuracy at the trade-off of a steeper cost, more complex software, and increased latency.

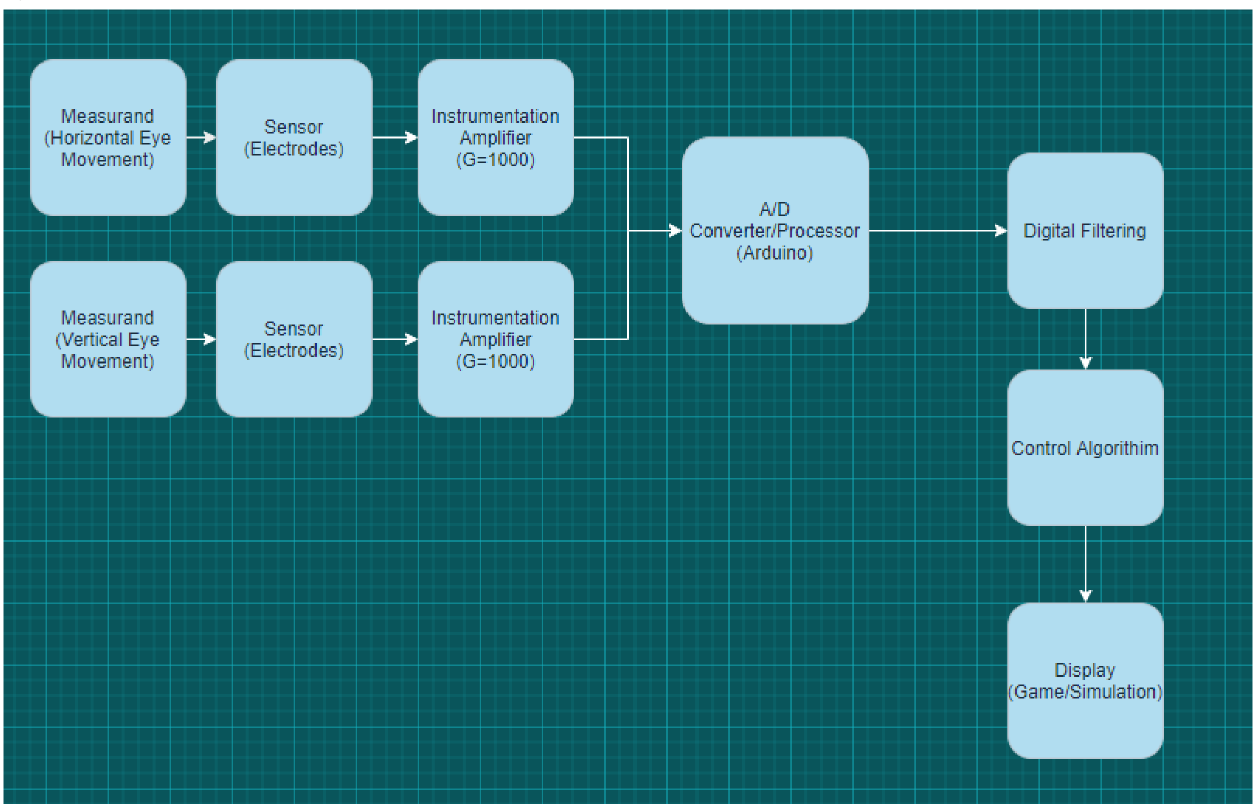
Filtering:

- Analog Filtering Design
    - The design could be switched to perform all filtering through circuit components. This would add more components to a PCB without offering much gain. This would be more useful if the signal frequency was much higher. The Arduinos sampling frequency of 9.6kHz is well above the nyquist frequency of 40 Hz.
- Digital Filtering Design
    - With low frequencies, this would allow for a simpler board as the initial worry of aliasing will not occur. Arduinos sample at 9.6kHz, well over the nyquist frequency of 40 Hz.
    - With time filtering, we can filter our blinks and quick involuntary movements.

Housing alternatives:

- The electrode housing and VR headset are the same unit.
- The electrodes are housed in a glasses-style design. The VR headset is designed to mesh with the glasses.
- The electrodes are housed in a flexible mask. The VR headset rests on top of the mask.

System-level Overview



Applicable Standards

- IPC-2221B - General PCB standards
  - This standard provides the rules for manufacturability and quality of printed circuit boards. This includes requirements for material properties, component placement, dimensioning, tolerances, and more. For our project, this general standard was automatically applied when designing our PCB through Altium.
- IEEE - VR Standards
  - It is important to note that there are no standards for VR currently. IEEE is in the process of creating 12 standards for virtual reality and augmented reality. In the future, this could have an impact how we communicate with a VR program as well as the development of VR programs as well.
- ISO/TC 261 - Additive Manufacturing
  - This is a standard that defines terminology, specifies calibration of additive machines, measures performance of processes, and ensures quality of end products. For the purpose of our project, this would apply to the 3D printing of our casing. Majority of the standards are geared towards the production of the machine itself. Although, there are recommendations included for the design of products using additive manufacturing.
- EIA/CEA-861 - HDMI Standards
  - Defines the format of videos, waveforms, compressed and uncompressed LPCM audio, and implementations of the VESA EDID. This applies to our use of an HDMI in displaying our VR game. It has no impact on us as designers for this project.
- USB 2.0 - Arduino to Computer Communication
  - Establishes specifications for cables, connectors, and protocols for connection, communication, and power supply interfacing between computers and peripherals. This applies to our connection between the Arduino and computer for both serial communication and power supply interfacing.

Module-level Descriptions

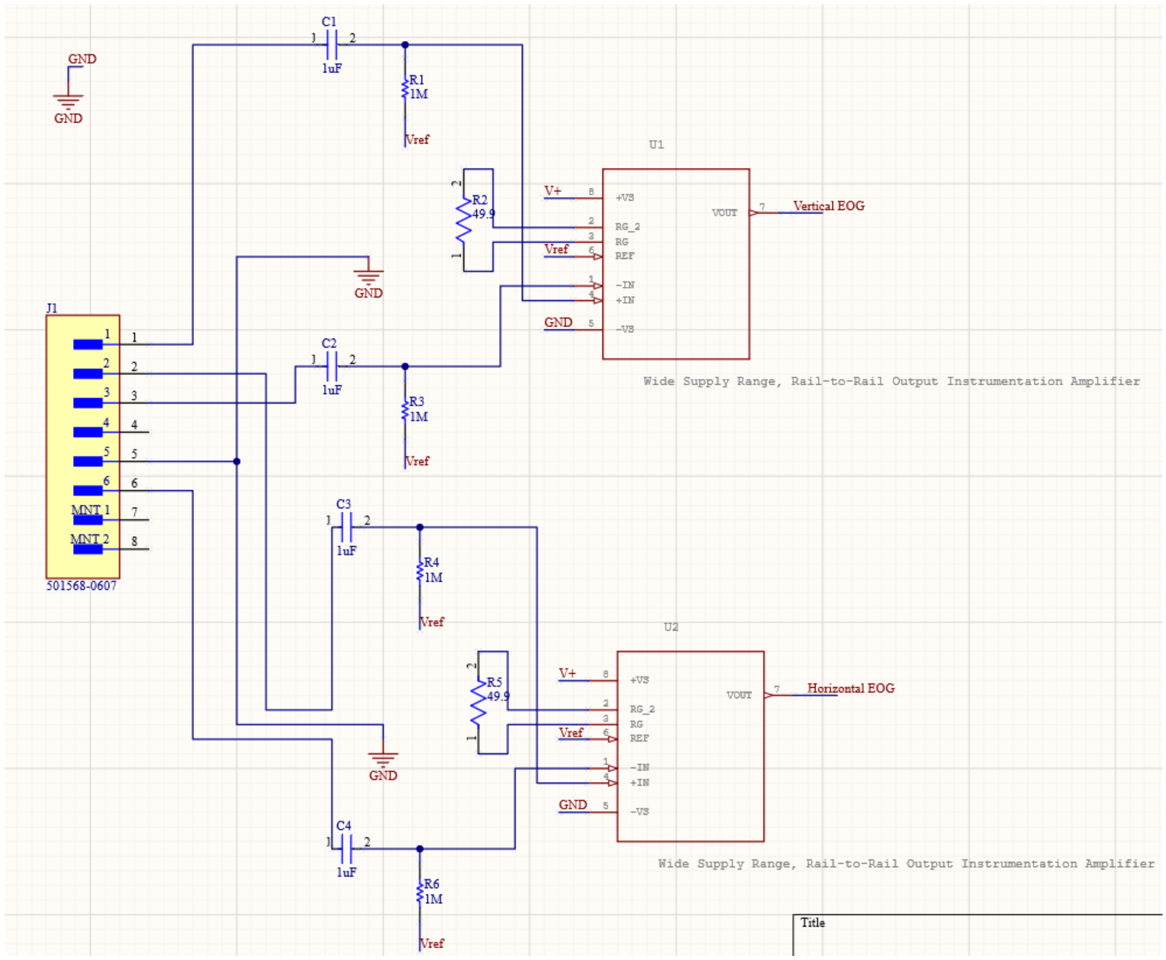
- Signal Acquisition
  - 5 Electrode connections
  - Signal Amplification
    - Signal ranges from 100-3500uV.
    - Gain of 750
      - Implement AD8226 Instrumentation Amplifier with a gain resistor of 100 Ohms to acquire a gain of 750. The use of an instrumentation amplifier will provide high accuracy and stability due to the low drift, noise, and high input impedance characteristics.
  - Digital Filtering
    - Bandwidth of .1-20 Hz
    - Use a Median Sliding window filter to clean up the signal
- Data Acquisition
  - 2 analog inputs at processor (arduino)
    - Vertical movement
    - Horizontal Movement

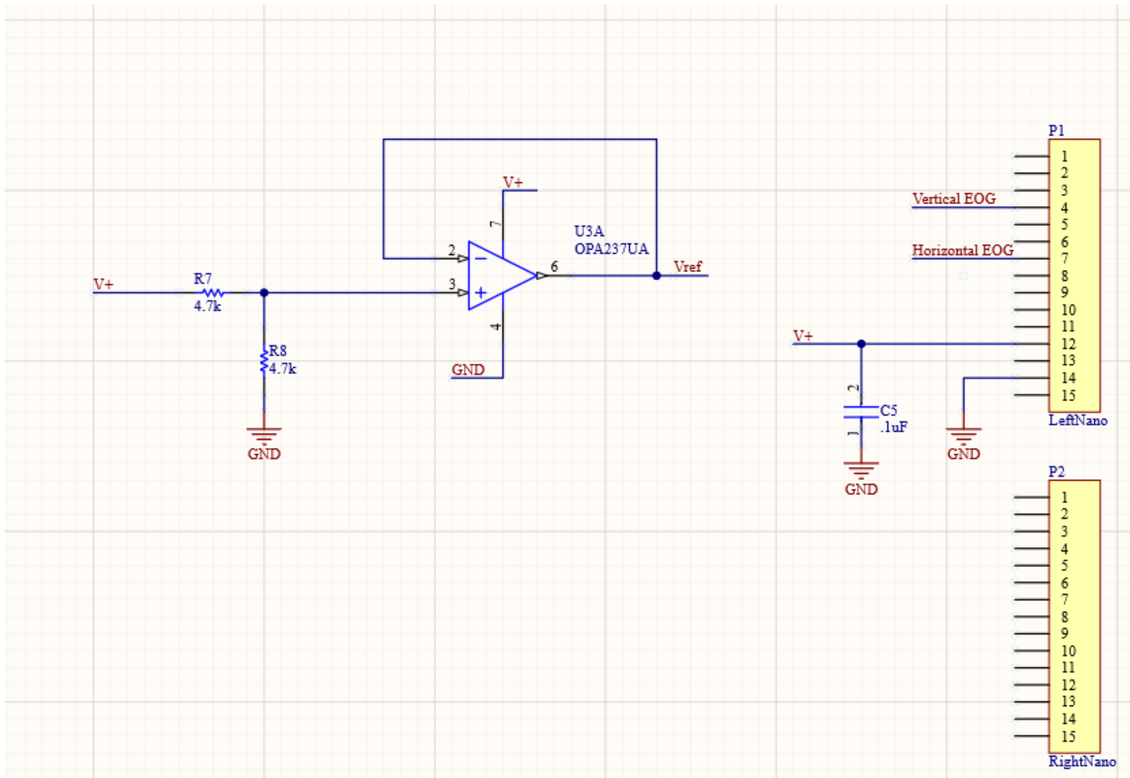
- Processing Algorithm - Derivative Option (Inspired by reference 1) - Appendix B
    - Conduct a pre calibration process
        - In order for subsequent max/min and time window values to have meaning, a set of calibration values will need to be set. These include:
            - Time Weighting
            - Max/Min Weighting
                - Horizontal
                - Vertical
        - This can be done by having the user quickly look left/right and up/down fully in each direction.
            - Using the same methods detailed below, the time between derivation peaks and overall max value from the time signal can be determined. Subsequent window signal data can then be normalized to these values on a scale of 0-1 for quick time movement. The values for the horizontal/vertical max and min weighting will be on a scale of 0 to 1. This will provide a full range of “view” in both directions.
    - Windows of time of the signal will be collected (test effectiveness of .05, .1, .25 sec)
        - This will be used as the input to our control algorithm
        - The window of the signal will directly control the “latency” or “lag” of our system. A .05 second window is an indication of the time from signal acquisition to control output.
            - The accuracy of these windows may also be affected by sampling rate. A larger sampling rate will provide more data in each window but will also require more power to function. This is a decision point to consider when testing effectiveness of each window size.
        - Referenced as inSig
    - Take the derivative of the signal (derivSig)
        - The derivative will show the speed at which a user moves their eyes
    - Acquire Max/Min and time of peaks from derivSig
        - By knowing the max/min and the time of each peak for the derivSig, we can apply specific weightings to each to influence the movement of the controller.
            - A long time between min/max indicates slower movement of the eye and will thus will have a larger weighting to indicate this
    - Acquire Max/Min of inSig to match peak windows from derivSig
        - The max/min values of the original input signal are an indication of the distance the user is looking. Larger max values for the horizontal electrodes will correspond to the user looking further to the right for example.
    - Weighted Values sent as an output
        - The weight values acquired in previous steps will be sent as our control output in moving a cursor (or other designed system).
    - Filter Out Blinks
        - There will be a timed threshold that will filter out blink and other involuntary movement.
    - Loop to the beginning of algorithm with subsequent window

        - The program will loop to the start control process as the next window of signal data is acquired.
- Processing Algorithm - Absolute Option - Not Used
    - Conduct a pre calibration process (Same as stated in Derivative Option
    - Take input data as raw voltage values (Horizontal and Vertical separately)
        - Normalize the voltages according to the calibration process
        - Use the normalized values as a coordinate system corresponding to the VR simulation. The horizontal values will equate to the x-axis while the Vertical values will equate to the y-axis.
        - Output the coordinates to the VR simulation to adjust the cursor/output position
- Electrode Housing
    - No housing of electrodes.Used adhesive disposable electrodes in prototype.
- VR Headset
    - Small (5.5”) screen with standard HDMI input
    - Pair of convex lenses
        - Focal length = lens-screen distance (45mm)
    - Casing
        - Securely houses monitor
        - Houses lenses. Adjustable eye-width. Allows for lens replacement
        - Houses PCB
        - Comfortably meshes with user’s face - uses ergonomic foam
        - Can be disassembled and reassembled with a screwdriver
    - Straps
        - Adjustable elastic side straps - positioned above ears
        - Adjustable elastic top strap. Keeps headset from shifting down the face.
- Game
    - Engine and Development Application: Unity
    - Application of EOG
        - Pointing a cursor
        - Cursor-less aiming. This is the application used in the prototype. In the game, the user manipulates the angle of a turret to aim at and shoot asteroids. The goal is to minimize damage to a spaceship and to maximize asteroids destroyed.
        - Any control mechanism which would typically be guided by the hand, but while both hands are occupied with other tasks.
        - Direction Selection. Register “up”, “down”, “left”, “right” and “neutral” as inputs to the game. Half-way directions such as “upper-left” may also be registered.

<u>Detailed Design Descriptions</u>

- Circuit Schematics





V+
R7
4.7k
R8
4.7k
GND
V+
2
3
7
4
6
U3A
OPA237UA
GND
Vref
P1
Vertical EOG
Horizontal EOG
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
LeftNano
V+
C5
.1uF
GND
GND
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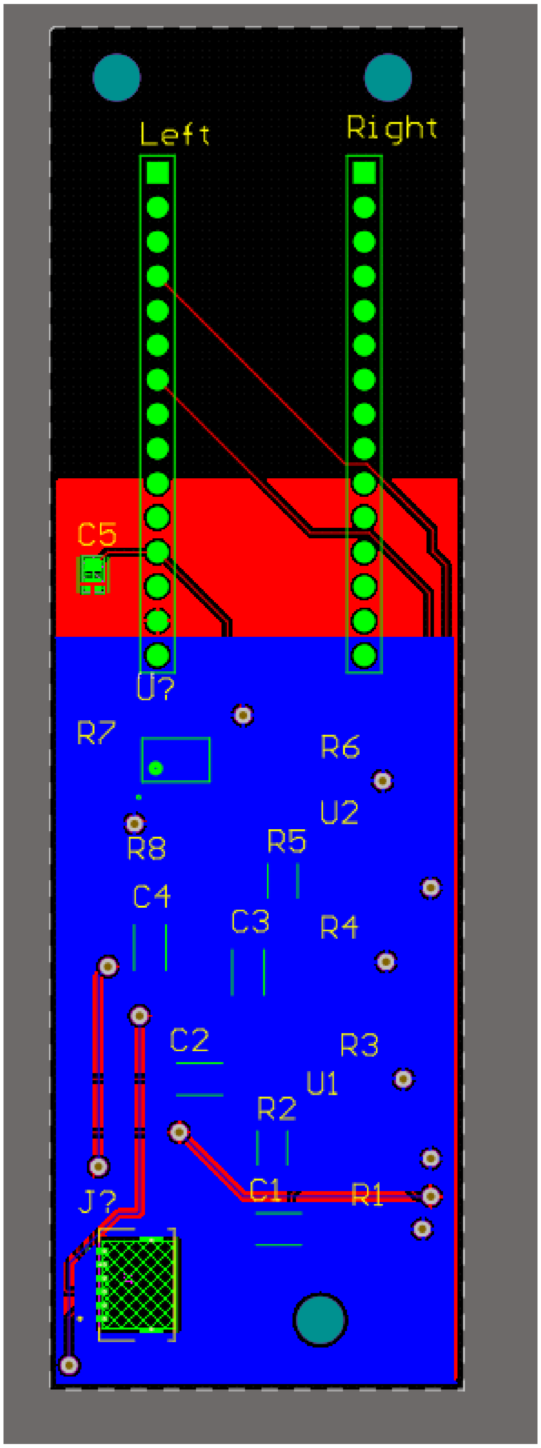
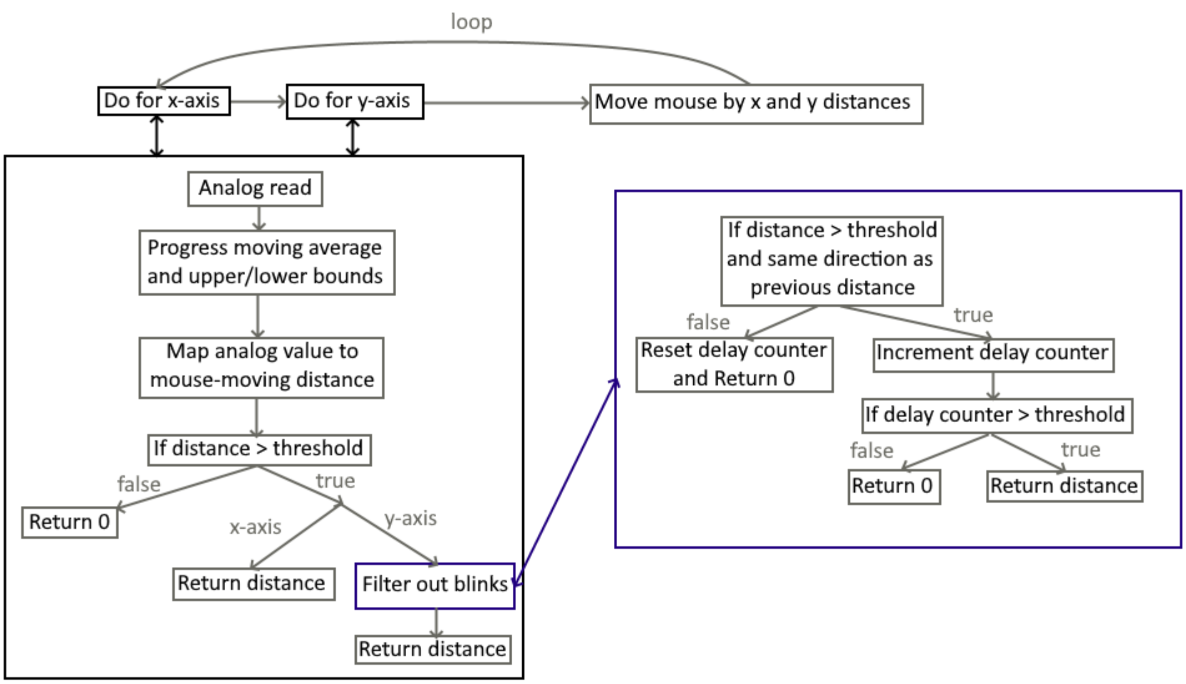
RightNano

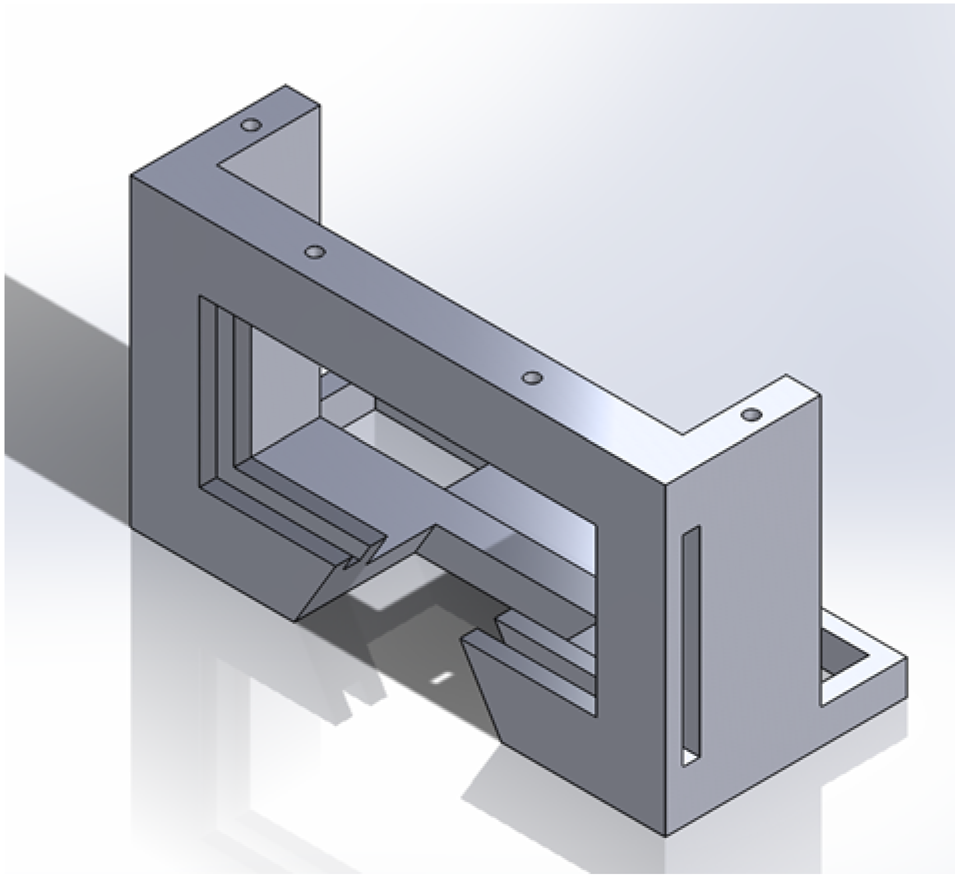
- PCB Layout



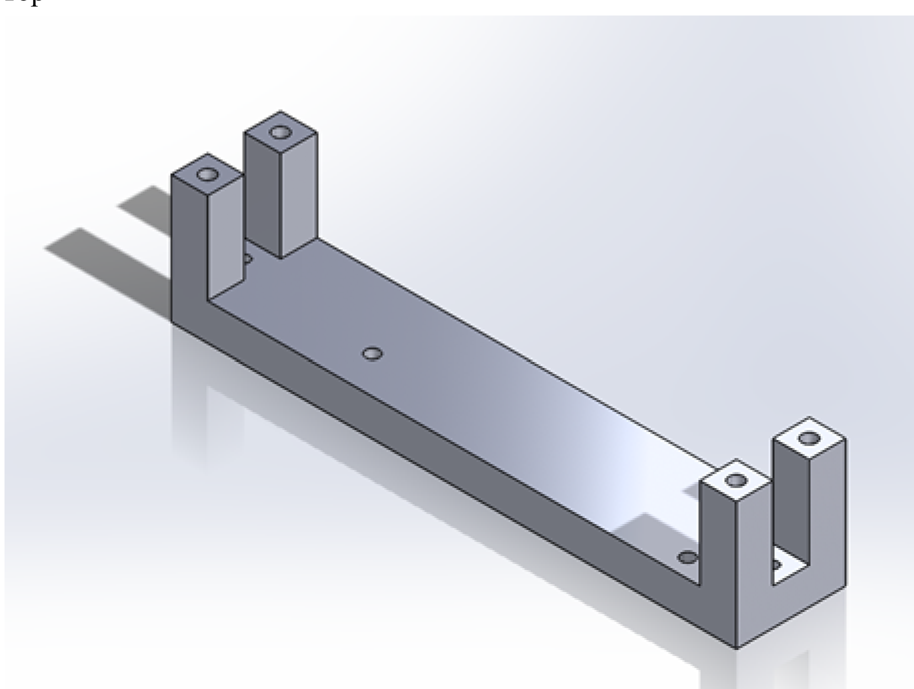
- Process Algorithm Flowchart (prototype implementation)



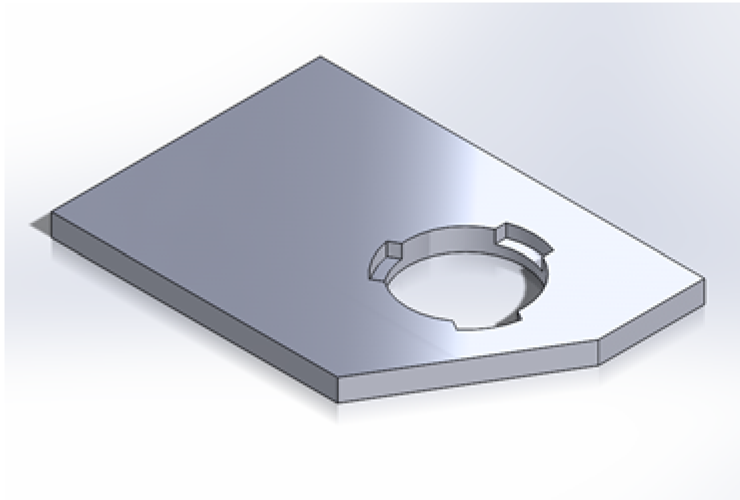
- Casing Design
    - Base

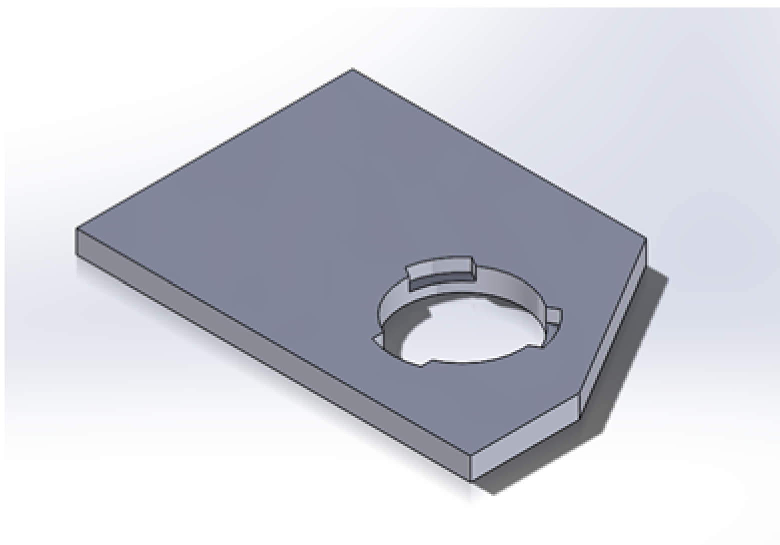


    - Top



- Lens-Plates

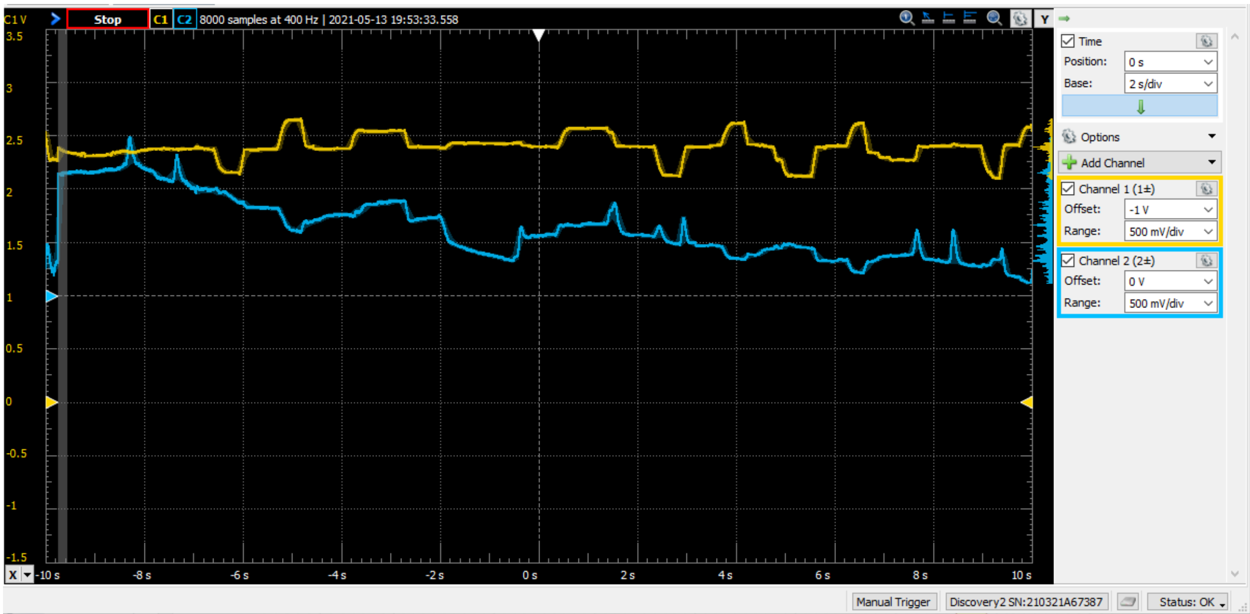




Validation and Acceptance Test Results

- Supply Output
    - Confirmed with headset turning on
    - Voltage level at circuit input from microcontroller read 3.3V as intended.

- EOG Reading/Gain Stage
  - The figure below displays our circuits ability to read an EOG and have distinguishable peaks/troughs as an indication of looking left/right or up/down. This is proof of both the circuit and gain stage in action. Without the gain stage, the peaks would be hard to notice at 50-3500 uV



- Cursor Accuracy
  - A traditional mouse grants vastly superior accuracy. It is possible to aim with the EOG, but it requires large, deliberate movements of the eyes. EOG is not well suited to this test. Due to the high threshold "on/off" nature of EOG signals that we observed, we think EOG would be better suited for a direction-select control mechanism.
- Latency
  - The blink-removal algorithm introduced ~100 ms delay into the vertical axis. There are no other significant sources of latency.
- Headset "Experience"
  - The current prototype is using a breadboard, not the PCB as intended. As a result, setup is not easy. With implementation of a proper PCB, ease of setup would improve.
  - The headset is structurally very sound.
  - The headset is reasonably comfortable. This could be improved with higher quality foam.
  - The headset is not uncomfortably heavy, nor does it shift due to weight.
  - The casing looks acceptable. Management of electrode wires and hiding of circuitry could be improved.

Global Issues

- Global Compatibility
  - Battery Charger accepting input ranging from 110VAC to 220VAC will be incorporated, alongside plug adapters. This is designed to adhere to local electrical standards.
  - The device would meet FDA standards for a Class II device. The device will have to meet

the regulation standards for all countries it is distributed in.
    - Game Simulation: Various countries will have different restrictions on the type of content that can be distributed. This will be addressed by providing a local game rating, as designated by the local ratings board. For example, in the U.S, the product would be submitted to the Entertainment Software Rating Board (ESRB) for proper designation.
- Individual Health
    - The success of our project was impacted by one of the members getting a concussion early in the semester. With this being at our PCB design stage, it delayed our testing and made it difficult to make necessary changes later in the semester. This partially reflects the issue of a single dependency for circuit design. In a larger company or project group, this health issue would not have nearly as big of an impact on the project outcome. Yet, for our class it did affect our ability to make a more complete product.

Work Plan

Gantt Chart

See Appendix A

Work Breakdown Structure

[planned]/[actual]

R: Responsible

A: Assisting

[blank]: No part in it

Task	**People**		
	JJ	Shivum	Jordan
Order prefabricated components	R/R	/A	A/A
Design PCB	A/	R/R	A/
Order PCB	A/	R/R	A/
Solder/Construct Board	A/A	A/R	R/R
Design casing in CAD	R/R	A/	A/
3D Print casing	A/A	/	R/R
Conduct initial circuit testing	A/	R/R	A/A
Conduct EOG signal testing	A/A	R/R	A/A
Design EOG control algorithm	A/A	R/A	A/R
Assemble headset	R/R	A/	A/A
Research VR game development	R/R	/	A/
Design VR game	R/R	/	A/
Final validation/acceptance testing	A/R	A/R	R/R
Performance testing/analysis	R/R	A/R	A/R

Proposed Budget

Items	Cost
Reusable Snap Electrodes	$50.00
EEG Silver Cup Electrodes	$49.95
Arduino Nano	$0.00
HC-05 Arduino Wireless Bluetooth Receiver	$0.00
Electronic Components	$40.00
Feelworld FW568 5.5" Camera Field Monitor	$99.99
Lenses x 5 pairs	$4.50
PLA Filament (3D Printing) 1Kg x 3	$77.97
Digilet Analog Discovery 2	$0.00
AD8226 Amplifier	$12.08
Capacitors and Resistors	$5.00
PCB Board	$18.00
NP-F550 RAVPower Batteries and Charger	$35.99
Shipping and Handling	$66.73
Total	$460.21

Final Expenditures

Items	Cost
3m EEG Electrodes	$0.00
Danlee Leadwires	$30.73
Arduino Nano	$0.00
Arduino Micro x2	$38.00
Feelworld FW568 5.5" Camera Field Monitor	$99.99
Lenses x2 pairs	$1.80
Diglilet Analog Discovery 2	$0.00
PLA Filament	$0.00
AD 8226 Amplifier x2	$6.40
PCB Boards	$17.80
NP-F550 RAVPower Batteries and Charger	$35.99
Resistors and Capacitors	$11.73
AD8226 x 1 and Socket Adapter	$20.23
Shipping and Handling	$66.73
Total	$329.40

The final expenditures are significantly lower for two main reasons. First, we opted to use disposable 3M EEG electrodes rather than permanent electrodes. Second, we used the free 3D printing service offered by the ECE shop. It was necessary to upgrade from an Arduino Nano to an Arduino Micro because the Micro has HID support (used for sending mouse signals to the computer) and the Nano does not. The second Micro had to be bought because the first had been soldered into a faulty PCB circuit. Also, two of its analog inputs were damaged during testing. This expenditure could have been mitigated by having a more mutable PCB design (use sockets for the arduino, not through-hole soldering).

Feasibility Assessment

This project is very feasible. The concept and implementation of EOG based gaze-aiming has been explored in several published research papers. Instructional resources are available for the other aspects of the project, and our team has adequate experience to handle most of the technical challenges. We expect the implementation of the processing and control algorithms and the design of the housing will present the biggest challenges. There is also some concern about the usability of EOG based gaze-aiming. Here is a more detailed list of the project's strengths and weaknesses:

Strengths:

- A team member has experience with electrooculography.
- A KSU faculty member has experience with electrooculography.
- A team member has experience with game design.
- Acceptable budget.
- Instructional resources are available for these parts of the project:

        - VR game development.
        - VR headset design.
        - CAD design.
    - A signal processing algorithm has been outlined by Iáñez, Eduardo, et al.
    - EOG has less cognitive load than traditional hand-eye controllers which could lead to faster response time.

Weaknesses:
    - EOG is notoriously inaccurate compared to traditional hand-eye controllers.
    - Implementing the processing and control algorithms will likely be a major challenge.
    - Designing the headset housing to be 3D-printed will likely be a major challenge.

<u>Lessons Learned and Recommendations for Feasibility and Risk Mitigation</u>

- PCB construction: We soldered the Arduino and the electrode leads directly to the PCB. This made for tough situations if something went wrong with the Arduino or the leads. This issue could have been mitigated by incorporating sockets into the PCB.
- PCB soldering: We hand-soldered the surface-mount components to the PCB. Faulty soldering cost us several work-hours in troubleshooting and repairs. The use of a stencil and reflow soldering could have mitigated these problems.
- Feasibility: Through testing in our VR environment, we found an EOG to be inadequate for controlling sharp and fluid movements. It functions in a similar manner to a digital signal in which it is either "on" or "off". Combined with rise and fall times of ~80ms, it is much more suitable to use an EOG for direction-select applications.
- Derivative Algorithm: Although the derivative algorithm does work well with direction selection, using the derivative algorithm for precise manipulation of a cursor or target crosshairs is less than satisfactory. The absolute method would have been a more accurate way.

Conclusion

The goal for our project was to design and build an ocular controlled VR headset and virtual testing simulation. The user can manipulate a cursor and perform cursorless aiming tasks via ocular control. The capability of the VR headset and the abilities of the user was to be tested in a simulation that consists of various mini-games which will be designed in the Unity engine.

We succeeded in constructing a prototype for the VR headset and EOG system. In its current state, the headset and EOG system are separate, not one streamlined unit as originally intended. Regardless, the prototype functioned as a proof-of-concept of EOG technology in a VR environment. Our results showed that EOG can function as a control mechanism for cursorless aiming, however, it is inferior to traditional mouse control in both accuracy and convenience. Due to the high threshold "on/off" nature of EOG signals, we reach the conclusion that EOG is better suited for a direction-select type of control mechanism.

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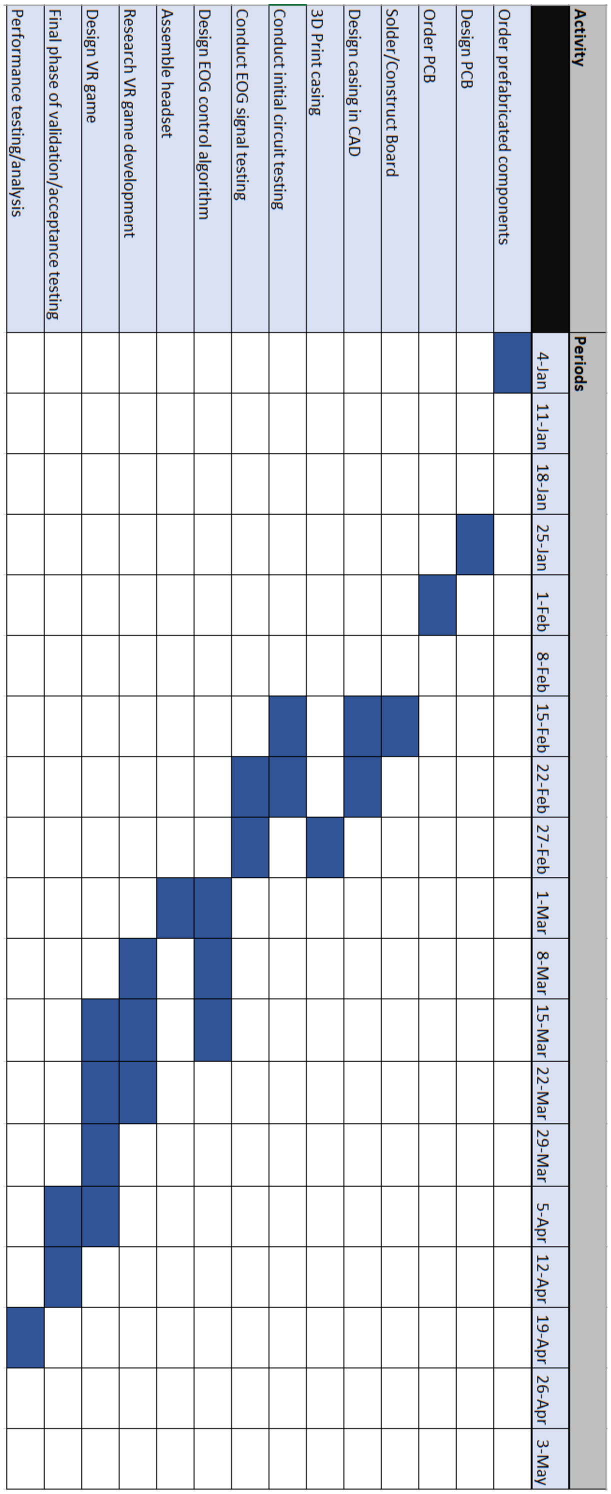
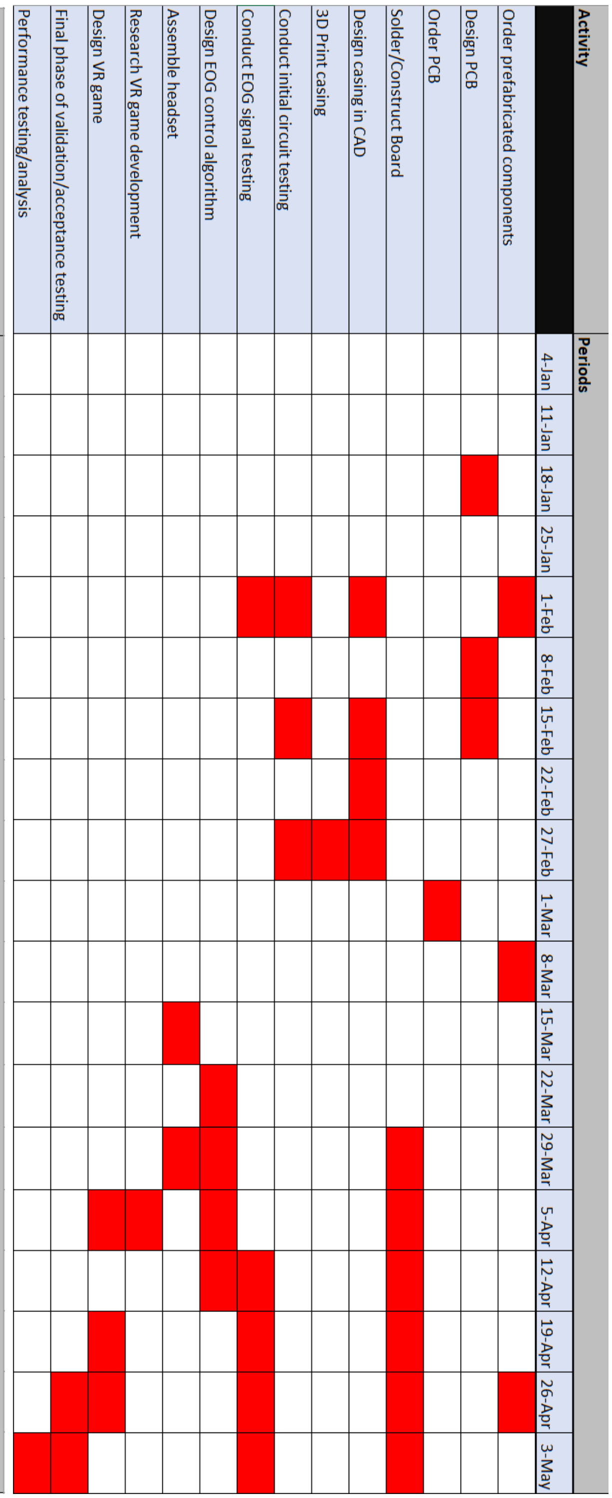
Entertainment Software Rating Board. “Ratings Process.” *ESRB Ratings Process*, ESRB, https://www.esrb.org/ratings/ratings-process/.

Appendices

Appendix A: Gantt Chart

Blue is the initial plan. Red is actual.





Appendix B: Processing Algorithms

Derivative method: