Electrooculography (EOG) Dinosaur Game

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***Abstract*—The use of an EOG circuit can be utilized to control basic keyboard operations to perform simple tasks such as playing games. Specifically, the signals from a person's eye movements were used to control the up and down arrows of a computer keyboard. In order to prevent unwanted noise from affecting the circuit's control ability, a bandpass filter was utilized. Though this is a simple control system, the concept of a non-verbal communication device is not new in modern medicine. For example, there are existing examples of individuals suffering from locked-in syndrome and Lou Gehrig's disease using an eye-controlled communication device due to their inability to speak or use other gestures. This project employs the usage of Falstad to digitally simulate this control circuit for visualization and a physically-built circuit with an Arduino DUE to translate signals into keyboard presses.**

I. Introduction

Amyotrophic Lateral Sclerosis (ALS) a progressive neurodegenerative disease which leads to full body paralysis due to weakness, muscle atrophy, and loss of motor neurons. People in late-stage ALS usually only left with eye movements and blinking. To establish communication with their surroundings devices can be used to translate eye movements into outputs.

Electrooculography (EOG) is a non-invasive technique that measures the electrical signals generated by the eye muscles by using surface electrodes. By detecting these signals and translating them into commands, EOG can enable users to interact with digital environments in novel and exciting ways. One popular application of EOG is a keyboard controlled by eye movements to communicate more efficiently.

In this project, we aim to design and build an EOG controller that allows users to play the "no-wifi" dinosaur game using only their eyes. No-wifi dinosaur game, a simple but addictive game that challenges players to control a running dinosaur and avoid obstacles. Our controller will consist of a circuit with EOG sensor, an arduino microcontroller, and a software interface that maps the EOG signals to game actions.

By developing an EOG-based game controller, we hope to contribute to the growing field of human-computer interaction and explore the potential of EOG as a new input modality for gaming and beyond. We also aim to inspire future research and development in this area and encourage more people to discover the exciting world of EOG technology.

II. EOG Falstad Simulation Circuit

A. Overview

Before any circuit construction, the best course of action is to simulate ideal scenarios. Through a simulation, as shown in Figure 1, testing signals and understanding the roles of each section of the circuit become much easier. For the purposes of the lab, the circuit simulation provided by Falstad was utilized.

B. Theoretical Calculations

In order to record eye signals with an EOG, the gain and cutoff frequencies must be calculated. A table of the theoretical and measured values can be found in the appendix, denoted as table A1.

The gain of this EOG circuit can be calculated with

$$G = (1 + \frac{R_1}{R_4}) \cdot (\frac{50.5k\Omega}{R_g} + 1)$$

$$= (1 + \frac{150k\Omega}{5.1k\Omega}) \cdot (\frac{50.5k\Omega}{100k\Omega} + 1)$$

$$= 45.77$$

The cutoff frequencies can be calculated with

$$f_c = \frac{1}{2\pi \cdot R \cdot C}$$

Theoretical High-Pass Cutoff:

$$f_c = \frac{1}{2\pi \cdot 100k\Omega \cdot 22\mu F}$$

$$= 0.072\, Hz$$

Theoretical Low-Pass Cutoff:

$$f_c = \frac{1}{2\pi \cdot 150k\Omega \cdot 10nF}$$

$$= 106.103\, Hz$$

C. Choosing Components for the Low Pass Filter

In order to filter out small signals and other noises that come from actions like blinking, a low pass filter should be utilized. This would allow the group to set a signal threshold so that the person using the device could actively control the video game without unwanted interference.

In the process of choosing components for the low pass filter, the group aimed to make the low pass cutoff as close to 106.103 Hz as possible while only utilizing a resistor and a capacitor. In order to achieve this, the equations above can be referred to which resulted in the desired component values for R_1 and C_1 being chosen to be 150 kΩ and 10 nF respectively (Figure 1). These values were primarily chosen since they are values that one would typically encounter in a lab setting. By choosing such values, finding physical components would be fairly simple.

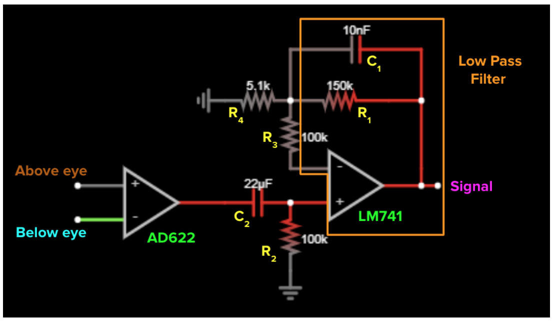

Figure 1: The low pass filter consists of C_2 and R_2 as indicated and is located between the AD622 and LM741.

D. Choosing Components for the High Pass Filter

Just as how the low pass filter was used to filter out noise, the high pass filter was added to insure that there will not be unwanted signals from DC drift. This would allow the user of the device to have consistency in the game controls without worrying about having signal offset.

In order to choose reasonable components for this purpose, the high pass cutoff should be approximately 0.072 Hz. In order to satisfy this condition, the equations above can be utilized again which lead to the components R_2 and C_2 being chosen to be 100 kΩ and 22 µF respectively (Figure 2). These values can be reasonably found in a physical lab setting, making these chosen theoretical values work. By choosing these values, it will also be easier for individuals to reconstruct in a lab setting.

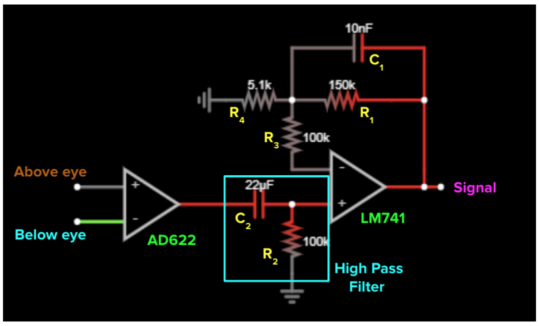

Figure 2: The high pass filter consists of C_2 and R_2 as indicated and is located between the AD622 and LM741.

III. EOG Circuit Prototype

A. Overview

The circuit design that we used is largely based on an existing ECG circuit, but we used it to take EOGs instead. The design consists of an AD622 instrumentation amplifier and an LM741 operational amplifier, as discussed in previous sections. The physical circuit design can be visualized in Figure 3. See table A1 for the measured component values.

B. Circuit Schematic

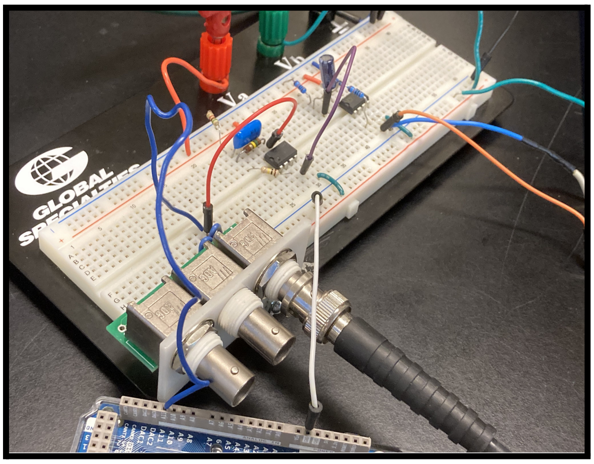

Figure 3: circuit prototype used to filter & amplify raw EOG signals.

Figure 3 depicts the general layout of the circuit that is used for our design. Figure 4 shows the circuit at a different angle, and the connections are labeled.

C. Measured Value Calculation Formulas

Similarly to the theoretical calculations, the measured calculations will use the same formulas. The only difference is, the calculations will be done with the measured values instead of the theoretical component values. A table of the theoretical and measured values can be found in the appendix, denoted as table A1.

The gain can be calculated as such:

$$G = (1 + \frac{R_1}{R_4}) \cdot (\frac{50.5k\Omega}{R_g} + 1)$$

$$= (1 + \frac{166.4k\Omega}{5.05k\Omega}) \cdot (\frac{50.5k\Omega}{98.4k\Omega} + 1)$$

$$= 51.37$$

The cutoff frequencies can also be calculated with:

$$f_c = \frac{1}{2\pi \cdot R \cdot C}$$

Measured High-Pass Cutoff:

$$f_c = \frac{1}{2\pi \cdot 99.1k\Omega \cdot 20.6\mu F}$$

$$= 0.078\ Hz$$

Measured Low-Pass Cutoff:

$$f_c = \frac{1}{2\pi \cdot 166.4k\Omega \cdot 9.701nF}$$

$$= 98.59\ Hz$$

D. Choosing Components for the Low Pass Filter

The reasoning behind choosing these values is to get a low-pass cutoff of around 100 Hz. The calculations show that the cutoff is approximately 100 Hz (1.4% off).

E. Choosing Components for the High Pass Filter

Similarly, the components chosen for the high pass filter are 99.1 kΩ and 20.6 µ*F* for the resistor and the capacitor, respectively. The goal behind these two parts is to get a high-pass cutoff of around 0.07 Hz. The calculations show that the cutoff is approximately 0.07 (11.4% off).

F. Assembling the Prototype

To assemble our eye-tracking prototype, we used the following materials: an Arduino Due, electrodes, a computer with Google Chrome installed, a USB cable, a cable to an oscilloscope, cables to a power supply, a breadboard, Op Amps, jumper wires, resistors, and capacitors. All components used were chosen to mimic the theoretical circuit that was initially designed. The measured component values were recorded in order to calculate the measured gain and cutoff frequencies.

The initially designed circuit was reconstructed on a breadboard. The input of the filtering circuit was connected to the electrodes with jumper wires. The circuit's output was forwarded into the A11 pin of the Arduino Due using more jumper wires. Ground and power wires were places where appropriate. We connected the arduino to the computer via USB cable and programmed it using the code that is discussed in the next section. The sticky ends of the electrodes were placed above and below a test-subject's eyes. Finally, through multiple rounds of trial and error, we adjusted the threshold values such that the dinosaur in the "no-wifi" game would jump according to each appropriate eye movement.

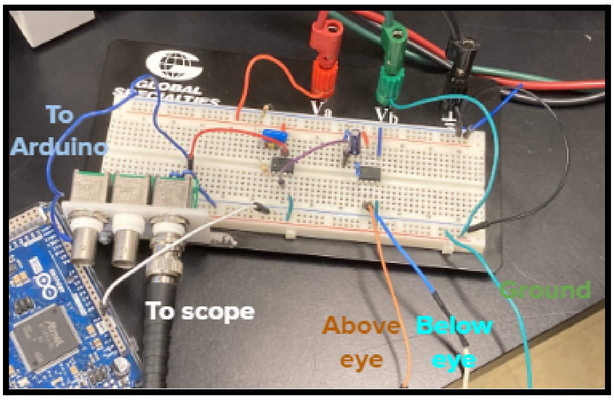

Figure 4: Prototype Circuitry.

G. Understanding the Arduino Code

The code we used is a basic Arduino program that defines the analog input pin and two threshold values for triggering the "up arrow" and "down arrow" keys. In the setup function, the program initializes serial communication, sets the pin mode for the analog input, and initializes the Keyboard library. In the loop function, the program reads the analog input and maps it to a range of values, prints the values for debugging purposes, and triggers the appropriate key based on the mapped value. The program also includes a delay to prevent multiple key presses from a single eye movement. The thresholds for triggering the "up arrow" and "down arrow" keys can be adjusted by changing the values of thresholdUp and thresholdDown.

H. Distinguishing Between Blinks and Looking Up

This code does not falsely trigger the arrow keys when blinking because it reads the analog input signal from the eye-tracking sensor and maps it to a range of values that are compared to the predetermined threshold values for triggering the arrow keys. When you blink, the sensor may briefly show a change in the analog input signal, but it should not be enough to reach the threshold values and trigger the arrow keys. Additionally, the code includes a delay() function that prevents the arrow keys from being triggered too frequently, so even if there is a momentary change in the signal due to blinking, it is unlikely to cause a false trigger.

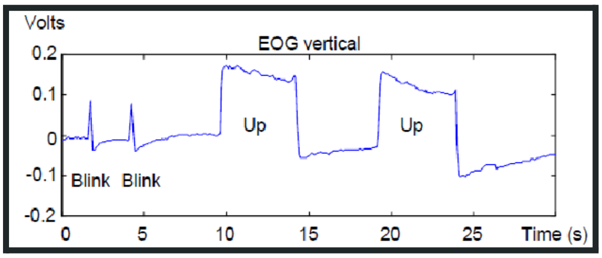

Figure 5: Example of Blink vs. Looking Up Signal Amplitudes [8]

I. Choosing Electrode Placement

When choosing the electrode placement for an eye-tracking sensor, it is important to consider the specific use case and the type of eye movement you want to track. Generally, electrodes should be placed around the eye to measure the electrical potential difference that occurs when the eye moves. One common placement is to place one electrode above the eye and one below the eye, with a reference electrode placed on the hip. While the specific placement of electrodes can vary depending on the eye-tracking sensor being used and the specific use case, it is important to note that the differences in the measured signals caused by different placements are typically negligible. In general, the electrical potential difference that occurs when the eye moves can be reliably measured by electrodes placed in the general vicinity of the eye, and the placement of the electrodes is unlikely to significantly affect the accuracy or reliability of the measurements. However, it is still important to follow best practices and guidelines for electrode placement to ensure consistent and accurate measurements. If there are any concerns about the quality or consistency of the signal, it is helpful to adjust the threshold values in the arduino code so that the system becomes more or less sensitive.

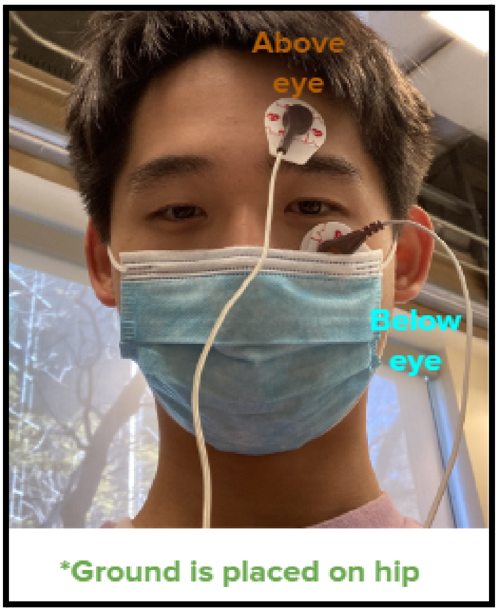

Figure 6: Visualization of electrode placement.

IV.. RESULTS

Ultimately, the device succeeded in taking in the physiological voltage from the EOG electrode leads and amplifying the signal with sufficient gain that it allows for well-defined boundaries to be set very easily in order to distinguish when the player is looking upwards or downwards. The boundary condition for the Arduino to input a jump or duck keypress into the browser can also be easily changed depending on the specific gain of acceptable configurations.

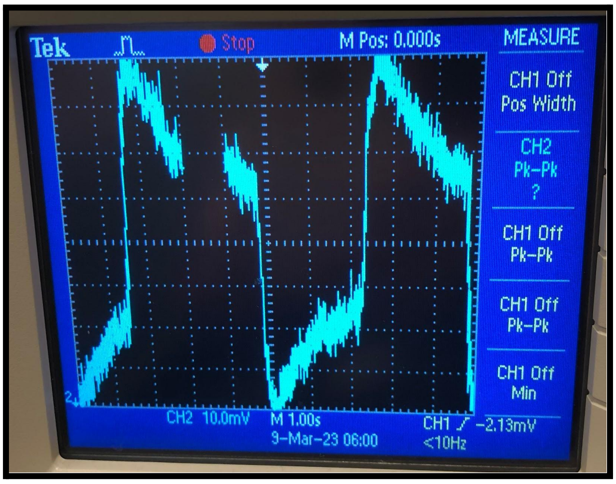

Figure 8: Recorded EOG Signal (looking down, up, down, up)

A. Limitations

A limitation of the device for consideration would be that in a normal desk setup based on ergonomics, the monitor for the user would be at the height of at or below the user's eye level. As such, looking up in order to input a command would necessitate the user to look away from the screen, which could present a challenge for the user later into the game once the dinosaur has less time to react to obstacles.

B. Future Directions

An alternative possibility for the device's software could be that instead of filtering out blinks, the threshold could be set to detect blinks and register them as jump inputs. It would be more intuitive than looking up and presumably easier, mitigating the delay of looking up and back down, but it would still run into the same problem eventually where there's an inevitable and fixed amount of lag when the user can not see the screen.

```
// Define the threshold for trig
const int thresholdUp =8;

// Define the threshold for trig
const int thresholdDown = 0;
```

Figure 7: Threshold Boundaries in Arduino

```
// Trigger the appropriate key based on tl
if (mappedValue > thresholdUp) {
  Keyboard.write(KEY_UP_ARROW);
  delay(50);
} else if (mappedValue < thresholdDown) {
  Keyboard.write(KEY_DOWN_ARROW);
  delay(50); // may also need to adjust tl
}
```

Figure 8: Output logic in Arduino

A more elaborate solution to the aforementioned limitation of the project if someone were to develop it further in the future could be to have the monitor physically move up or down in coordination with the user's eye movements. This would probably be accomplished by taking in the user's height and position relative to the monitor and having the monitor move mechanically based on the person's change in eye angle and distance from the screen in a way akin to eye tracking. The setup would be similar to the figure below

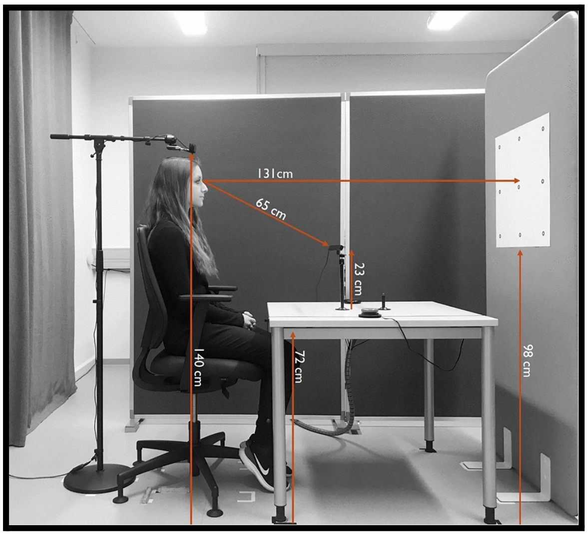

Figure 9: Sample setup of an eye-tracker taking relative positions into account [9]

C. Industry Significance

The significance of the device in the context of the industry is that it is yet another application of a bioinstrument, in which it takes in a physiological signal, processes it in some meaningful way, and outputs a desired response to the input signal. Specifically, it accomplishes this using widely accessible commercial components and functions as an effective biosensor.

E. Applications

A potential application of our device would be enabling users that suffer from various conditions that impairs their finer motor functions, such as locked-in syndrome, where the victim's body is paralyzed except for their eyes or Lou Gehrig's Disease, which is a neurodegenerative disease that progressively debilitates the motor nerves. In both cases, the user would essentially be re-enabled to interact with a digital interface in a binary fashion using up or down eyeball movements.

IV. Conclusion

Utilizing a combination of a physical circuit, an Arduino, as well as user inputs via an EOG, our project was effectively able to demonstrate that it is relatively simple to control an application of binary input, such as the offline dinosaur game. The game features jumping up & down at its base level, which makes it so the circuit would only need to detect the voltage changes that occur when the user moves their eye up or down, and translate that into a keyboard input so that the dinosaur can jump and duck inside the game and avoid obstacles.

The development of this project is a proof of concept for controlling a simple application without the use of one's hands. This concept could be further developed and applied to far more complex applications that can alter the lives of those who cannot use their hands, due to injury or disease.

Acknowledgments

We would like to express our gratitude to Dr. Gert Cauwenberghs and the BENG 186B TA's for their lectures and guidance throughout the quarter. Their expertise and support helped gain a better understanding of the concepts and challenges associated with this project. In addition, we'd like to thank Dr. Bruce Wheeler for providing us with guidance and circuitry components for assembling our prototype.

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Appendix

A1. Table of the theoretical and measured values for the design.

	Theoretical	Measured
R_g	100kΩ	98.4kΩ
R_1	150kΩ	166.4kΩ
R_2	100kΩ	99.1kΩ
R_3	100kΩ	99.8kΩ
R_4	5.1kΩ	5.05kΩ
C_1	10nF	9.701nF
C_2	22μF	20.6μF