EoG to Convert Blinks into Morse Code

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***Abstract* — This paper presents the use of Electrooculography (EoG) to facilitate communication for individuals suffering from ALS who no longer have the ability to communicate through normal means, whether verbally or through sign language. The device accomplishes this by recording blinks and translating the blinks into Morse Code symbols. The backbone of our communication system is our biopotential amplifier EoG circuit consisting of an instrumentation amplifier, operational amplifier, and other passive components. The circuit is complemented by software (MATLAB) for signal processing to precisely detect and differentiate blinks. Our circuit was able to successfully generate voltage values through inputs replicating the electrode inputs. We found that many factors affect the signal recorded and produced by the EoG, and that in order for our device to operate successfully, it had to be able to recognize and filter out non-communicative signals. Applications for this device could be extended to non-clinical settings.**

I. Introduction

Amyotrophic lateral sclerosis (ALS), or more commonly known as Lou Gherig's Disease, is a neurodegenerative disease that attacks motor neurons responsible for voluntary muscle control [1]. The degeneration of motor neurons initially causes fatigue, weakness, and difficulty in accomplishing everyday tasks such as eating, breathing, and speaking. In late-stage ALS, these symptoms cascade into almost complete muscle paralysis [2]. However, an individual's eyes are typically the last to be affected by ALS, and our project aims to take advantage of the prolonged functionality of the eyes.

Electrooculography (EOG) is used to measure the electrical potential generated by the movement of the eyes, and the signal is then processed and converted into Morse Code. An EoG is our technique of choice because it is a non-invasive form of recording data from the human body. EoG's function through electrodes that are placed around the eyes. The specific location can be manipulated depending on the type of eye movement being targeted. In our project, we are focusing on blinking, as we believe it is less physically exhausting and dizzying than other eye movements, such as looking in various directions. We want to reduce the amount of labor considering our intended audience. Blinks are translated into electrical signals which are converted into morse code and further translated into letters through MATLAB.

This project aims to increase the quality of life for individuals with ALS by providing them a form of independent communication. Independence is something that many people take for granted, and ALS patients have no choice but to abandon independence as symptoms worsen. Potential future applications include increasing independence and a sense of normality by incorporating text-to-speech software for our Morse Code translations.

II. Methods

A. Circuit Overview

The goal of the EoG circuit is to take the signal from electrodes placed on the face and measure voltage deviations from a reference and run it through a biopotential amplifier. The objective of the amplifier is to sense, amplify, and filter out the signal, then output a modified signal into MatLab to convert the voltage into Morse code. The circuit components used in the EoG circuit are a 9 V battery to power the circuit, an instrumentation amplifier, an operational amplifier, resistors and capacitors. Two electrodes will be connected to the inverting and non-inverting input nodes of the AD622 and the third electrode will be connected to the reference ground pin of the AD622.

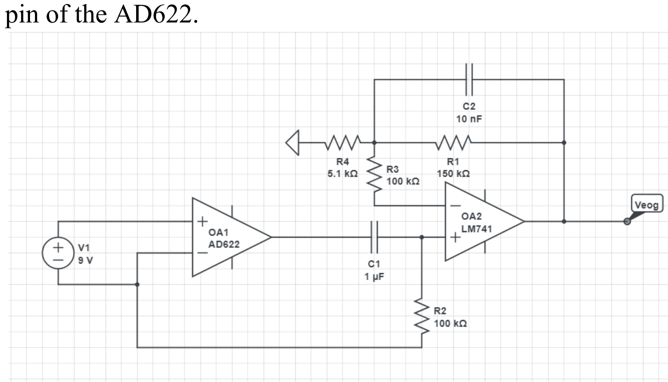

Figure 1: Circuit diagram of EoG circuit that is powered by a 9V battery. *In reality, the inputs of AD622 are connected to the positive and negative electrodes and the electrode connected to ground is connected to the reference node of the AD622.

B. Instrumentation Amplifier

The first component of the circuit is an instrumentation amplifier that is intended to amplify the signal by amplifying the difference in voltage between the two input signals. The circuit component used is an AD622 standard instrumentation amplifier. This component buffers the input, has a high input impedance, and provides differential amplification with a high common-mode rejection ratio due to the CMRR of the AD622 in order to preserve the integrity of the original signal. The gain of this component is calculated via:

(1) $R_{gain} = 50.5\ k\Omega / (Gain_{In\ Amp} - 1)$

For this EoG circuit, a R_{gain} value of 2 kΩ was used so the gain can be calculated as 26.25. The CMRR of the circuit can be calculated via:

(2) $CMRR = Gain_{Differential} / Gain_{Common\text{-}mode}$

Ideally, the common-mode gain should be zero while the differential gain is the gain calculated from R_{gain}. The circuit components downstream of the AD622 are for additional gain and filtering.

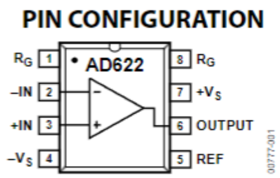

Figure 2: Pin configuration of the AD622

C. Operational Amplifier

The operational amplifier acts as additional gain downstream from the AD622. Operational amplifiers are used to acquire a signal of interest and they are voltage amplifiers with high gain. A LM741 operational amplifier is used in this EoG circuit. The operational amplifier is used as a non-inverting amplifier and the gain can be calculated via:

(3) $Gain_{Op\ Amp} = 1 + (R_1 / R_4)$

For this EoG circuit, R_1 is 150 kΩ and R_4 is 5.1 kΩ, and the gain can be calculated as approximately 30.41. The overall gain of the entire EoG circuit can be calculated as:

(4) $Gain_{total} = Gain_{In\ Amp} \bullet Gain_{Op\ Amp} = ((50.5\ k\Omega / R_{gain}) + 1) \bullet (1 + (R_1 / R_4))$

The overall gain of the circuit is calculated by multiplying the gain from the instrumentation amplifier which is rearranged to solve for gain from equation (1) and the gain from the operational amplifier. From the values that were chosen, the gain of the instrumentation amplifier is 26.25 and the gain of the operational amplifier is 30.41 and the resulting total gain will equal 798.3.

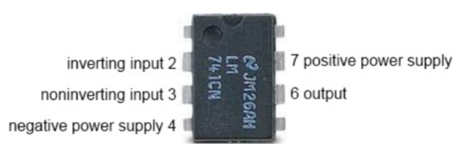

Figure 3: Pin configuration of LM741

D. Low-pass filter

R_1 and C_2 make a low-pass filter which only allows low frequency signals to pass through. For low frequencies, the capacitor is open and for high frequencies, the capacitor is closed. The time constant can be calculated via:

(5) $\tau = R \bullet C$

For the low-pass filter, the time constant is R_1 multiplied by C_2 which is equivalent to 150 kΩ multiplied by 10 nF which equals 0.0015 seconds. The cutoff frequency is calculated via:

(6) $f_C = 1 / (2\pi \bullet \tau) = 1 / (2\pi \bullet R \bullet C)$

For this filter, the cutoff frequency is calculated as 106.1 Hz and this means that any signal with a frequency higher than the cutoff frequency can't pass through.

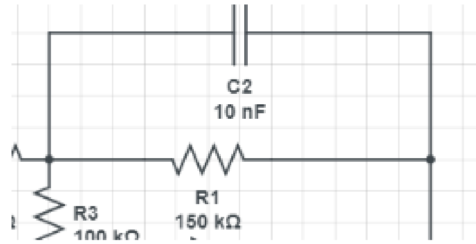

Figure 4: Circuit configuration of the low-pass filter

E. High-pass filter

R_2 and C_1 make a high-pass filter which only allows high frequency signals to pass through. The filter blocks DC drift and the value of C_1 was chosen to be 1 μF because this is better for EoG and EMG signals when compared to ECG signals. The time constant calculated using equation (5) is R_2 multiplied by C_1 which is equivalent to 100 kΩ multiplied by 1 μF which equals 0.1 seconds. The cutoff frequency calculated using equation (6) is equal to 1.6 Hz. This means that any signal with a frequency lower than the cutoff frequency can't pass through.

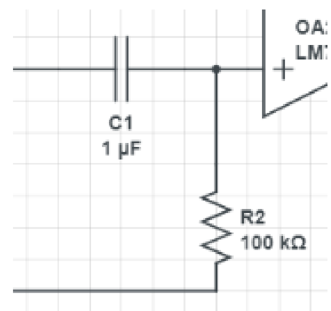

Figure 5: Circuit configuration of the high-pass filter

F. Extra information

R_3 has the same value as R_2 (100kΩ) so bias currents so that bias currents are canceled by the differential amplifier which eliminates the effect of bias currents while not affecting the desired gain.

The filters act as a bandpass filter from 1.6 Hz to 106.1 Hz which is good at rejecting common mode 60 Hz noise, but won't reject any 60 Hz in the differential between the two voltage inputs. The circuit is good at removing high frequency noises.

G. Conceptual Explanation of the MatLab Code

The goal of the MatLab code is to convert the EoG blinking signal into Morse code. This is done by converting the blinks into dots and dashes based on the duration of the activity spikes of the blink in the signal. First the EoG output signal will be inputted into MatLab through the DAQ or data acquisition. Next, the MatLab code will recognize the signal as an array or matrix so that it can perform calculations and commands on. The code will assign dots or dashes based on spike duration in the EoG signal that indicates short or long blinks, short blinks will be assigned dots and long blinks will be assigned dashes. Matlab will then recognize sequences or patterns of dots and dashes within a period to assign a letter to from a list of morse code translations.

H. Overview of MatLab Code
First, the Matlab code initializes the data acquisition system (DAQ) to read the signal at a rate of 50 Hz (as any higher would be higher resolution, but would take up more space than would provide a benefit. Then the DAQ is run for a period of 3 minutes, which is the limit on the length of messages of this system. During this, the data is compiled into a matrix of values.

After the data has been collected, the program starts at the 50th value and averages that value and the 49 prior values. If it measures a voltage above a resting threshold, the system triggers a loop that calculates the length of the activation. Depending on the length of the activation, a value is put into a matrix with a length of 4. After the matrix is full, then the final stage of the code is triggered. In this stage, the matrix is run through a series of nested loops to determine the letter that corresponds to the combination of values in the matrix. The letter is then displayed.

III. Results

From the generated voltage output, precise signal processing is critical for effective communication, as communication is dependent on accurate blink differentiation. The electrical signal produced from our EoG system can be plotted as a function of time. The plot depicts a baseline voltage, and a blink or some other form of eye movement causes a spike in the voltage. Different eye movements produce spikes of varying amplitudes, shapes, and widths. The specific width that we are interested in is the FWMS, which is the full width at maximum slope [3]. The FWHM, or the full width at half maximum, is another valid analysis metric.

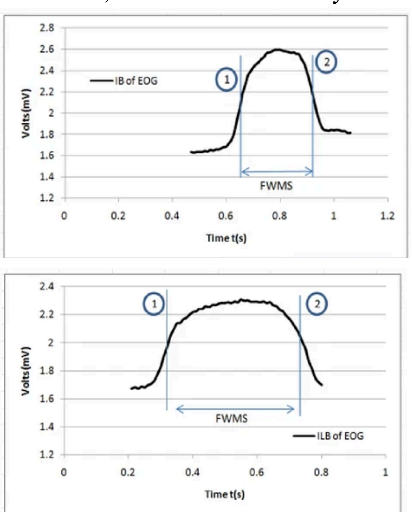

Figure 6: The upper plot depicts the electrical signal of a short blink as a function of time, and the lower plot depicts the electrical signal of a long blink as a function of time [3].

The initial voltage and time data however is incomprehensible for a computer and our MATLAB code. To give the data substance, the first derivative of the signal is taken and digitized. The purpose of taking the first derivative is to create more variance in the plot characteristics. Without taking the derivative, the only variable differentiating eye movements is the FWMS, and while this may be used to differentiate between blinks of different durations, it lacks the ability to differentiate when other factors such as blink force are introduced.

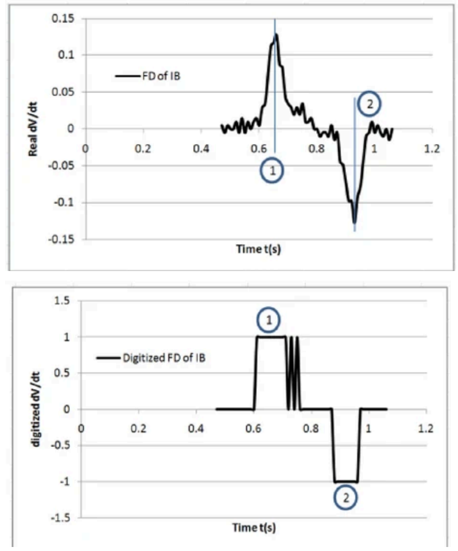

Figure 7: First derivative of signal (upper). Digitized first derivative (lower) [3].

Now, along with the FWMS information, we have information about the number of peaks and troughs. However, these peaks and troughs are arbitrary, and the computer cannot count the number of peaks and troughs because the peaks and troughs aren't all the same value. The digitized derivative converts all peaks to one, and all troughs to negative one, which allows the computer to identify the number of peaks and troughs as all peaks are assigned values of one and all troughs are assigned values of negative one [3]. Depending on the number of peaks and troughs in the digitized signal and the length of the FWMS (which is proportional to blink duration), the computer recognizes the type of blink, and each type of blink corresponds to either a dot or a dash in MATLAB. This is how communication is facilitated.

Another benefit of analyzing the FWMS/FWHM is to filter out accidental blinks that were not meant to count for communication. Tolerances can be set, and any blink duration above or below a set threshold can be omitted. This also filters out eye twitches, as the duration of an eye twitch is typically shorter than the blinking time range of 100 to 400 milliseconds [4]. If someone were to rest their eyes, and keep them closed for an extended period of time, this motion would also get filtered out if the time exceeded the threshold. This automated filtering provides some leniency in the translation. An example threshold would be blinks between 100 and 400 milliseconds count as a short blink, and blinks between 800 and 1200 milliseconds count as a long blink. The 400-800 milliseconds range provides some latitude in the intervals, and more clarity as to the differences between a long blink and short blink. We want to reduce overlap whenever possible.

Since the issues of involuntary blinks and intentional non-communicative blinks have been addressed, the last factor taken into consideration is the force behind the blink.

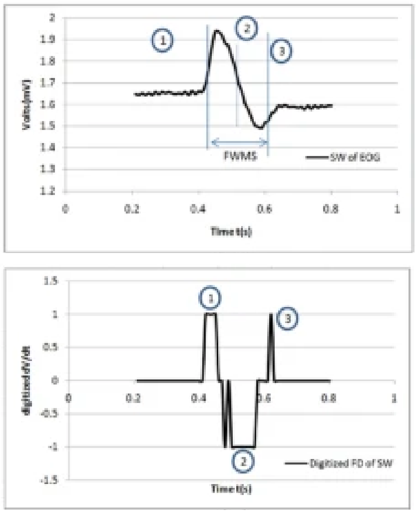

Figure 8: Electrical signal of intentionally forceful blink (upper). Digitized first derivative (lower) [3].

The issue with tolerancing forceful blinks is that the shape of the signal is different. Rather than the signal being a simple spike, we see an increase above the baseline, a decrease to below the baseline, and then a subsequent increase after that. Normal blinks do not have this third increasing component. This changes the number of peaks and troughs in the first derivative, which changes the digitized first derivative processed by the computer. The baseline measurements are pre-calibrated, and the acceptable FWMS/FWHM ranges can be calibrated according to the blinking speed of each individual. However, one of the things that the individual has to manually monitor and maintain is the force in which they blink with.

IIII. Discussion

A limitation of this device lies in the effectiveness of Morse Code itself. The use of Morse Code may not be the most efficient way of communicating, especially with longer messages. For longer messages, a person would need to blink many times, which may become uncomfortable or tiresome. Furthermore, each person's blinking pattern is unique, so the device must be calibrated to each user. The device must be able to distinguish short blinks from long blinks, and this differentiation may vary for each user. A short blink for one individual might register as a longer blink for another individual if the instrument wasn't uniquely calibrated. Another limitation is that the device must also filter out any eye movements that are not blinks such as eye twitches. Eye twitches provide unwanted signals that would result in the facilitation of inaccurate communication if not filtered out.

Non-twitch eye movements also present a challenge. For example, the device must be able to determine when a person is looking left/right or looking up/down, and omit this signal from being processed. This differentiation will ensure the intended communication signal is processed without interference from unintentional movement. Consistency with the user's eye movements is critical since irregular eye blinking would cause the system to incorrectly process eye movements. Given the potential for a myriad of factors to cause unwanted signals that disrupt communication, the calibration process must be extremely precise, and any tolerancing thresholds would need to be carefully set.

However, despite the limitations, our device does grant ALS patients a form of independence, which is something that has been ripped apart from them as a result of the disease. ALS patients need assistance with most of their everyday tasks, including eating, transportation, and general personal care [5]. For people with disabilities such as deafness, there are alternative methods for communication such as using sign language or speech generating devices. Late-stage ALS patients do not have this capability. As ALS progresses within a patient, muscles tend to become weak and muscle paralysis occurs, preventing them from making sign language [6]. This limits ALS patients' options in choosing communicating tools. An EoG communication device is a viable option for ALS patients since eye muscle control is sustained the longest when compared to the degeneration of other muscles. The use of text to speech technology could also be implemented, allowing for patients to communicate auditorily in real time, rather than having the person they are communicating with read words off a screen.

From a broader perspective, eye movements can also be indicators of neurological disorders of neurodegenerative diseases. For example, patients with Alzheimer's tend to exhibit eye movements such as saccades and smooth pursuit as a result of the disease [7]. EoG's can identify these eye movements and help with early diagnosis. EoG's could also be utilized in non-clinical forms, such as in a military environment where communication may be critical but traditional methods are not feasible. Another application could be in enforcing driver safety, as EoG's can help track a driver's eyes to ensure that they are focused and alert.

V. Acknowledgements

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VI. References

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