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Electrooculogram based system for computer control using a multiple feature classification model

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***Abstract*- This paper discusses the creation of a system for computer-aided communication through automated analysis and processing of electrooculogram signals. In situations of disease or trauma, there may be an inability to communicate with others through standard means such as speech or typing. Eye movement tends to be one of the last remaining active muscle capabilities for people with neurodegenerative disorders, such as amyotrophic lateral sclerosis (ALS) also known as Lou Gehrig's disease. Thus, there is a need for eye movement based systems to enable communication. To meet this need, the Telepathix system was designed to accept eye movement commands denoted by looking to the left, looking to the right, and looking straight ahead to navigate a virtual keyboard. Using a ternary virtual keyboard layout and a multiple feature classification model, a typing speed of 6 letters per minute was achieved.**

***Keywords*- electrooculography, computer control, hands free speller, eye movement analysis, amyotrophic lateral sclerosis, ALS, Lou Gehrig's disease, sensorimotor and neuromuscular systems.**

I. INTRODUCTION

The eye acts as a dipole with the front of the eye electrically positive in reference to the electrically negative back of the eye. This phenomenon was first observed by Emil du Bois-Reymond in 1848 and is foundational in electrooculography [1].

Electrooculograms are taken with bi-polar electrodes on the outside of each eye. Exact electrode placements vary, but the electrodes are generally placed on the temples or on the distal ends of the forehead. When there is eye movement, a differential potential results that is also related to the magnitude of rotation. In Figure 1, the magnitudes of the right and left eye movement can be seen as 150 µV and -75 µV respectively. The recorded polarity is dependent on the electrode setup since the signal is positive when the eyes are moving toward the positive electrode [1].

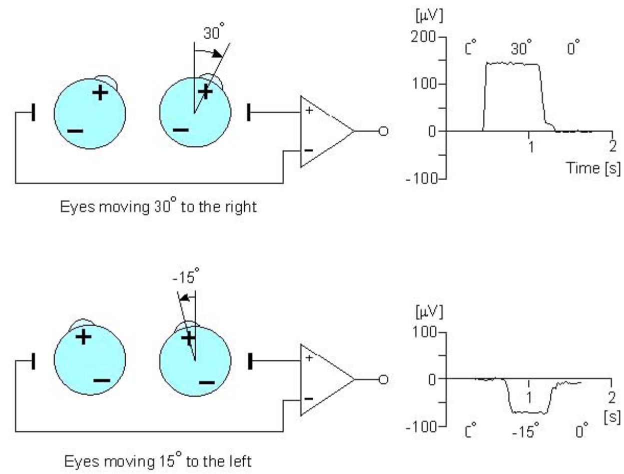

Figure 1. An illustration of the electrooculogram signal generated by horizontal movement of the eyes [1]

Today the recording of the electrooculogram is a routinely applied diagnostic method for investigating the human oculomotor system, such as in sleep studies [2]. It has been established that electrooculography has potential in applications beyond diagnostics, for instance, in assisting the disabled [3, 4]. Recent advances in robotics have led to the development of eye movement based systems to facilitate patient mobility [5]. In addition to assisting in movement, enabling communication is paramount.

With the technology described in this paper, a person with limited motor control such as someone with ALS, can have a new means to communicate. In the U.S. alone 30,000 people are currently suffering from ALS and there are 5,000 new cases each year. As the oculomotor nuclei have some resistance to the crippling neurodegenerative effects of ALS, possibly due to the role of glutamate neurotransmitter transporters, eye movement is one of the last remaining active muscle capabilities in the latter part of the disease [6]. Thus, utilizing eye movement is at the core of our strategy for enabling extended communication ability.

II. Methodology

The system, named Telepathix, was created to allow users to interact with a computer only by moving their eyes. The system prompts the user to make eye movement commands to navigate the ternary keyboard shown in Figure 2. With each successive eye movement command (*Left*, *Center*, or *Right*) the keyboard iteratively splits into thirds until a letter is chosen. The letter selection process ends when the user initiates the stop sequence by "typing" two blank spaces.

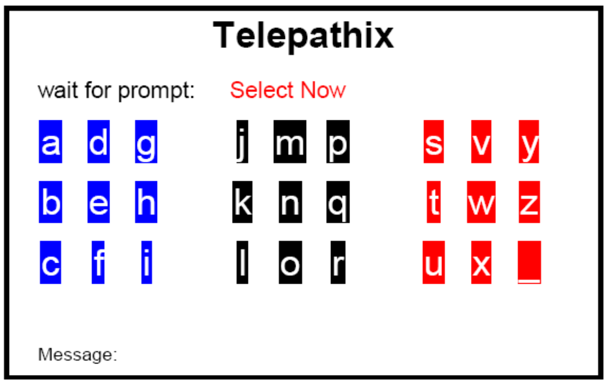

Figure 2. Ternary keyboard for electroocular spelling interface

A. User Interface

The Telepathix system employs a multi-colored virtual keyboard and a prompt line to facilitate usage. If the user wanted to spell "*hi*" using eye movement commands and was presented with the keyboard in Figure 2, he or she would go through an iterative three step process to select each letter. Specifically in the "*hi*" case, when prompted, the user would first make a *Left* eye movement command to select the left third, or blue third, of the keyboard. Then the keyboard would change, only to present the nine letters of the selected third. Next, the user would make a *Right* eye movement command to select a third of the blue letters, namely, the *g*, *h*, and *i*. The interface would then orient the final three letters horizontally, and so the user would make a *Center* eye movement command to select the *h*. Thus, the user would have selected the *h*. Choosing the *i* would be a similar process.

B. System Setup

Signals were acquired through two bi-polar electrodes placed on the user's forehead. The overall system setup can be seen in Figure 3. The Gould box was used for basic filtering and signal amplification, the Data Acquisition (DAQ) hardware for converting signals from analog to digital form, and the Laptop for digital signal processing, classification, and user feedback. The signals were acquired at 200 samples per second and for three second time windows.

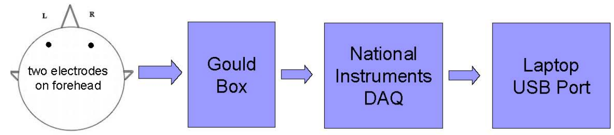

Figure 3. System setup showing major components

C. Ideal Signals

In Figure 4, there are four instances of clearly identifiable eye movement commands: *Center* as denoted by a comparatively flat line due to no eye movement, *Left* as denoted by an initial positive potential followed by a negative potential, *Right* as denoted by an initial negative potential followed by a positive potential, and *Blinks* as denoted by sharp lower magnitude peaks.

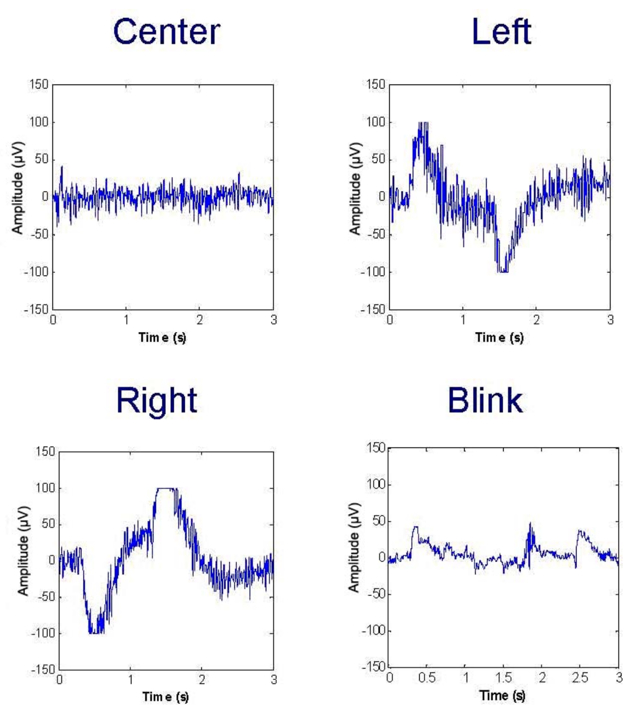

Figure 4. Recorded eye movement commands to navigate keyboard

Ideally, the user's eye movement commands would always result in clearly distinguishable signals as shown in Figure 4. The classification problem of determining where the user wanted to go on the keyboard would in turn be much simpler. However, clearly distinguishable signals are not always acquired, as can be seen in the eighth exemplar of a live spelling trial shown in Figure 5.

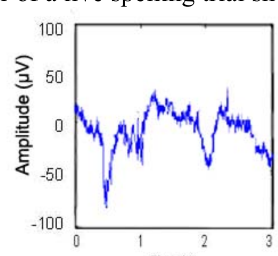

Figure 5. Possible *Right* or *Center* eye movement command

Filtering

To assist in choosing appropriate features and to have a stronger foundation for a classification scheme, a smoothing filter was employed to improve the ability to distinguish the exemplars and thus their respective eye movement commands. Two examples of filtered signals, one being the ambiguous signal from above and the other a clear signal, are seen in Figure 6. After filtering, *Center* and *Left* eye movement commands were determined.

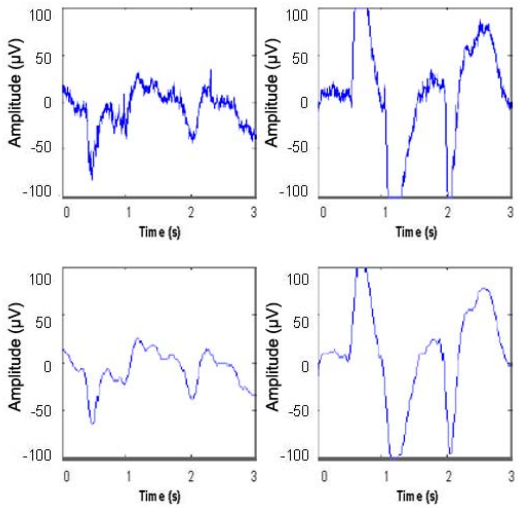

Figure 6. Effect of smoothing filter (bottom two panels) on original signal data (top two panels)

E. *Feature Identification*

To create a robust classifier, representative and significant features must be selected. The following are the set of features that were explored in developing a classification scheme:

1. Peak Polarity – *Left* and *Right* commands correspond to positive and negative potentials, respectively.
2. Slope – In comparison to noise and artifacts, there exists a characteristic slope for potential changes due to eye movement.
3. Threshold – Left and Right commands generally exceed a set value in their respective directions.
4. Mean Value – Since the Center command is given by no eye movement, the mean for those commands should be near zero.
5. Command Timing – Since the user is prompted and then a three second command recording window opens, the true command signal start point should be expected with a slight delay due to human response time.
6. Peak Duration – In comparison to noise or interference, true command signals have characteristic peak durations.
7. Correlation of Model Peak – A characteristic peak can be created and used to serve as a model to find similar peaks in other signals.

F. *Classification*

The classifier is used to determine true eye movement commands amidst random eye movement and noise. The three eye movement commands each have unique characteristics, but the *Center* command significantly differs from both the *Left* and *Right* commands in that there should be no major peaks. Thus, first grouping the signals into two categories, Center Commands and Non-Center Commands, was a useful step in the overall classification scheme. This concept is illustrated in Figure 7 as a hierarchical clustering procedure using divisive steps.

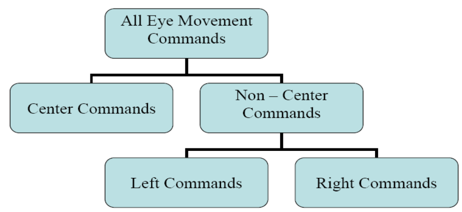

Figure 7. Hierarchical Clustering Procedure

In order to clearly distinguish the command signals, several features were used in tandem. During a signal acquisition time window, multiple signals may be present. For example, after the user makes a *Left* eye movement command, the person may blink or even accidentally make a *Right* eye movement command. Thus, to improve translation of the user's intent, the first present eye movement command is processed. This triggering approach also allows an experienced user to rest after he or she has given the eye movement command. Accounting for the degree of the peak slopes as well as peak mean values is a reliable classification scheme for this application. A trial for spelling a five-letter word is shown in Figure 8 with each eye movement command plotted. A total of 15 points is shown since choosing a letter entails making three eye movement commands.

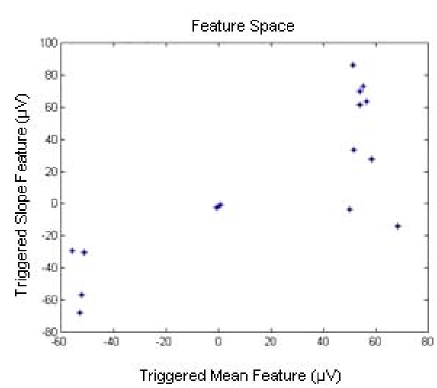

Figure 8. Feature space for a single spelling trial consisting of a total of 15 eye movement commands

As can be seen in Figure 8, the eye movement commands are in three clusters corresponding to *Left* (4 points), *Center* (2 points), and *Right* (9 points) eye movement commands.

III. Results and Discussion

Spelling trials with 13 different users were conducted. Each subject was required to spell 6 five-letter words with a roughly equal distribution of required *Left*, *Right*, and *Center* eye movement commands. The words were zebra, noisy, igloo, input, punch, and pixel. The improved accuracy can be seen in Figure 9. Users gain experience in using the system by the time they reach the sixth word.

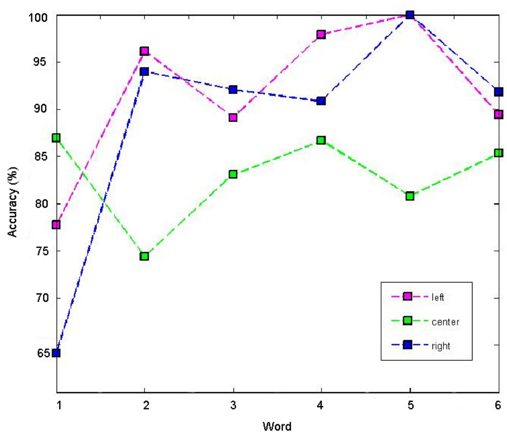

Figure 9. Overall accuracy for 13 users plotted over spelling 6 five-letter words

Overall accuracy for *Left* and *Right* eye movement commands improved when comparing the first spelled word with the last. Center eye movement command accuracy stayed relatively constant. This may be due to the nature of making a Center command, which entails no eye movement during the recording window, coupled with the system's sensitivity to acting upon the first perceived eye movement command.

Additionally, in the entire dataset of eye movement commands for 78 five-letter words each peak was profiled for better signal characterization:

Left Potential: 88.92 +/- 11.88 μV
Max = 105.17 μV
Min = 58.00 μV

Right Potential: -91.91 +/- 10.78 μV
Max = -61.24 μV
Min = -129.36 μV

Peak Duration: 0.289 +/- 0.067 s
Max = 0.484 s
Min = 0.119 s

Peak duration data were also found to be significantly different between users ($p < 0.05$). This opens up the possibility of integrating an adaptive training module to future designs, which could recognize specific users and adapt to their specific eye movement signatures, improving accuracy and data collection times.

As for typing speed, the users in the study were set at a pace of 3 letters per minute. Users having practiced spelling entire sentences were able to operate at a faster pace of 6 letters per minute or roughly 200 bits per minute. This is a high rate of information transfer for people who may not have been able to communicate, as can be the case with severe neurodegenerative disease, paralysis, or stroke. The next phase of the research will include trials with users with neurodegenerative disease such as ALS to further determine the utility of the system.

IV. Conclusion

Classification plays an important role in many biomedical applications. Additionally, it is important to automate the classification process since hand processing is often not a viable option. In this example of a hands free speller, both automation and reliable classification were needed. Otherwise, the whole system would have been severely limited in scope and use. Utilizing the triggered slope and mean features of the eye movement command signals, a reliable classification scheme was implemented. Thus, the system described can be used as an important communication tool, particularly for those who may not be able to communicate in other ways.

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