An Electrooculogram based Assistive Communication System with Improved Speed and Accuracy Using Multi-Directional Eye Movements

Divya Swami Nathan, A. P. Vinod, and Kavitha P. Thomas

***Abstract*—Human-Computer Interface (HCI) enables people to control computer applications using bio-electric signals recorded from the body. HCI can be a potential tool for people with severe motor disabilities to communicate to external world through bio-electric signals. In an Electrooculogram (EOG) based HCI, signals during various eye (cornea) movements are employed to generate control signals. This paper presents the design of an EOG-based typing system which uses a virtual keyboard for typing letters on the monitor using 8 types of distinct EOG patterns. Identification of EOG pattern is based on the amplitude and timing of positive and negative components within the signal. Experimental results show that proposed EOG-based typing system achieves a higher typing speed of 15 letters/min and an improved accuracy of 95.2% compared to the state-of art method that has a typing speed of 12.1 letters/min and accuracy of 90.4%.**

***Keywords*—Electrooculogram, Eye movements, Graphical User Interface, Human Computer Interface, Virtual keyboard.**

I. Introduction

ESTABLISHING an efficient communication and control channel without overt speech and hand movements is essential to improve the quality of life in patients suffering from Amyotrophic Lateral Sclerosis, Guillain-Barre syndrome and many others those make affected individuals with little motor ability, especially in their later stages. Due to these afflictions, about 150,000 people in the world retain only their ability to move their eyeballs [1]. To aid these individuals, a new communication channel between human and machine has been evolved termed as Human Computer Interface (HCI) which is controlled by bio-electric potentials produced in the body rather than normal communication pathway of nerves and muscles.

In order to develop eye based assistive devices, various technologies such as Video-oculogram (VOG), infrared reflectance, eye gaze, P300, and EOG methods are employed. The VOG based system tracks the user's eye movements with a video camera and translates them into movements of mouse pointer on the screen [2]. The merits of VOG based systems are comfort (no body attachments) and ease-of-use, but they are expensive and require intense training for users [3, 4]. In Infrared based system, an infrared light emitting diode mounted on the nose pad of an ordinary pair of eyeglass frames, floods the cornea with light [5]. The cornea acts as a convex mirror and reflects the light into an image transducer, which is a dynamic random access memory (RAM), mounted on the bow of the frames. The address of the illuminated cell of the RAM determines the position of eye. This system is easy to use without any training for the users, but the eyes may tend to become dry and fatigued if used for long time.

In the eye gaze based approach, the digital portrait of the user's eye is specially recorded with the help of eye tracking systems such as digital camera, ultra sound sensors etc. It permits the user to interact with the computer, run software application and manage peripheral devices simply by looking at an appropriate sequence of menu options displayed on the screen [6]. But it is reported that the accuracy of eye-gaze system is not sufficient for practical applications [3, 4]. Another technique termed as P300, recorded using Electroencephalography (EEG), can also be employed to detect eye movements. P300 is an event related potential (response of eye to the stimulus or light) appearing as a positive shift in voltage at a latency of 300 ms in the EEG, after the stimulus. In an assistive typing system called "Brainy Communicator" reported in [7], a number of buttons are displayed on the monitor and P300 activation is analysed to determine the specific button the user intend to select. Even though the Brainy Communicator system employs expensive EEG amplifier for data collection, it offers only a typing speed of about 4.7 letters/minute at an accuracy of 95%.

EOG signals have been effectively used to distinguish between different eye movements. They can easily be measured by placing electrodes on the skin in the neighbourhood of eye [8]. EOG reflects the electric field changes during eye (cornea) movements. It is due to the equivalency of eye to an electric dipole where cornea and retina represent positive and negative polarities respectively. When eye moves, electric field around it changes producing specific EOG patterns which can be translated as control signals in HCI. Compared to the other 4 types of eye movement detection technologies discussed here, EOG method is simpler and less expensive. A large number HCI systems based on EOG signals have been reported in literature for developing assistive devices such as robots [8], wheelchairs [9], computer mouse [10] and virtual keyboards [11].

This paper presents an EOG-based virtual keyboard as an assistive technology communication device. EOG signals show unique patterns for each kind of cornea movement namely left, right, up, down, up-right, up-left, down-right and down-left. These signal patterns can be accurately recognized

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and translated as control signals to select target characters from a virtual keyboard for typing onto the screen.

Among various EOG-based virtual keyboards proposed in literature, the system proposed in [11] offered the best performance. It has been reported that the typing speed and accuracy achieved by this EOG-based system are 12.1 letters/min and 90.4% respectively. However, these results were based on testing using a single phrase 'good morning' and the selection of this phrase was in favour of the character layout in standard PC keyboard (called 'QWERTY' keyboard). This is because, when a 'QWERTY' virtual keyboard is used, selecting a character can take 1 to 9 eye movements, depending on the word to be typed, whereas only 1 to 6 eye movements are required to select any character in the phrase 'good morning' used for testing in [11]. Thus the result shown in [11] is not a representative of various words/sentences. We found that when a variety of words/sentences are attempted, [11] offered an average typing speed of only 9 letters/minute at 90% accuracy. The speed achieved by this system is insufficient and far below the normal human typing speed of 33words/min. There is also a need to improve the typing accuracy of the system. This system employs a 'QWERTY' type of virtual keyboard in which selection of a character can take 1 to 9 eye movements depending on the word to be typed. In order to obtain a better performance in terms of typing speed and accuracy, a novel approach towards the design of virtual keyboard controlled by 8 EOG patterns is proposed in this paper. The novelty of the proposed system is the matrix-coded virtual keyboard which requires only a fixed number of 2 eye movements (first movement to select the row number and the second movement to select the column number assigned to the character) for typing any character whereas the conventional 'QWERTY' keyboard would require 1 to 9 eye movements to type a character, depending on the location of the character on the virtual keyboard.

The rest of this paper is organized as follows: Section II presents the framework of proposed communication system including EOG data acquisition, signal processing algorithm, virtual keyboard interface and system integration. Results are discussed in Section III. Section IV concludes our paper.

II. PROPOSED EOG-BASED COMMUNICATION SYSTEM

In the proposed system, EOG signals resulting from voluntary eye movements are used to type desired characters on the monitor with the aid of non-invasive EOG sensors, data acquisition hardware, personal computer (PC) and on-screen virtual keyboard. The system setup is shown in Fig. 1. The EOG data acquisition system comprises of EOG sensors (attached on the face), signal processing hardware, virtual keyboard (on 21-inch monitor) and a PC. After data acquisition, the signal processing algorithm detects the performed eye movement and output is fed to the virtual keyboard for actual selection of characters. The graphical user interface (GUI) on the monitor consists of the virtual keyboard and display panel. The keyboard is arranged in a matrix form, with rows and columns numbered. Using the proposed matrix layout in the virtual keyboard, any character

Fig. 1.EOG based typing system.

can be typed using 2 eye movements whereas the required number of eye movements can vary from 1 to 9 in a conventional 'QWERTY' design [11]. Various stages of the proposed system are described here.

A. Data Acquisition

During the experiment, the subject sits in an armchair facing the computer monitor. EOG signals are measured by placing electrodes on the region surrounding the eye. Usually they are recorded from two separate regions - horizontal and vertical regions. Hence both vertical and horizontal channels are used in the work to measure EOG. The up and down cornea movements are reflected in the vertical channel whereas the left and right eye movement generates changes in horizontal channel. Other diagonal eye movements (up-right, up-left, down-right and down-left) have respective components along these two channels.

Two electrodes, one above and one near the corner of right eye are used to measure vertical and horizontal EOG signals respectively. The reference electrode is placed on the right mastoid. A gUSB amplifier [12] used in the recording of EOG allows the signal to pass through various processing stages such as filtering, amplification and analogue to digital conversion. Filtering stage employs a 2 - 30 Hz bandpass filter. As the inbuilt bandpass filter in the gUSB amplifier [12] is a relatively lower order filter, the attenuation provided by this filter at power line frequency of 50 Hz may not be sufficient. Therefore, a notch filter is also enabled at 50 Hz to attenuate the power line interference, as precautionary measure. The sampling frequency is set as 128 Hz.

B. Signal Processing Algorithm

Fig. 2 shows 8 types of distinct eye movements and expected EOG patterns [11] employed in this work. These EOG patterns are generated by left, right, up, down, up right, up left, down right and down left eye movements. Voltage fluctuations appear in both horizontal and vertical channels for every eye movement. In every pattern, the positive and negative components appear in a unique manner and they are utilized to distinguish between various eye movements.

As the Fig. 2 indicates each EOG signal has unique pattern for positive and negative components in horizontal as well as vertical channels. The most common algorithm for identifying eye movements is by comparing the obtained EOG signal's amplitude with a predefined threshold [11]. When signal amplitude exceeds the threshold value, it is considered to be a valid signal for recognition. Usually, the threshold values are determined through trial and error method. Also, as EOG signals are subject-specific, a fixed

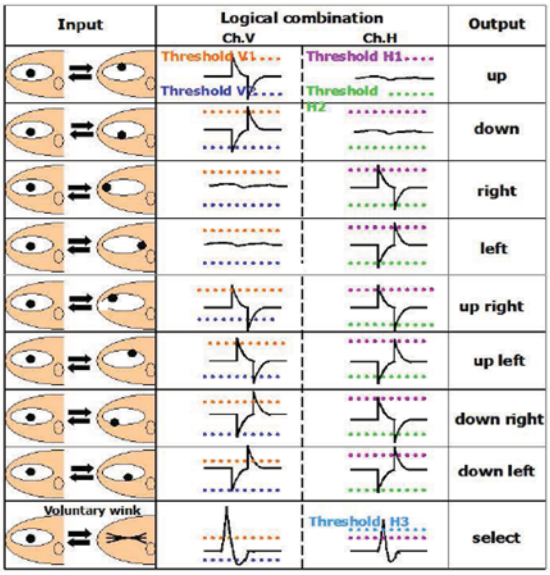

Fig. 2. Relationship between eye movements and EOG patterns.

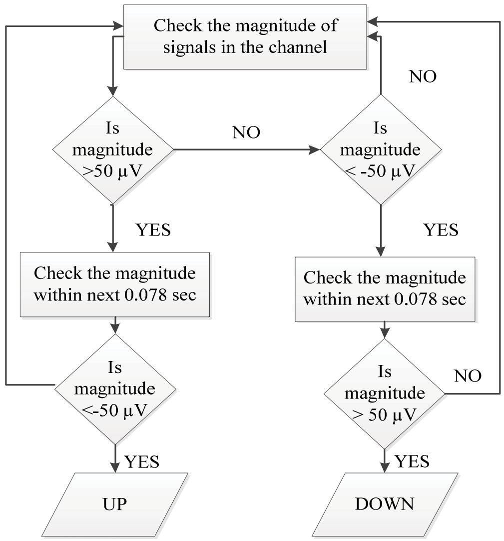

Fig. 3. Flow chart for signal identification.

Fig. 4. QWERTY type virtual keyboard [11].

threshold will not work well for all subjects. Extensive experimental analysis has to be performed to find out the subject-specific optimum threshold. Besides, if the signal amplitude changes over time, the threshold based signal detection leads inaccurate results too. In order to identify EOG patterns more effectively, a new algorithm is presented here. The proposed algorithm employs threshold values for both positive and negative components and also employs a time factor to ensure the occurrence of these components within a fixed period.

The flowchart of the detection algorithm is shown in Fig. 3, which describes the sequence of steps to identify up and down eye movements. The signals recorded from both horizontal and vertical channels are processed as per the algorithm in Fig. 3.

The threshold values used in the algorithm are determined through calibration. To perform threshold calibration, the user has to look at specific positions on the computer screen at regular time intervals. These positions are designed such that those require the user to move his/her eyes in the eight directions as shown in Fig. 2. By repeating this exercise for a few times, many sets of EOG patterns are obtained corresponding each direction. From these sets, a number of maximum (for positive component) and minimum (for negative component) values are computed. The averages of these peak values are assigned as the threshold values for positive and negative components respectively. Experimental analysis shows that the peak amplitude usually has a magnitude 50µV in both positive and negative components.

The second aspect in the algorithm is the permitted time period between the two peaks within the same EOG pattern. Specific occurrence of positive and negative components is found in every EOG pattern (as described in Fig. 2) depending on the type of eye movement. Therefore, after detecting the presence of positive/negative component that occurs at first, algorithm waits for a certain time period to estimate the presence of next component. This time factor provides more robustness to the signal identification procedure ensuring better detection accuracy. From the experimental analysis, the distance between two components in a single EOG pattern is found to be 10 samples which is equivalent to a time interval of 0.078 sec. for the sampling frequency of 128 Hz.

Numerous experiments have been conducted to investigate whether the values of algorithm parameters (threshold and time interval) are effective in correctly identifying eye movements. It is observed that algorithm works well in different persons even with a fixed threshold and thereby eliminates the need for subject-specific threshold selection.

C. *Virtual keyboard Interface*

Interface design of the virtual keyboard is very important in achieving high communication speed. The most commonly used virtual keyboard design is of the QWERTY design [11]. Its layout is shown in Fig. 4. A cursor on the letterboxes of the screen keyboard moved step by step in response to the subject's intention. Eye movements operate cursor movements in 8 directions, scanning through one letter for each movement, and a selection is indicated by a voluntary eye blink. In this approach, typing a word whose letters are located at far locations would require many eye movements which in turn reduces the typing speed. However, a study conducted in [3] reports that the QWERTY design may not be the most suitable choice for disabled persons. The study suggests that a faster communication is possible if the most commonly selected letters are placed close to each other. They should also be near to the location where the user is expected to concentrate before selecting a letter. Motivated by this fact, a modified version of keyboard design is presented here providing an efficient access to the most frequently used characters.

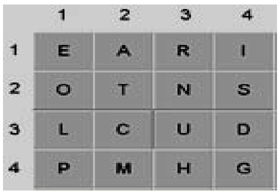

Fig. 5. The basic 4 by 4 matrix in the proposed virtual keyboard.

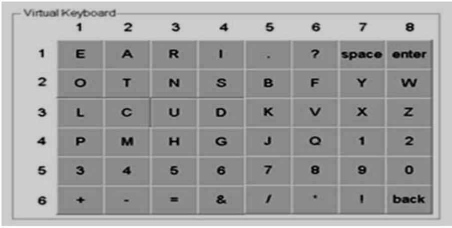

Fig. 6. Layout of proposed virtual keyboard.

The placement of the characters within the cells of the matrix has been performed in a specific manner. The list of the most frequently used letters in the English alphabet has been reported in a study conducted by Oxford University Press [13].

At first, a 4 by 4 matrix shown in Fig. 5 is designed to accommodate these letters. Since the basic eye movements (towards up, down, left and right) are easier for users than diagonal movements, the interface is designed such that letters in this matrix are controlled by these four basic EOG signals. Once this matrix is filled, the remaining alphabets and characters are filled to form the final matrix shown in Fig. 6.

Fig. 6 shows the complete matrix layout used in the interface to depict the characters. According to this keyboard layout, users have to generate 2 eye movements in order to select one character on the keyboard whereas QWERTY design in [11] requires 1 to 9 eye movements for single character selection. For example, choice of the letter D in the proposed matrix layout requires the selection of the row number 3 at first, followed by the column number 4. Even though 64 outputs are possible using 8 distinct EOG patterns, only 48 outputs are used under the assumption that they are sufficient to depict the most important characters that the user might require.

Fig. 7 shows the complete GUI used in this system. The virtual keyboard, Direction Keys, the feedback strategy and 'MOVE' box are the main components in the display channel. The 'Direction Keys' found in the GUI inform the user the relationship between displayed number and required eye movement. Up, right, down, left, up-right, down-right, down-left and up-left movements have been performed by looking at numbers 1, 2, 3, 4, 5, 6, 7 and 8 respectively as shown in Fig. 7. In this system, users are not actually looking at the keyboard in order to select their desired letter. This requirement stems from the fact that EOG signals require at least a 30^{o} movement in the eye before producing a legitimate signal. Fulfilling this requirement between the characters in the keyboard would make the keyboard too large.

In this implementation, the 8 directions are labelled at the corners of the screen as indicated by the green buttons in Fig. 7. A highlighting strategy is employed here as feedback

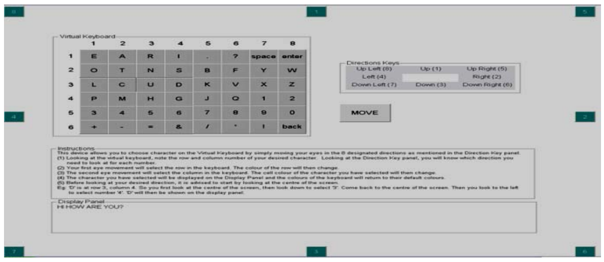

Fig. 7. The graphical user interface.

mechanism instead of cursor movement in conventional methods [11]. Hence, these buttons change colour if the system detects its corresponding EOG. For example, if the user looks up to select '1', row 1 and the green box indicating '1' also immediately changes colour to inform the user that he/she has performed a successful selection.

The 'MOVE' box found in the middle of the screen serves as an indicator to the user when he should start moving his eyes such that the system will be ready to detect it. When the box becomes green, user gets informed that the simulation is running and that has to perform the required eye movement to select a number. When the box returns to the original colour, the user is free and can refer to the virtual keyboard to obtain the next number regarding the desired character. The 'MOVE' box also serves another purpose. It is placed at the centre whereas the numbers to be selected are placed at the corners of the screen. It is to ensure that that eye moves a significant enough distance to produce signals at detectable magnitudes. The 'MOVE' box achieves this by forcing users to concentrate at the centre of the screen at the beginning.

The 'Display Panel' shown at the bottom part of the GUI in Fig. 7 is to print out all the characters that the user has selected.

D. *System Integration*

System integration is essential to ensure the synchrony of hardware and software operations. When the subject intends to type a letter using the keyboard, various aspects of system such as the data acquisition, timing protocol, signal processing, signal detection, passing the information to GUI and display of selected letter, have to be time-synchronized for getting desired results. During the data acquisition, user is requested to look at the virtual keyboard to select letter. After starting stimulation, data during a period of 2 sec (1 sec for system stabilization and 1sec for eye movement generation) is analyzed. Another 1sec is allowed before next selection so that user can refer to the virtual keyboard to note down the next number. Experimental analysis shows that user can register the selection of one number in 2 sec and consequently, the time taken to output one character in display panel is 4 sec. This allows a constant typing speed of 15 letters/min using the developed virtual keyboard, as any letter can be typed using two eye movements.

III. Experiments and Results

During the testing of the proposed system, a 21 inch PC monitor is used to display the user interface. Users are seated 30 cm away from the monitor and they are requested to keep the eye position in line with the center of the screen. Signals are collected from 2 healthy individuals, one male and one female named as User-1 and User-2 in Table I. Both users are allowed to get familiar with the system and are given time to practice eye movements. For comparing typing speed and accuracy, the same sentence as that in [11] is tested, namely, 'GOOD MORNING'. The whole testing mechanism in the proposed system consists of 6 rounds of typing with 'GOOD MORNING' for each subject. The accuracy is computed as the percentage of correctly identified letters over the total number of letters typed, and these accuracy values are shown in Table I. The typing tests with 2 users provide an average accuracy of 95.15 %.

The results of the proposed algorithm are compared with average typing speed and accuracy that reported in [11] for two subjects and are described in Table II. It can be seen that the performance of the proposed system is better in terms of typing speed and accuracy. Higher performance is on account of the improved signal processing algorithm used and the modified layout of the user interface.

In addition to this, another longer sentence consisting of 44 characters is also tested using the proposed system, 'THE QUICK BROWN FOX JUMPS OVER THE LAZY DOG 246138 579'. This sentence is chosen because it is a standard, universal sentence used in the measurement of typing speeds and is used in the performance assessment of HCI systems too [14]. It is found that the proposed system offers a consistent typing speed of 15 letters/min at an average accuracy of 95% in both subjects.

The proposed algorithm basically depends on the amplitude and timing of positive and negative components present in the EOG signals. This mechanism offers better discrimination between EOG signals and noise, resulting in improved accuracy than employing a single threshold value. The interface used within this system also exploits the proximity of commonly used characters as opposed to the QWERTY style which is geared more towards the ease of typing by hands.

TABLE I
TEST RESULTS BY PROPOSED METHOD

Test Results	Accuracy (%)	
	User-1	User-2
Round 1	100	100
Round 2	91.3	100
Round 3	100	91.6
Round 4	100	91.6
Round 5	100	100
Round 6	91.8	92.2
Average	94.4	95.9

TABLE II
COMPARISON OF TEST RESULTS

Performance measure	Method in [11]	Proposed method
Typing speed (letters/min)	12.1	15
Typing accuracy (%)	90.4	95.15

IV. CONCLUSIONS

Human computer interface systems based on EOG signals can serve as an efficient communication tool for paralyzed persons. In this paper, EOG patterns corresponding to 8 types of different eye movements have been successfully employed to control a virtual keyboard. Using an efficient EOG signal processing algorithm and enhanced version of keyboard, the proposed communication system offers better performance than the state-of art by achieving a typing speed of 15letters/min at a typing accuracy of 95.15%. The improved performance of the proposed system is on account of the matrix-coded virtual keyboard which requires only a fixed number of 2 eye movements to type any character whereas the state-of art method employing conventional 'QWERTY' keyboard would require 1- 9 eye movements to type a character, based on the location of the character on the keyboard.

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