DEVELOPMENT OF A HUMAN-COMPUTER INTERFACE DEVICE USING ELECTROOCULOGRAM FOR THE AMYOTROPHIC LATERAL SCLEROSIS PATIENT

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Abstract: Human-computer interface (HCI) device by utilizing electro-oculargram(EOG) signals can be an alternative means of communication especially for amyotrophiv lateral sclerosis(ALS) patients.

For confirming the validity of using EOG signals of ALS patients, we contacted an ALS patient in Seoul National University Hospital, recorded EOG signals and analyzed them. Then we developed a HCI input device using EOG signals. For utilizing obtained signals, the peak detection algorithm and efficient graphic user interface(GUI) were suggested.

Based on the patient's analysis, we could confirm the validity of the EOG-based input device for patients. By suggested eye detection and GUI, we successfully optimized both the accuracy and robustness of the input signals from the EOG-based input device.

Introduction

EOG is a body surface recording of the electrophysiologic signal originated by the difference in the electrical potential between the front and back of the eye. The corneal-retinal potential difference ranges from 0.05 to 3.5 mV in humans [1]. As eye bulbs behave like electrical dipoles in corneal direction, when eye bulbs move, the polarization potential or corneal-retinal potential changes, which are reflected in EOG signal amplitude. Analyzing the EOG signal measured using electrodes attached around eyes, one can estimate the direction of eye movement, which can be usefully applied to develop new input devices for computers. Thus many researchers have been trying to use EOG signals in Human Computer Interface (HCI) studies, where various types of devices have been developed to aid communication and mobility of elderly and/or disabled persons for improving their quality of live [2].

Most important advantage of the EOG-based HCI devices is that such a device can be used even by quadriplegic patients. According to the statistics, the disabled people who can control their eye muscles only are estimated about 150,000 today [3]. For such patients in end-stage of amyotrophic lateral sclerosis (ALS), EOG-based HCI devices are only way to communicate with others. But there are few devices simply applicable and affordable to those patients.

The objectives of this study are to develop a simple and efficient HCI device for ALS patients who cannot move other body parts except eyes. Technical challenges in developing such a device include design of a wearable hardware device to measure stable EOG signals and a robust algorithm to detect eye movements, and an application program efficiently applicable to the patients.

In this preliminary study, we have developed a portable EOG recording device with simple noise elimination methods. Then we have confirmed that the EOG signals measured by the developed device from an end-stage ALS patient could be used to identify the directions of her eye movement. A robust algorithm to identify the direction of eye movement was also developed and its performance was verified by a normal subject. Finally, a Graphic User Interface (GUI) program was also proposed for the patient to communicate with others in more efficient way of graphical drawing.

Materials and Methods

A. Portable EOG Recording Device

The developed device includes both hardware and software parts. The hardware part was designed to obtain 2 channels of EOG for detection of 4 directions of the eye movements (UP/DOWN, RIGHT/LEFT).

As shown in Figure 1, EOG signal waveforms was measured with 4 Ag-AgCl electrodes (Red Dot, 3M) attached around the eyes and another one attached to the neck for a reference electrode. (Left and right electrodes are attached for detecting horizontal direction and upper and lower electrodes are for the vertical direction of eye movements.)

Obtained 2 channel EOG signals were amplifed about 5000 times. Unwanted frequeny components in each amplified signal were removed by a hardware bandpass filter with cutoff frequencies of 0.1 and 20 Hz. Then the analog EOG signal was converted to digital data using a microcontrooler (MSP430F, TI, USA) which also transmitted the data to a PC through serial

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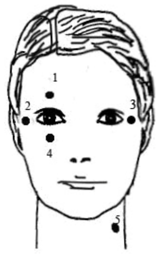
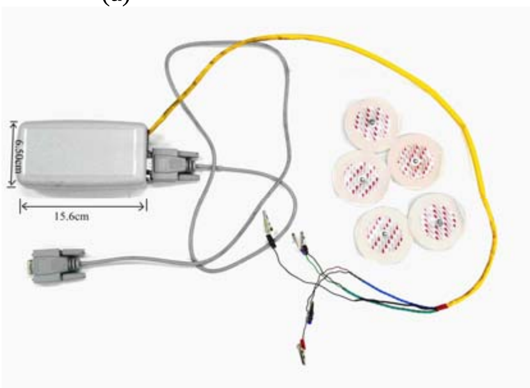
communication protocol(RS232) by the rate of 115,200bps. Whole device was made portable or wearable with the dimension of 7.200”x3.650”x1.200” (6.500 cm x 15.60 cm x 3.048cm).



(a)



(b)

Figure 1: (a) Electrode placement and (b) the developed portable hardware device for the EOG measurement

Since there are still many artefacts such as EMG signals mixed with the EOG signals, the obtained data were de-noised by a wavelet transform-based method. The main reason to use the wavelet transform is that in the wavelet transformation, the windows don’t need to be fixed. Also the wavelet analysis can examine waveform shapes at different levels of decomposition and selectively reconstruct them as desired [4]. The notation for the 2-D Wavelet Transform is

$$C(a,b) = \int_{-\infty}^{\infty} f(t)\varphi^{*}{}_{a,b}(t)dt$$

a=scaling factor, b=the position factor

where a mother wavelet is given by

$$\varphi_{a,b} = \frac{1}{\sqrt{a}}\varphi(\frac{s-b}{a})$$

In this study, the simplest Haar wavelet transform was used, where a mother wavelet is simply defined as

$$\varphi(x) = \begin{cases} 1 & 0 \le x < 0.5 \\ -1 & 0.5 \le x < 1 \\ 0 & otherwise \end{cases}$$

By eliminating insignificant components with lower transformed signals’ coefficients than a predetermined threshold, small artefacts such as EMG could be successfully eliminated.

Figure 2 shows a functional block diagram of the EOG measurement device and the de-noising algorithm as parts of the whole system.

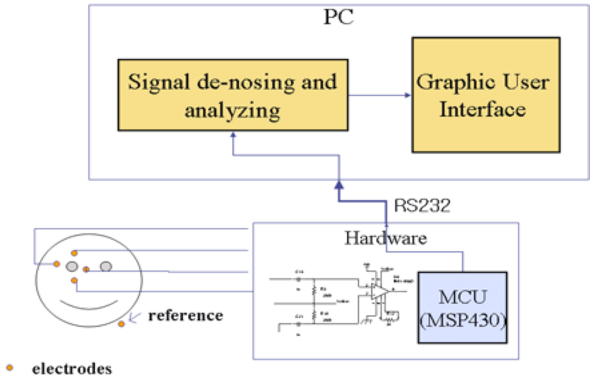


Figure 2: A functional block diagram of the developed EOG-based system as an input device for PC

B. Obtaining Data from an ALS Patient

Since the magnitude of the EOG signal may significantly differs from normal subjects to patients in their end-stage of ALS especially due to their weak muscle strength, it is important to confirm that the possibility of meaningful change detection using our EOG device during eye movements. We applied our device to an end-stage ALS patient (female, age of 65) at the Seoul National University Hospital. The subject’s EOG signals were obtained by the following order: gazing the front, moving eyes up and down, and moving eyes left and right as shown in Figure 3.

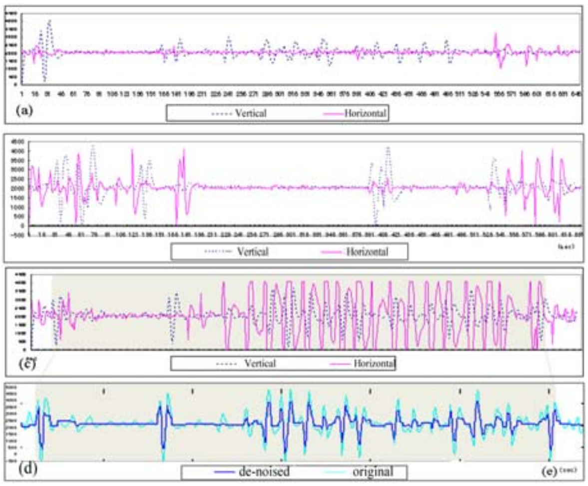


Figure 3: Two channel recordings of an end-stage ALS patient’s EOG signals obtained while (a) gazing the front, (b) moving eyes up and down, (c) moving eyes from left to right, and (d) de-noised waveform of the vertical channel signal in (c) by the wavelet transform-based method.

C. Identification of Eye Movement Direction

According to the given eye movement (UP/DOWN, LEFT/RIGHT, BLINK), each channel of EOG signal (vertical, horizontal) shows a specific fluctuation consisting of a series of peaks and valleys. Basically every single eye movement produces a biphasic waveform with different magnitude and sign. Through extensive case examinations, we concluded that if either a vertical signal or a horizontal signal has three consecutive peaks or valleys within a 64ms interval of the moving window, this indicates that an eye movement occurs and from the peak's magnitude, the direction of eye movement can be differentiated. Since eye bulbs move slightly upper side when eye lids are closed, eye blinking produces a very similar waveform to that of moving up,. Whether a given waveform is for eye blinking or not can be decided by setting a different threshold to the eye movement in 'UP' direction. In this way, identifying 4 directions of eye movements and blinking can be achieved relatively simply. Figure 4 and 5 show a flow chart of the identification algorithm and a typical EOG recording containing eye movement events, respectively.

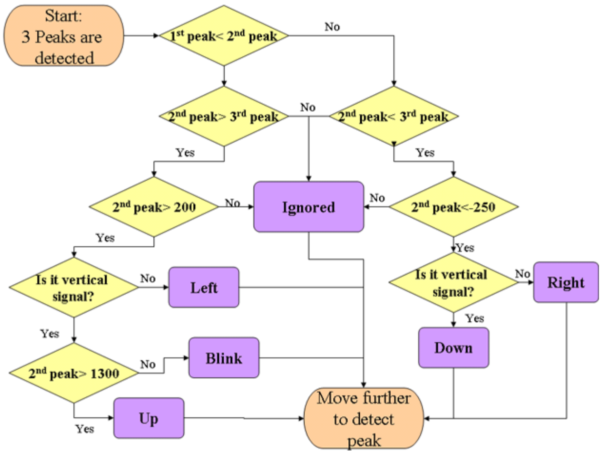


Figure 4: A flowchart of the eye movement direction identification algorithm.

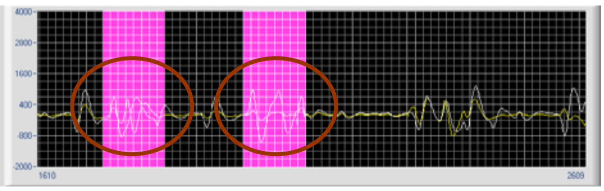


Figure 5: Sample EOG signals containing two eye movements which were successfully detected by the proposed algorithm as marked with a circle. Highlighted vertical bars represent the size of a detection window. A biphasic waveform with 3 peaks and valleys are noticeable within each window.

D. Graphic User Interface (GUI) for Graphic Drawing Operation

A Graphic User Interface (GUI) was developed to be used to express the patient's needs more efficiently. A prototype of GUI was designed for patients to select 9 different jobs with big buttons by moving eyes. Figure 6 shows the screen display of the prototype GUI.

Actual content of the job which each button represents can be customized for each patient's most important and frequent needs. Simple icons can also be overlayed on the button to represent urgent or frequent events.

For other patients' more complicated needs, a graphical drawing tool was also developed. The drawing tool gets eye movement direction from EOG signals as an input so the patient can draw something by moving eyes only. This is functionally similar to a PC mouse. Clicking left button of mouse was substituted by blinking eyes twice quickly.

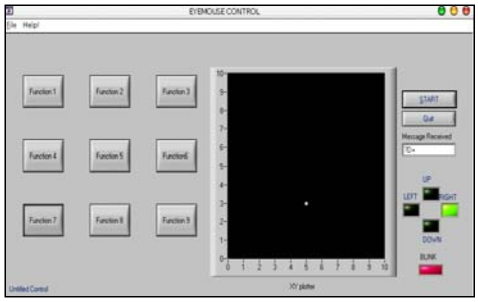


Figure 6: The prototype GUI for EOG input device. The white dot in the black window moves as the detected eye movements and 5 small rectangular boxes on the right side change their colour into green or red when the corresponding event is detected.

Results

The accuracy of the algorithm to identify the directions of eye movements is summarized in Table 1. This data was taken from a normal subject, who repeated each eye movement 120 times.

Table 1: The accuracy of eye movement direction identifying algorithm

	UP	DOWN	LEFT	RIGHT	BLINK
Success Ratio (%)	91.7	95	97.5	98.3	87.5

Easiness or hardness of selecting a specific GUI button was not quantified, but trained normal subjects were able to select a target button in less than 3 trials everytime.

Figure 7 shows the screen display of the developed drawing tool where a black line was actually drawn while a normal subject was trying to draw a line in the direction of a red line. In this specific case, drawing a line by eye movement along the diagonal line was completed in 1 minute.

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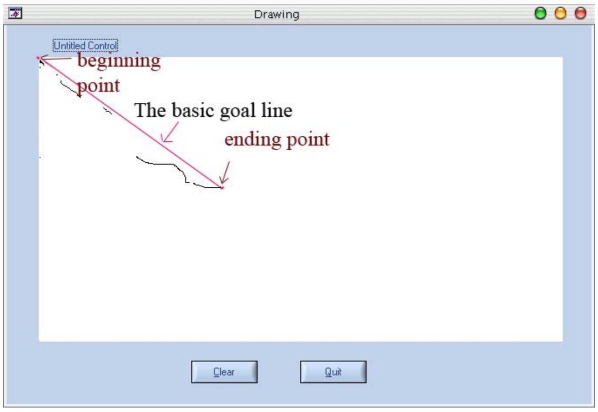

Figure 7: Screen display of the developed drawing tool.

Discussion

From the result shown in Fig. 3, we have confirmed that the EOG signals measured from an end-stage ALS patient using the device developed in this study could be used for an HCI device as a helpful communication tool for the patient. Even though there exists some unrelated waveforms to the ordered eye movement, this will be overcome as the patient adapts to the device and the processing algorithm evolves.

The suggested algorithm detecting peaks to find the eye direction was also feasible. Though satisfying results were shown in 'Down', 'Left', and 'Right' direction. Relatively lower success ratio of identifying 'UP' and 'BLINK' as shown in Table 1 was caused by the similarity between two waveforms. Actually overall detection rate for both activities were not significantly lower than others. The developed algorithm confused 'UP' with 'BLINK' and identified wrong results, which produced lower accuracy for both cases.

A drawing tool using GUI was proposed in that it would be more efficient way for the end-stage ALS patients to express their needs rather than writing a long sentence with the virtual keyboard on the monitor. There must be some cases when this kind of drawing function is better solution, however, we need to improve overall performance of the GUI and optimize several parameters to fit each patient.

In so far, the data obtained from an ALS patient were analyzed and we found the possibility of using an EOG-based input device. Overall, manipulating the device with the eyes is easy and effective way to use for ALS patients or someone who has trouble with moving their other muscles than eyes. EOG-based devices also have another advantage over other eye movement-based devices using infrared sensors or video oculogram (VOG) signals [5] in that they can be fabricated at relatively lower expense.

Conclusions

In this paper, we have proposed a new HCI device to PC for the end-stage ALS patient to use in communicating with family members and caregivers.

The developed hardware device was partly applied to a real patient and overall system performance was verified by normal subjects. The results show that the application of the developed system to the end-stage ALS patients is very promising after device improvements to meet the patient's specific requirements as well as operational environment's variation.

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