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Development of EOG-Based Communication System Controlled by Eight-Directional Eye Movements

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Abstract—**A communication support interface controlled by eye movements and voluntary eye blink has been developed for disabled individuals with motor paralysis who cannot speak. Horizontal and vertical electro-oculograms were measured using two electrodes attached above and beside the dominant eye and referring to an earlobe electrode and amplified with AC-coupling in order to reduce the unnecessary drift. Eight directional cursor movements and one selected operation were realized by logically combining the two detected channel signals based on threshold setting specific to the individuals. As experimental results using a projected screen keyboard, processing speed was improved to 12.1 letters/min. while the accuracy was 90.4%.**

I. Introduction

Communication is essential for humans to remain part of their community. However, developmentally disabled lateral sclerosis (ALS), Galilean-Barre Syndrome, or brain stem infarction, have difficulty in conveying their intentions, since the motor neurons influencing voluntary muscles are affected. Various assistive technologies supporting individual communication have been developed for disabled people. Some have facilitated inter personal communication by supplementing the individual's impaired functions with surviving functions. In terminal ALS patients, the eye movement muscles are usually not affected and thus, using them has the potential to improve the performance of input operations in communication support method.

Several practical devices have used eye movements as communication support [1]-[12]. The video-oculogram, which detects eye movements from pictorial images of the eyeball, is expensive because it requires a video camera to film eye movement in real time [1]. Eye movement detection using infrared reflectance of the cornea is difficult to use over a long period because the eyes tend to become dry and fatigued [2]. The sclera reflection method detects eye movements using the differential reflectivity of eyes, but its accuracy is not sufficient for practical application [3]. In these methods, a part of looking is prevented by the devices.

Several methods have been proposed that use electro-oculograms (EOGs) occurring as a result of eye movements [4]-[12]. A simplified switching system has been proposed, using EOGs detected by three electrodes [4], [5]. An automatic scanning selection on the screen keyboard must be used for information input to apply this system to a computer interface. Devices with five or more electrodes, including a reference electrode have been developed for detecting eye movements in four directions [6]-[9]. However, the processing speed of these systems is slow because it takes time to accomplish the cursor movements or selection operation. An electric wheelchair controlled by EOG has also been developed as movement support device [10]. An eye gazing system that can detect any point where the eye gazes on the screen was developed for communication assistance purposes [11], [12]. In these methods, additional processing is necessary to reduce the drift in long-term measurements.

The purpose of the present study is to develop a real-time EOG communication control system that offers improved operation and simple setup combined with high performance. We propose a device that outputs nine kinds of intentions: movement in 8 directions (up, down, right, left, up right, up left, down right, and down left) and one selection, by transforming two channel AC-coupled EOG signals detected by three electrodes. Eye movements operate cursor movements in eight directions and a selection is indicated by a voluntary eye blink. The present method shows that a quick and simplified selection can be done by cursor movements alone, without the need for automatic scanning selection. That is, our system is an intermediate system between switching EOG and eye gazing systems. The evaluation of this new system was made through virtual communication experiments using a screen keyboard.

II. Method

A. Eye Movements and Electrical Activity

Biomedical signals used in the present study are EOGs: horizontal and vertical eye movements and voluntary eye blinks generate electrical activity. Therefore, a positive potential is applied at the cornea side, a negative potential is applied at the retina side, and a constant potential difference (the corneal-retinal potential) is applied between the cornea and the retina. Body surface electrodes situated around the eyeball socket can detect potential changes resulting from eye movements.

On the other hand, eye blinks are classified into two categories: the involuntary eye blink, which occurs frequently

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or is spontaneously provoked by an external stimulus such as a flash of light, and the voluntary wink caused by intentional eye closing. These EOG or EMG (electomyogram) signals can be detected by the same electrodes as a potential change caused by opening and closing of the eyelids.

In this study, potential changes resulting from eye movements (eight directions: up, down. right, left, up right, up left, down right, and down left) that move a screen keyboard cursor are detected and generate eight kinds of intended information by logically combining these potential changes. Moreover, the potential change due to voluntary eye blink is interpreted as selecting a certain position, similar to clicking a mouse button.

B. Composition of EOG Communication System

Figure 1 shows a block diagram of our EOG communication system. Actual EOG signals are detected using two pair of electrodes, one electrode on each temple and one above and underneath one eye. Usually, the detected signals are amplified by DC coupling to specify the direction of the gaze. In our experiments, three electrodes are placed on the dominant side of the eye according to the optimum positions [9]. Also, the detected EOG signals are amplified by AC instead of DC coupling in order to reject the drift which occurs in long-term measurements. That is, the detected signals are not EOGs in the strict sense of the word, however for convenience sake, we call them EOG signals. The signals are band pass-filtered to eliminate unnecessary DC component and high frequency EMG. The two channel signals are analog to digital converted and input to a personal computer. These signals are combined logically. Finally, they are converted to nine kinds of intention information.

C. Logical Combination

Figure 2 shows the relationship between eye movements (input) and the detected EOG signals (output). The left hand pictures show the nine kinds of eye movements used for intentional input. At rest, the subject is looking straight ahead. The subject is asked to look up, down, right, left, or four diagonal points and then return his/her eye to its original position to exposes his/her intention. Moreover, a sequence of voluntary eye closing and opening is used to indicate selective intention.

Let the upper and lower thresholds of the vertical channel V be V1 and V2, respectively, and the upper and lower thresholds of the horizontal channel H be H1 and H2, respectively. These thresholds should be determined beforehand. When the EOG potential exceeds one of these thresholds, the output assumes ON. The process of transforming EOG signals to intention is as follows:

1. Output Up when threshold V2 becomes ON during setup time after V1 becomes ON, whereas thresholds H1 and H2 remain OFF.
2. Output Down when threshold V1 becomes ON during setup time after V2 becomes ON, whereas thresholds H1 and H2 remain OFF.

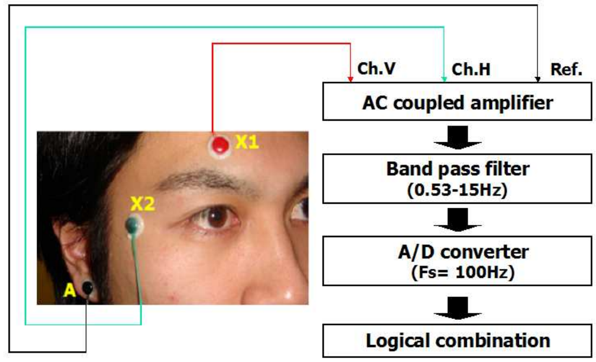


Fig. 1. Block diagram of EOG communication system. Three electrodes are used to detect two EOG signals as shown in left part.

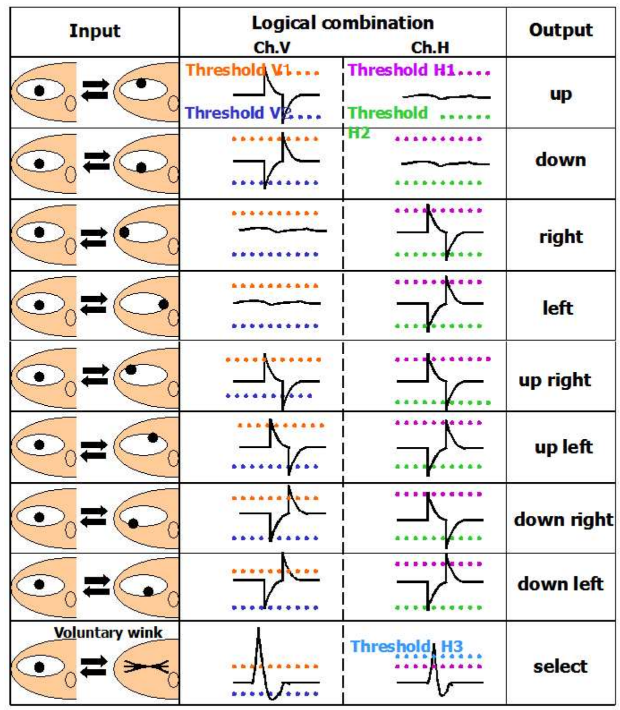


Fig. 2. Relationship between eye movements ,the detected EOG signals, and intention output.

3. Output right when threshold H1 becomes ON during setup time after H2 becomes ON, whereas thresholds V1 and V2 remain OFF.
4. Output left when threshold H2 becomes ON during setup time after H1 becomes ON, whereas thresholds V1 and V2 remain OFF.
5. Output Up Right when threshold V2 becomes ON during setup time after V1 becomes ON, whereas thresholds H2 becomes ON during setup time after H1 becomes ON.
6. Output Up Left when threshold V1 becomes ON during setup time after V2 becomes ON, whereas thresholds H2 becomes ON during setup time after H1 becomes ON. Output Down Right when threshold V2 becomes ON during setup time after V1 becomes ON, whereas thresholds H1 becomes ON during setup time after H2 becomes ON.
7. Output Down Left when threshold V1 becomes ON during setup time after V2 becomes ON, whereas

thresholds H1 becomes ON during setup time after H2 becomes ON.

8. Output up when threshold V2 becomes ON during setup time after V1 becomes ON, whereas thresholds H3 becomes ON.

The setup time is the time interval between the first and second peak of EOG signals. All thresholds automatically switch to OFF after intention is output. The optimum values for the thresholds and the setup time are determined by trial experiments.

D. Parameter Setting

The thresholds and the setup time of EOG signals should be used for distinguishing the intentional signals from artifacts such as eye blink and ordinary saccade eye movements.

Before applying the communication system, both the subject and the system are adjusted to fit each other to improve the accuracy of information input. First, the parameters of the four thresholds and the setup time for detecting intentional input are estimated according to the statistical data acquired in previous experiments. The subject is trained to input his/her intentions using these parameters. Second, the subject tries to move his/her input according to pre-programmed instructions shown on the computer's display. At this time, the subject is trained to match the system. Third, the parameters are adjusted to match each subject to obtain optimal performance as a communication support system, estimated using the training data and the computer's instructions with the aim of achieving high accuracy and low error rate. Once this is achieved, the subject and the communications system are matched.

E. Experiments

Experiments were performed using a virtual screen key board (Fig. 3) to examine the usability of the proposed EOG system. A cursor on the letterboxes of the screen keyboard moved step by step in response to the subject's intention. The subject sat in front of a projected display that displayed a virtual screen keyboard and eight markers that indicate the eye gazing points. The distance between the monitor and the subject was fixed at 1230mm for view angle of 30° (Fig. 4). The subject was instructed to move his eye as far as possible, but not to the point of discomfort. The low-cut and high-cut frequencies of the analog band-pass filter built-in EOG system were 0.53Hz (time constant of 0.5s) and 5Hz, respectively. The sampling frequency was set at 100Hz.

The experimental procedure for each subject was as follow.

1. First, the subject practiced freely for about 10 minutes prior to parameter setting.
2. Second, automatic parameter setting using computer instructions was carried out to adjust the communications system after practice, the protocol for computer instruction was a four-fold intention, that is, the sequence of eight directional movements followed by Select.

Fig. 3. A screen keyboard. A cursor on the letterboxes moved step by step according to subject's intention.

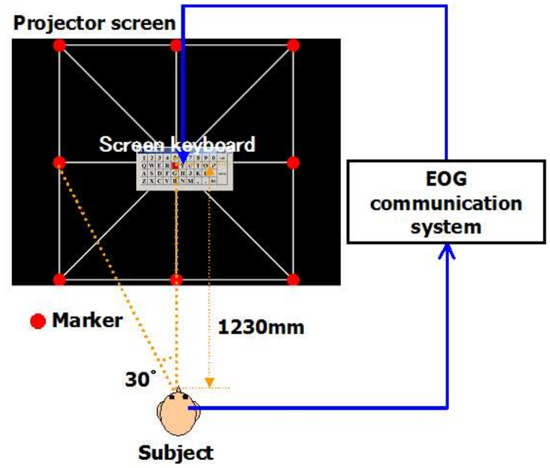


Fig. 4. Experimental setting.

3. Finally, by using the adjusted system, the subject was instructed to attempt to generate a sentence comprising twelve characters "GOOD MORNING".

To evaluate the proposed system, the accuracy of intention input was defined as

$$accuracy = \frac{correct\ \ output}{total\ \ number\ \ of\ \ input} \times 100\,[\%] \tag{1}$$

In addition, the error rate of operation was also defined as

$$error = \frac{wrong\ \ output}{total\ \ number\ \ of\ \ input} \times 100\,[\%] \tag{2}$$

where the wrong output is the total number of the unintended output and no output in spite of the subject intends to output. Moreover, the processing speed

$$speed = \frac{number\ \ of\ \ letters}{process\ \ time}\,[letters\ /\ min] \tag{3}$$

was measured to evaluate the usability and operativity of the proposed method. Fatigue of each subject was also evaluated by a questionnaire subjectively and a flicker test objectively. The overall performance of the proposed system was examined using these evaluation indices.Following two experiments were performed with five healthy male subjects. Experiment 1 was done by conventional four-directional input and Experiment 2 was done by proposed eight-directional input.

III. Results

Figure 5 shows the experimental results of virtual letter input by subjects A and B. The accuracy and error rate of two experiments (four- and eight-directional systems) were almost same. However, the processing speed was improved from 10.1

to 12.1 letters/min. The results by other subjects had same tendency.

IV. Discussion

This study intended to develop a communication support system for controlling the cursor on a screen keyboard and selecting letters. To accomplish this aim, the potentials generated by two-channel signals of vertical and horizontal EOGs with three electrodes, including a reference electrode on the earlobe. It had been reported that a baseline drift occurred for long term measurements of EOG and thus it is necessary to compensate them to detect the gaze precisely. To avoid the influence of the baseline drift, we measured AC-coupled EOG, that is, the derivative of EOG. The drift did not be seen in the detected signals.

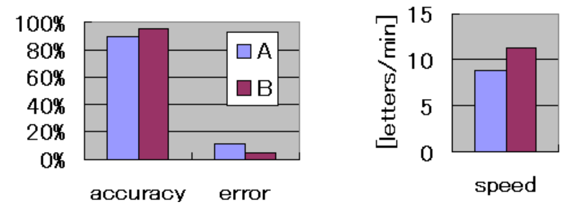
In this system, thresholds play an important role in improving system performance. When the threshold was set high, few of the detected EOG signals exceeded the threshold, resulting in poor accuracy. In contrast, when the threshold was set low, the error rate increased due to unintended output. In particular, the potential change observed during involuntary eye blink tended to be misconstrued as Up direction output. For this reason, setting the threshold carefully makes it possible to increase the accuracy of the proposed system.

The accuracy of 90% seems worse than that of the traditional EOG switching. If the system is reduced to simple functions, the accuracy will be improved. However, since the processing speed is slow, the usability or operativity will be insufficient for the user. Comparing with the communication system using eye movements with five electrodes, the accuracy of our method is almost the same as that of the proposed system. According to the opinions form ALS patients and their care manager, an accuracy of 80% may be enough for communication using switching systems in the condition of locked-on. Our experimental results demonstrated that horizontal movements and winks had few errors than vertical and diagonal movements.

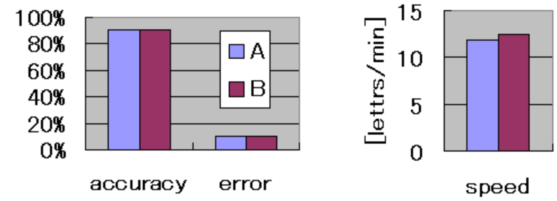
The processing speed of our system became much faster than that of the traditional EOG switching system and four directional EOG system. In order to apply to ALS patients, more sophisticated signal processing and parameter setting will improve the accuracy, speed, and usability of the communication system.

V. Conclusion

We have developed an EOG communication support system that outputs 9 kinds of intention information by adopting band-pass filtering and a logical combination to interpret the action potentials of eye movements and voluntary winks. Consequently, we achieved an accuracy of 90.4% and a processing speed of 12.1 letters/min. as a result of adequate training of both the subject and the communication device. We believe that the proposed method has potential use in practical situations.



(a) Four-directional input system.



(b) Eight-directional input system.

Fig. 5. Accuracy, error rate, and processing speed for two subjects A and B. in (a) four- and (b) eight-directional input EOG system.

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