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Development of Pointing Device using DC-Coupled Electrooculogram

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Abstract—**The purpose of this study is to support communication of individuals with motor paralysis having difficulty verbally communicating due to illnesses such as Guillain-Barre Syndrome or brain-stem infarction. We have developed and describe a pointing device controlled by DC-coupled electrooculograms (EOGs). The visual angle of the subject is estimated from the amplitude of vertical and horizontal EOGs for determining the two-dimensional pointing position on a PC screen in real time. The eye blinking artifact is reduced using a median filter. Electrode displacement is corrected by considering the potential gradient. Moreover, the position error caused by drift phenomenon is adjusted using head movement based on the vestibule-ocular reflex. The accuracy and operating speed of the proposed method were evaluated among a group of human subjects.**

I. INTRODUCTION

COMMUNICATION is one of the essential elements for humans to maintain their quality of life. In general, communication is accomplished by conversation, talking on the telephone, writing letters, and so on. In individual cases, dictation or sign language is used for communication. However, individuals with motor paralysis or neurodegenerative diseases such as Guillain-Barre Syndrome or brain-stem infarction have difficulty in conveying their intentions since the motor neurons influencing voluntary muscles are affected. Thus, assistive technologies supporting individual communication are required for enabling communication in affected people. Various communication support devices have been developed; some facilitate inter-personal communication by supplementing the individual's impaired functions by utilizing surviving functions. In terminal patients, the eye movement muscles are usually not affected. Thus, methods using eye movements have the potential to improve the performance of the communication device. In the present study, we focused on eye movements for developing a communication support device.

Several communication support devices have been developed using eye movements. The corneal reflex method, the limbus tracker method, and videooculography were nominated based on the measurement principles of eye movements [1]-[3]. These methods can track eye movements with high precision. However, they are expensive and sometimes require special measuring instruments or attachment devices such as goggles. Moreover, any method using infrared is invasive for subjects. Hence, we focused on the electrooculogram (EOG) to develop the communication support device [4]-[16]. EOG is one of the recording of the bioelectric activities in our eyeballs where a positive potential exists between the cornea and the retina. These charges cause a static potential named the corneal-retinal potential. Body surface electrodes attached around the eyeball sockets can detect the potential changes resulting from eye movements. EOG signals are measured with either an AC- or DC-coupling amplifier. The AC-coupling amplifier can reduce the drift artifact. We have developed a communication support device with four directional inputs and one selection [8]-[10]. However, the operation is limited to small number of functions. In the present study, we focused on the DC-coupled EOG measurement that includes information about the visual angle of the eyeballs. By eliminating the artifact error in DC-coupled EOG measurements, we developed a pointing device that performed like a mouse pointer. For the pointing device to operate like a mouse, the user must signal that this is the final position. We can use a "mouse hover" that is one of the accessibility features of the operation system. That is, the pointer remaining in the same position for a certain time period effects a "mouse click." Alternately, a voluntary eye blink, which is different from involuntary eye blink, may be used for the clicking method [8], [9], [13].

II. METHOD

A. EOG-based pointing device

The pointing device based on EOG signals for the communication support consists of five surface electrodes, an electrooculograph, an A/D converter, a laptop PC, a projector, and a screen as shown in Fig. 1. We attached the electrodes in order to measure horizontal and vertical EOG signals which were amplified by DC-coupling. The signals were collected by the PC with a sampling rate of 100 Hz. Figure 2 shows the system block diagram of the pointing device. First, the

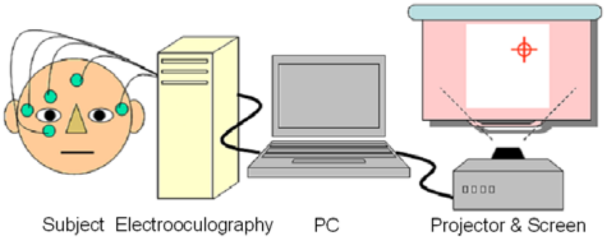

Fig. 1. System configuration and electrode positions.

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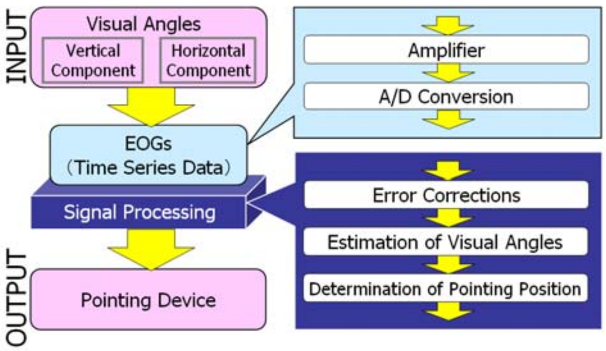

Fig. 2. System block diagram.

detected EOG signals were corrected by reducing or canceling the experimental errors (noise) involved. Second, visual angles were estimated using the amplitude of horizontal and vertical EOG signals. Finally, the coordinates of the pointing position were estimated in real time. The subject can continuously control the pointing position on the screen by moving his/her eyes.

B. Error Corrections

Figure 3 shows an example of the detected EOG signals during eye movements in the leftward direction. The waveforms show at least three types of errors. 1) Spike artifacts are caused by involuntary eye blinking. 2) The voltage error is caused by the offset of the electrode position from the horizontal and vertical lines on the eyeball. 3) Drift phenomena are seen as slow fluctuations. We must eliminate these errors to develop a sophisticated pointing device. The countermeasures for these errors are explained as follows.

1) Blinking artifact: Waveforms from the blinking artifact appear as spikes. We rejected them by applying a median filter for time-windowed EOG data [10]. Since the duration of the artifact was about 0.7 s, the interval of time window was set to 1.5 s. The median filter requires sorting to find the median value among the data. We developed a fast sort algorithm for time-series data considering the successive time windows. When the time window shifts one point, only one data is different from the previous time window. Thus, by replacing one data in the sorted data, the calculation cost of the successive median filter was dramatically reduced.

2) Electrode position error: As shown in Fig. 3, the voltage error in the vertical channel increased according to horizontal eye movements. This is not critical if the electrodes are attached at the appropriate position. We call this error the electrode position error. As a result of the fundamental experiment, we determined a linear relationship between visual angles and the electrode position error. We compensated for the error using this relationship.

3) Drift: Drift is the random direct current noise that causes baseline fluctuation unrelated to eye movements. We obtained long-term measurements of EOG data in order to characterize the drift phenomenon. The subject gazed at the center of the screen for 30 minutes. Drift tended to decrease 15 minutes after the experiment began. These results suggest that the electrical relationship between electrode and skin is almost stable during that time. The results are omitted according to the space. Based on these results, the subjects wait to begin the experiments for 15 minutes after attaching the electrodes. The human being has the ability to adapt for various environments. The vestibulo-ocular reflex (VOR) is a reflexive eye movement that stabilizes images on the retina during head movement by producing an eye movement in the opposite direction of the head movement, thus preserving the image in the center of the visual field [17]. We hypothesized that the VOR would be useful for reducing drift. If there are errors in the pointing device, the subject will experience lags between the pointer and the target he wants to point out. When the subject feels this gap, he/she can compensate by rotating his head toward the target according to the VOR. As a result, the drift decreases as the gazing point approaches the pointer. We expected that the operability of the system is improved by this compensation method with changing his/her head position optionally.

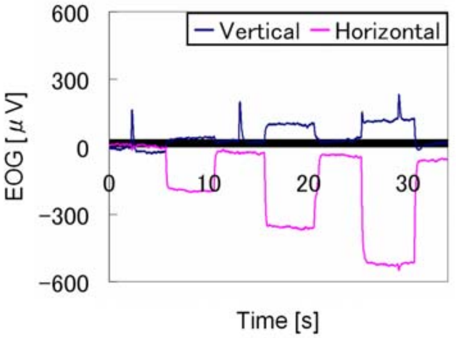

Fig. 3. EOG waveforms during leftward eye movements.

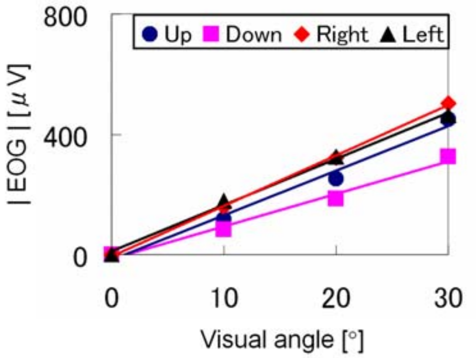

Fig. 4. Linear relationships between the visual angle and the absolute amplitude of the EOG signals.

C. Estimating visual angles

The visual angle was estimated from EOG data after applying the corrections from Sect. II.B. Figure 4 shows the relationship between the visual angle and the amplitude of the EOG. The stable amplitudes of each visual angle were measured and averaged over several times. The values of up and down are the absolute amplitude of the vertical channel and that of left and right are the absolute amplitude of the horizontal channel. The amplitude of the EOG linearly increases when the visual angle increases. Using this linear relationship, we estimated the visual angle from the EOG data.

The proportional coefficients of the relation equation were estimated by the preliminary experiments.

III. EXPERIMENTS

A total of nine subjects participated in the experiments. All subjects understood the aims of the experiments and were properly consented. The experiment environment is shown in Fig. 5. The subject sat facing the screen. The home position of the subject's eyes was the center of the screen. Targets appeared on the screen in random positions and a pointer whose position can be controlled by the subject.

First, we evaluated the error correction methods for the eye blinking artifact and the electrode position error. The corrected results for EOG data from Fig. 3 are shown in Fig. 6. As shown, eye blinking artifacts were eliminated. The voltage error caused from the gap of the electrode position was compensated, and the baseline of vertical channel became stable.

Second, we assessed the operability of the pointing device. Precision and operation speed were measured for several experimental conditions. In order to evaluate the anti-drift method we proposed, the experiments were conducted under two conditions: fixed or unfixed head positions. Five subjects participated in the precision experiment. The other four subjects and one who participated in the precision experiment participated in the experiment of the operation speed.

In the experiments to determine operation precision, the target intermittently jumped from one point to another at uniform time intervals. The subject moved the pointer as close to the target as possible. The target was set to the visual angles of 10, 20, and 30 degrees. The time interval of the target was set to 5 s. The average errors from 36 trials were obtained for each subject. Figure 7 shows the experiment results for five subjects. The parameter *p* is the significance level of student's t-test. Each bar shows the mean and the standard deviation over 36 data. As shown in Fig. 7, significant differences between errors under fixed and unfixed head positions were confirmed in most of the subjects. The error was reduced when the head was unfixed compared to fixed head conditions.

Next, while the pointer was fixed at one location for a certain period, the target jumped to another position to measure operation speed. The subjects pursued the target as quickly as possible. The target was a circle with a radius of 4 degrees and it was set to the visual angles of 10, 20, and 30 degrees. The retention period was set to 3 s. The average operation time from 18 trials were obtained for each subject. Figure 8 shows the experiment result of the each four subject. One subject could not accomplish the experiment task because of drift. The operation time does not include the fixed retention period. The operation speeds tended to be faster when the head was unfixed than when the head was fixed in one position.

Finally, we evaluated the time-series characteristics of the pointing device. We focused on drift increasing with time. The subjects performed the operation precision experiments under conditions of a single trial or continuous trial. Here, the single trial means that the drift was zeroed in every trial. In particular, the error in the continuous trial was reduced when the head was unfixed. This result indicates that our method is effective for drift rejection. Moreover, it is necessary to investigate the influence of the subject's facility for the device. The subjects performed the experiments for 4 days. The error dramatically decreased during the second day and gradually decreased after the third day.

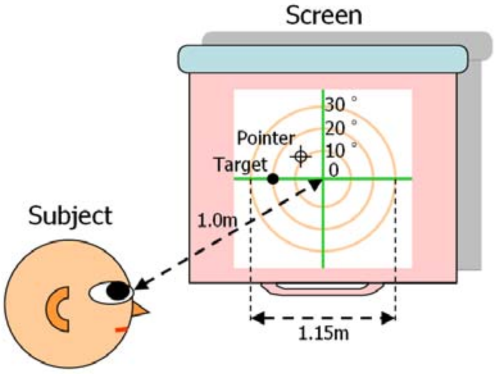

Fig. 5. Experimental conditions. The subject pursued targets by controlling the pointer via eye movements.

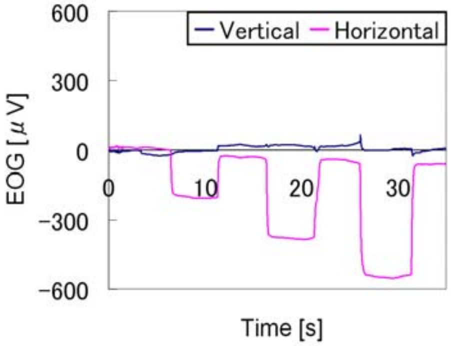

Fig. 6. Corrected results of Fig. 3. Blink artifacts and electrode position errors were reduced, especially in the vertical channel.

IV. DISCUSSION

By comparing Figs. 3 and 6, we can see the effect of the error corrections we proposed. The blink artifacts observed in the vertical channel were rejected by the median filter. The time delay mainly caused by the median filter was approximately 0.75 s and it set to not influence operability. We can also see the decrease in the electrode position error in the vertical channel. As a result, stepwise-tracking of the EOG data could be obtained for estimating the pointing position.

Figure 7 shows that the average error under unfixed head positions was smaller than in the fixed head position. The tolerance error of the viewing angles was 3 degrees in the case of the unfixed head. That is, these errors may be feasible to the communication support system of the resolution of 3 degrees or more.

Likewise, Fig. 8 shows that the average operation time when the head was unfixed was faster than that of the fixed head. These results suggest that the operation of the

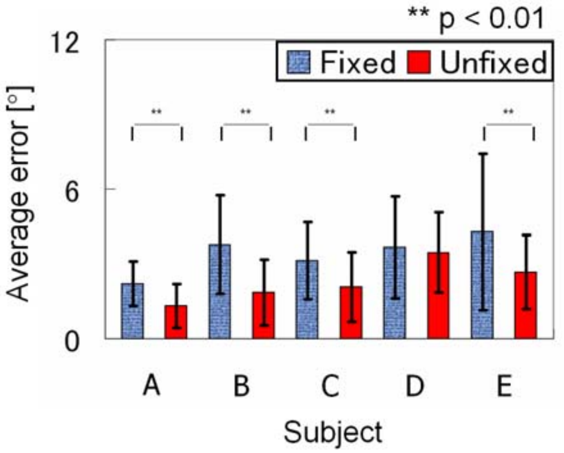

Fig.7. Average error for each subject. Average error was measured as the difference in the visual angle between the target and the pointing position under fixed and unfixed head conditions.

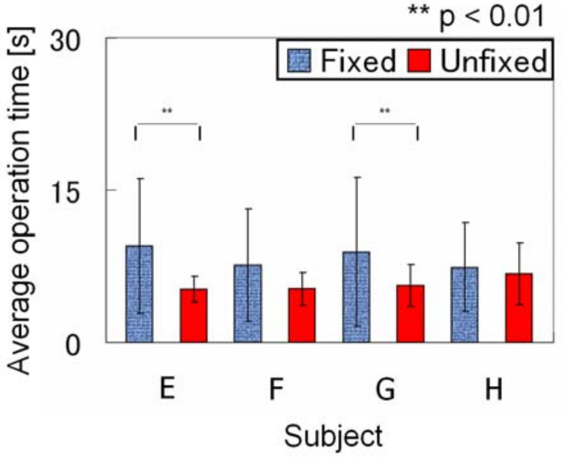

Fig. 8. Average operation time for each subject.

EOG pointing device is better with free movement of the head. However, we confirmed that there is an individual difference in the operation time. One subject could not accomplish the task because of drift errors. Moreover, some subjects felt difficulty to control the pointer quickly because the EOG system faithfully pursued user's saccadic eye movements. Further improvement of the operation speed is necessary for the operability of the support system.

In our experiments, five electrodes were attached on the skin surface in order to obtain the EOG signals. All subjects understood the aims of the experiments and they were properly consented to the experiments. However, the attachment of electrodes may not be friendly to users. We have to reconsider appropriate electrodes. In our present system, we used a projector and a 1.15m-wide screen to feedback the pointing position to users. The feedback can be projected not only on the screen but also on the wall or ceiling. Moreover, since the EOG signals do not depend on the absolute distance between the user and the measurement device, the system is applicable to various users' postures. This system can also be accomplished using commercial CRT or LCD.

V. CONCLUSION

In the present study, we developed a pointing device using DC-coupled EOG signals. Errors such as the eye blinking artifact, electrode position error, and drift were corrected to precisely locate the pointing position on the screen. Operating precision and speed were improved by compensating for drift by allowing free movement of the head. Further examination of error corrections is necessary for practical use. We are arranging the experiments with disabled subjects in the near future.

REFERENCES

[1] M. Betke, J. Gips, and P. Fleming, "The camera mouse: visual tracking of body features to provide computer access for people with severe disabilities," IEEE Trans. Rehabil. Eng., vol.10, no.1, pp.1-10, 2000.

[2] G.A. Rinard, R.W. Matteson, R.W. Quine, and R.S. Tegtmeyer, "An infrared system for determining ocular position," ISA Trans., vol.19, no.4, pp.3-6, 1980.

[3] T. Huntchinson, K.P. White Jr., W.N. Martin, K.C. Reichert, and L.A. Frey, "Human-computer interaction using eye-gaze input," IEEE Trans. Syst. Man Cybern., vol.19, no.6, pp.1527-1533, 1989.

[4] J.H. ten Kate and P.M. van der Meer, "An electro-ocular switch for communication of the speechless," Med. Progress Through Technology, vol.10, pp.135–141, 1983/1984.

[5] J.R. LaCourse and F.C. Hludik, Jr., "An eye movement communication-control system for the disabled," IEEE Trans. Biomed. Eng., vol.37, no.12, pp.1215–1220, 1990.

[6] J.J. Tecce, J. Gips, C.P. Olivieri, L.J. Pok, and M.R. Consigio, "Eye movement control of computer functions," Int. J. Psychophysiology, vol.29, pp.319–325, 1998.

[7] R. Barea, L. Boquete, M. Mazo, and E. Lopes, "System for assisted mobility using eye movements based on electrooculography," IEEE Trans. Neural Sys. Rehab. Eng., vol.10, no.4, pp.209–218, 2002.

[8] J. Hori, K. Sakano, and Y. Saitoh, "Development of a communication support device controlled by eye movements and voluntary eye blink," IEICE Trans. Info. & Syst., vol.E89-D, no.6, pp.1790-1797, Jun. 2006.

[9] K. Yamagishi, J. Hori, and M. Miyakawa, "Development of EOG-based communication system controlled by eight-directional eye movements," Proc. of 28th Annual Int. Conf. of IEEE EMBS, New York, pp.2574-2577, 2006.

[10] J. Gips, P. DiMattia, F. X. Curran, and P. Olivieri, "Using EagleEyes—an electrodes based device for controlling the computer with your eyes—to help people with special needs", Proc. of the 5th Int. Conf. on Computers Helping People with Special Needs. part I, pp.77–83, 1996.

[11] Y. Kuno, T. Yagi, I. Fuhii, K. Koga, and Y. Uchikawa, "Development of eye-gaze input interface using EOG", IEICE Trans. Info. & Syst., vol.39, no.5, pp.1455-1462, 1998.

[12] T. Ohya and M. Kawasumi, "Development of an input operation for the amyotrophic lateral sclerosis communication tool utilizing EOG", JSMBE, vol.43, no.1, pp.172-178, 2005.

[13] J. Hori, K. Sakano, M. Miyakawa, and Y. Saitoh, "Eye movement communication control system based on EOG and voluntary eye blink" Lecture Notes in Computer Science, vol.4061, pp.950-953, 2006.

[14] W.S. Fang and N. Itakura, "Evaluation for measurement of continual eye-gaze shift for the eye-gaze input interface using electro-oculogram amplified by AC coupling: comparison with limbus tracking method", IEICE, vol.WIT2006-39, pp.41-44, 2006.

[15] M. Trikha, A. Bhandari, T.Gandhi "Automatic electrooculogram classification for microcontroller based interface design", Syst. Inf. Eng. Design Symposium, pp.27–27, 2007.

[16] B. Estrany, P. Fuster, A. Garcia, and Y. Luo, "Human computer interface by EOG tracking", ACM Int. Conf. Proc. Series, vol.282, 2008.

[17] L.R. Squire, F.E. Bloom, S.K. McConnell, J.L. Roberts, N.C. Spitzer, M.J. Zigmond, "Fundamental Neuroscience, 2nd Ed.", Academic Press, 2003.