Eye Movement Detection Using EOG for Communication of People with Disabilities

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Abstract

This research attempts the eye movement detection for the communication of people with disabilities by employing the electrooculographic (EOG) signals. Eye movements for the left and the right are detected by capturing the peak which appears in the waveform. Then, the judgment for left or right eye movement is conducted based on four parameters about the detected peak. To confirm the effectiveness of the eye movement detection method considered in this research, experiments were performed.

1 Introduction

Some people with disabilities have the difficulty in the communication using utterance, action, utilization of equipment etc. However, there is a possibility that his/her eye movement is available until he/she reaches totally locked-in state.

From this point of view, a nurse call system for people with such heavy disabilities has been developed by using image processing from camera images [1]. The system has a remarkable feature that non-contact detection of eye movement is realized. However, the success of detection is heavily affected by the condition of the environment (e.g., lighting condition). Furthermore, image processing may require relatively high computational burden. On the other hand, electrooculogram (EOG) [2] is recognized as one of the most useful information to capture the eye movements. Therefore, EOG signal may be effective in the extraction of human intention. Indeed, EOG signal was applied to the hands free remote operation of a mobile robot [3].

In this research, the detection of the eye movements for the communication of people with heavy disabilities is considered by using EOG signals.

2 System Configuration

The system configuration of this research is shown in Fig. 1. First, horizontal EOG is acquired from three electrodes placed on the subject's face as shown in Fig. 2. Exploring electrodes for EOG recording are placed at both left and right outer canthus. Secondly, acquired EOG is magnified by an AC amplifier with a high cutoff frequency of 15.9 [Hz] and a low cutoff frequency of 0.23 [Hz] and are stored into the PC with the sampling interval of 5 ms via AD converter. Horizontal eye movement is extracted by signal processing.

Fig. 1: System configuration

- ... Electrode to acquire EOG
- ... Electrode for ground

Fig. 2: Electrode placement

3 Eye Movement Detection

For the detection of eye movement, it is judged whether the user looks at the left or right from EOG signal. Figs. 3 and 4 show the relationship between EOG waveform and eye movement for the left and the right, respectively. As shown in Fig.3, rapid amplitude change occurs in the case that eyes move from front to left. Then after, the amplitude gradually decreases due to the filter property of AC amplifier. The case of gazing right direction shown in Fig.4 is vice versa. These figures indicate that the distinguishing peak corresponding to the direction of eye movement appears in the waveform. Therefore, in this research, eye movements are detected by extracting the peak of the signal $y(k)$.

3.1 Peak Detection

In order to extract the peak corresponding to eye movements, three points F, P and B of the signal $y(k)$ shown in Fig. 5 or Fig. 6 are firstly detected [2]. Points F and P are defined by $y(k_f)$ and $y(k_p)$ satisfying

$$[y(k_* + 1) - y(k_*)][y(k_*) - y(k_* - 1)] < 0 \quad (1)$$

where $y(k_*)$ means $y(k_f)$ or $y(k_p)$. (See Fig. 7.)

On the other hand, point B is defined by $y(k_b)$ ($k_b > k_p$) satisfying

$$y(k_b) < y(k_f) \quad \text{for left gaze} \quad (2)$$

or

$$y(k_b) > y(k_f) \quad \text{for right gaze}, \quad (3)$$

where minimal k_b satisfying (2) or (3) is adopted. In the following argument, the times corresponding to k_f , k_p and k_b are expressed by t_f , t_p and t_b , respectively.

Fig. 3: Relationship between EOG waveform and eye movement for the left

Fig. 4: Relationship between EOG waveform and eye movement for the right

Fig. 5: Peak detection and judgment for left eye movement

Fig. 6: Peak detection and judgment for right eye movement

Fig. 7: Detection of points F and B

3.2 Judgment for Eye Movements

Four parameters H_f , H_b , D_f and D_b shown in Figs. 5 and 6 are used for judging eye movements. H_f and H_b mean the amplitude and D_f and D_b correspond the duration of EOG waveform. Derivation of these parameters are listed in Table 1.

Table 1: Parameters for judgment

Name	Parameter
Forward amplitude	$H_f = y(k_p) - y(k_f)$
Backward amplitude	$H_b = y(k_p) - y(k_b)$
Forward duration	$D_f = t_p - t_f$
Backward duration	$D_b = t_b - t_p$

3.2.1 Judgment for Left Eye Movement

If the following conditions:

$$H_f \geq \Lambda_{lhf} \quad (4)$$

$$H_b \geq \Lambda_{lhb} \quad (5)$$

$$\underline{\Lambda}_{ld} \leq D_f + D_b \leq \bar{\Lambda}_{ld} \quad (6)$$

$$H_f/D_f \geq \Lambda_{ls} \quad (7)$$

are satisfied, then it is judged that there is a movement for left direction of the user's eyes. Thresholds for left judgment are listed in Table 2.

Table 2: Thresholds for left eye movement

Name	Parameter
Forward amplitude threshold	Λ_{lhf}
Backward amplitude threshold	Λ_{lhb}
Duration threshold (minimum)	$\underline{\Lambda}_{ld}$
Duration threshold (maximum)	$\bar{\Lambda}_{ld}$
Sharpness threshold	Λ_{ls}

3.2.2 Judgment for Right Eye Movement

If the following conditions :

$$H_f \leq \Lambda_{rhf} \quad (8)$$

$$H_b \leq \Lambda_{rhb} \quad (9)$$

$$\underline{\Lambda}_{rd} \leq D_f + D_b \leq \bar{\Lambda}_{rd} \quad (10)$$

$$H_f/D_f \leq \Lambda_{rs} \quad (11)$$

are satisfied, then it is judged that there is a movement for right direction of the user's eyes. Thresholds for right judgment are listed in Table 3.

Table 3: Right judgment parameter

Name	Parameter
Forward amplitude threshold	Λ_{rhf}
Backward amplitude threshold	Λ_{rhb}
Duration threshold (minimum)	$\underline{\Lambda}_{rd}$
Duration threshold (maximum)	$\bar{\Lambda}_{rd}$
Sharpness threshold	Λ_{rs}

4 Experiment

In order to verify the effectiveness of the eye movement detection method developed in this research, experiments were conducted.

4.1 Experimental Condition

Three experiments were performed by three healthy subjects (Subject K, Subject N and Subject T). Experiments are done with that the subject lies down on the bed.

The subjects moved their eyes according to the instruction as listed in Table 4.

The thresholds for judgment were selected for all the subjects as shown in Table 5. Those values were determined by using the data recorded from the subjects in advance.

Table 4: Instruction for experiments

Time[s]	Instruction
10	Please move your eyes to the right
15	Please return your eyes to the front
25	Please move your eyes to the left
30	Please return your eyes to the front
40	Please move your eyes to the right
45	Please return your eyes to the front
55	Please move your eyes to the left
60	Please return your eyes to the front

Table 5: Thresholds for experiments

Parameter	Threshold
Λ_{lhf}	250[μV]
Λ_{lhb}	250[μV]
$\underline{\Lambda}_{ld}$	0.3[s]
$\overline{\Lambda}_{ld}$	1.5[s]
Λ_{ls}	600[$\mu\text{V/s}$]
Λ_{rhf}	-250[μV]
Λ_{rhb}	-250[μV]
$\underline{\Lambda}_{rd}$	0.3[s]
$\overline{\Lambda}_{rd}$	1.5[s]
Λ_{rs}	-600[$\mu\text{V/s}$]

4.2 Experimental Results

Experimental results by Subject K, Subject N and Subject T are depicted in Figs. 8-10, respectively, where the detection results are also shown in the same figures. Furthermore, detection rate, undetected rate, over-detection rate and false detection rate are also s-

ummarized in Table 6. From Figs. 8-10 and Table 6 we see that eye movements were perfectly detected in all experiments.

Fig. 8: Experimental result (Subject K)

Fig. 9: Experimental result (Subject N)

Fig. 10: Experimental result (Subject T)

Table 6: Detection results

Subject	Subject K	Subject N	Subject T
Detection rate [%]	100	100	100
Undetected rate [%]	0	0	0
Over-detection rate [%]	0	0	0
False detection rate [%]	0	0	0

5 Discussion

In this research, the judgment of eye movements is realized by considering four parameters (i.e., forward amplitude H_f , backward amplitude H_b , forward duration D_f and backward duration D_b) and suitable thresholds. Since the thresholds could be appropriately given for three subjects, sufficient accuracy of the eye movement detection was achieved. Therefore, the system developed in this research may also be effective for people with disabilities if suitable thresholds can be selected.

Furthermore, the experimental results imply that perfect manipulation of the method for communication by, at least, healthy users can be expected. Therefore, the method has an excellent potential to construct an effective communication system for people with disabilities.

6 Conclusions

In this research, the detection methodology for eye movement using EOG signal was investigated. Eye movements were detected by capturing the peak which appeared in moving user's eyes. Furthermore, it was verified that the developed detection system could achieve sufficient accuracy to apply to the construction of the communication system using EOG signal. In the future work, the authors will conduct some experiments of eye movement detection and communication system operation by people with disabilities.

References

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