ORIGINAL RESEARCH

Eye-glance input interface for a small screen

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Abstract

Optical measurement devices for eye movements are generally expensive and it is often necessary to restrict user head movements when various eye-gaze input interfaces are used. Previously, we proposed a novel eye-gesture input interface that utilized electrooculography amplified via an AC coupling that does not require a head mounted display. Instead, combinations of eye-gaze displacement direction were used as the selection criteria. When used, this interface showed a success rate approximately 97.2%, but it was necessary for the user to declare his or her intention to perform an eye gesture by blinking or pressing an enter key. In this paper, we propose a novel eye-glance input interface that can consistently recognize glance behavior without a prior declaration, and provide a decision algorithm that we believe is suitable for eye-glance input interfaces such as small smartphone screens. In experiments using our improved eye-glance input interface, we achieved a detection rate of approximately 91% and a direction determination success rate of approximately 85%. A smartphone screen design for use with the eye-glance input interface is also proposed.

Key Words: Eye gesture, Eye-glance, AC-EOG, Smartphone, Screen design

1 Introduction

Human computer interactions (HCI) are an important field in computer science. Many computer interfaces are being developed for people with disabilities.[1,2] One such computer interface type utilizes eye-gaze behavior. An eye-gaze interface can be faster than a computer mouse for inputting user selections and is convenient in situations where it is essential that a user keeps his or her hands free in order to perform other tasks.[3,4] Previously, eye-gaze interfaces with direct input methods that rely on detecting the user's gaze point have been most frequently studied.[1–4,12] However, optical measurement devices for eye movements are generally expensive, and it is often necessary to restrict the user's head movements when using various eye-gaze input interfaces to prevent the introduction of diagonal eye movements.

Based on the amplification method used, there are currently two types of electrooculographs(EOGs) in use: DC coupled (DC-EOG) and AC coupled (AC-EOG). In DC-EOG, voltage must be applied manually to the amplifier in order to adjust the baseline to zero in response to changes in the resting potential. In contrast, AC-EOG does not re-quire such adjustments.

In our earlier studies,[5–8] we discussed an eye-gaze input interface that combined a head mounted display (HMD) with an AC-EOG. That interface was relatively inexpensive and enabled users to escape head movement restrictions. It was also noteworthy because it permitted the introduction and use of diagonal eye movements, thus introducing 12 possible eye-gaze movement choices. However, it was considered suboptimal because it required the use of a costly HMD that was time consuming to put on and troublesome for the users. In addition, that particular gaze input method required the user to spend uncomfortable amounts of time watching the target.

Separately, another eye-gaze interface that can be used to control a cursor by detecting the user's gaze direction has been investigated.[9–11] However, the number of movement directions that can be identified by this interface is be-tween 4 and 8 without target. Furthermore, taking into consideration the original function of an eye, it is reasonable to assume that allowing users to look directly at the target when

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detecting eye-gaze movements would allow for more natural eye movements.

In the study described in Reference 8, a display based on measuring diagonal eye movements was proposed. In that interface, to determine the eye's position during diagonal motion, information about vertical eye movements is combined with the horizontal AC-EOG signals. This design permitted 12 possible choices, the mean accuracies of which were 89.2%.

This interface determines the choices made from the vertical eye movement direction and amount of eye movement in the horizontal direction. Thus, to obtain a precise measurement of the amount of eye movement in the horizontal direction, the relative position of the input screen and the eyeball must be known, which made it necessary to secure the HMD to the user's head.

2 Eye gesture input interface

In Reference,[12] we reviewed previous input methods with an aim towards reducing system costs and restrictions placed on the user. The result was a novel eye-gesture input interface that did not require a HMD. Instead, direction combinations for eye-gaze displacement were used as the selection method. We found that eye-gaze displacements could be determined precisely using a derivative EOG signal amplified via AC coupling. A desktop display design created for use with the eye-gesture input interface is shown in Figure1. In that study, it was assumed that eye-gesture movements followed oblique patterns (upper left, lower left, upper right, lower right), and that each pat-tern consisted of a combination of two movements.

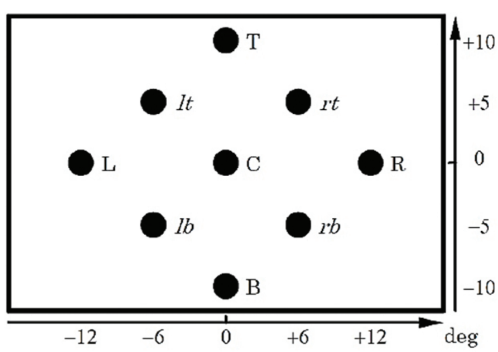

Figure 1: Experimental screen design for eye-gesture input interface.

Users were instructed to initiate use of the input method by following the three instructions provided below:

(1) Glance at the central C while pressing the enter key (Gesture start).
(2) Glance first at the targets lt, lb, rt, and rb.
(3) Glance at the targets C, T, B, L, and R (Gesture finish).

Using this method, the eye movements of the pattern could be saved as a combination of $4 \times 3 = 12$ pairs. For this interface, eye movement was detected twice in the oblique direction during steps 1 3. Furthermore, the user eye-gesture input is determined as a pattern combination. The advantage of this eye-gesture input interface is that determinations were made from the combination of diagonal eye movements, and there was no need to calculate precisely the amount of eye movement and the like.

Accordingly, the need to fix the relative position of the eyeball and the input screen is eliminated, which also eliminates the need for a HMD, and an input interface that can be utilized in numerous situations was made possible.

However, this interface required the user to declare the initiation of an eye gesture by, for example, blinking or pressing enter key. In this paper, we propose an upgraded eye-glance input interface that can be used consistently, and which does not require the user to declare his or her initiation of an eye gesture. A decision algorithm created for use with the eye-glance input interface is also proposed.

3 Eye-glance input interface

3.1 Eye-glance

An eye-glance is defined as an action used to obtain a characteristic waveform whereby a user glances at a target for just a moment. It is different from reading and/or searching text on a screen. For a small screen, such as a smartphone, we restricted recognition to four possible choices - from the center of the screen to the four corners in a round-trip oblique series of eye movements (upper left, lower left, upper right, lower right) as shown in Figure 2.

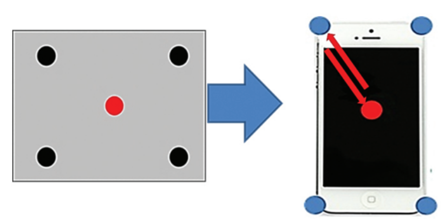

Figure 2: Eye-glance input interface using a smart phone screen (target and arrow aren't shown).

An eye-glance has the following three characteristics:

(1) A dual eye movement from and to the center is provided to the horizontal AC-EOG, as shown in Figure 3.
(2) There is a "pause" time τ between the times of occurrence of the dual eye movement.
(3) The vertical AC-EOG is the same as the horizontal AC-EOG, and occurs at the same time.

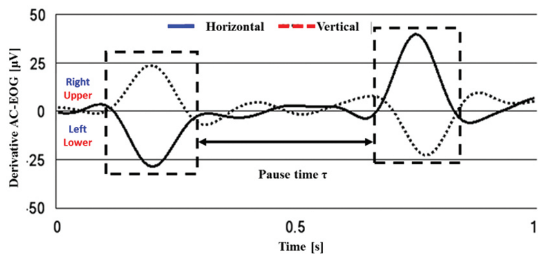

Figure 3: Example of a derivative AC-EOG signal created from a single eye-glance.

With these characteristics in mind, we performed experiments to evaluate a standard that can be used to distinguish eye-glance input from normal eye movement.

3.2 Methods

Four healthy male subjects ranging in age from 21 to 24 years old (mean = 22.5 years, SD = 1.3 years) volunteered to participate in our study. None of the subjects reported any medical or psychiatric problems at the time of testing. All volunteers were informed about the aims and the possible risks of the study. During the experiments, the subjects were asked to sit on a chair and manipulate a keyboard with their right hand. The AC-EOG signals were captured by 10-mm Ag-AgCl metal electrodes (NIHON KODEN Corp., Tokyo, Japan) placed around the subjects' eyes, as shown in Figure 4. For the horizontal AC-EOG, two electrodes were placed 2.0 cm lateral to the outer canthi. For the vertical AC-EOG averaging the two vertical AC-EOGs, four electrodes were placed 2.0 cm above and 2.0 cm below the two electrodes for the horizontal AC-EOG. Finally, another electrode placed on the left ear served as a ground.

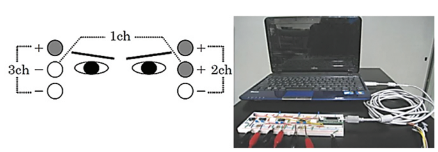

Figure 4: Electrodes, channels, and our original apparatus.

The AC-EOG signals obtained from the amplifiers were fed into an apparatus of our own design connected to a PC.[12] The amplifiers have a gain of 10,000, a high pass analog filter with a 0.1 Hz cut-off frequency, and a low pass analog filter with a 10.0 Hz cut-off frequency. The amplified AC-EOG signals were sampled at a rate of 100 Hz using a 12-bit resolution. Before conducting the experiments, the following assumptions and preconditions were set:

- The average value of 2-ch and 3-ch was used to create a fourth channel (4-ch) on the computer
- 1-ch corresponds to the horizontal AC-EOG
- 4-ch corresponds to the vertical AC-EOG
- Positive and negative values for 1-ch correspond to eye movements to the left and right
- Positive and negative values for 4-ch correspond to upward and downward eye movements

3.3 Experimental procedure

Each test subject performed a total of 10 eye-glance attempts during which he glanced at each of the four corners. A standard value for a 6°movement was used to calibrate the interface prior to the experiments. Each attempt was performed using the following steps:

(1) The subject picks up and uses a smartphone normally (Free time).

(2) The eye-glance maneuver begins when the subject focuses his gaze on the center of the screen and then presses a timer.

(3) The subject then performs a round-trip series of eye movements in an oblique direction from and to the cen-ter screen, viewing each corner in series.

(4) The eye-glance maneuver finishes when subject return his gaze to the center of the screen a final time and presses the timer again.

(5) The subject then operates the smartphone normally (Free time).

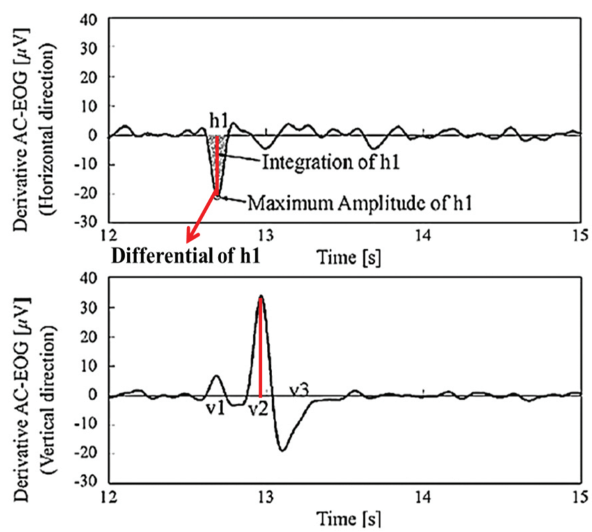

Figure 5: Example derivative of a horizontal and vertical direction AC-EOG signal.

3.4 Displacement calculation

The derivative AC-EOG signal, an example of which is shown in Figure 5, was used to calculate the displacements of the eye movements. The value of the derivative AC-EOG is directly proportional to the velocity of the eye movement. A saccade is defined as a rapid eye movement, during which the eye's velocity changes from zero to a large value and then returns to zero. Therefore, a 0-to-0 interval of the derivative AC-EOG (0-0 wave) such as that shown as h1 in Figure 5, can be considered a saccade interval.

In previous study,[8] the integral of a 0-0 wave is used as the proportional value to the displacement of a saccade. However, the maximum amplitude of a 0-0 wave is also thought to have a value that is proportional to the displacement of a saccade.

In this study, the large maximum amplitude of a saccade can be detected from the maximum amplitude value of a 0-0 wave. In contrast, a state of prolonged fixation is considered an eye-gaze state. Whenever an eye-gaze state was detected, the displacement of the preceding movement was calculated as the sum of the displacement values of saccades occurring between the previous and the present eye'gazes.

3.5 Decision algorithm

Determinations were carried out by focusing on the 0-0 wave at the intersection of the baseline 0V and the differential of the AC-EOG. In our proposed method, the system makes a determination using the following algorithm 1:

Algorithm 1 Algorithm of eye-glance

1: Processing of the high cut-off 20 Hz FIR filter to the AC-EOG begins.
2: Differential processing begins.
3: Processing of the high cut-off 15 Hz FIR filter begins.
4: To reduce steady-state noise by calibration.[8]
5: If the threshold value of the integral of the first horizontal 0-0 wave and the second horizontal 0-0 wave have the same sign, reduce the equivalent 2°(If the signs are opposite, take no action).
6: Detect the vertical 0-0 wave in the time series that occurs nearest to the horizontal 0-0 wave.
7: If it is the same as the first eye movement direction determined by the second time, this decision will continue to be discarded.
8: Repeat steps 5, 6, and 7 to determine eye-glance behavior.

3.6 Result of eye-glance detection

As described in the experimental procedure outlined in Section 3.3, two zones of experiment time (eye-glance and free time) were observed. An example of the derivative AC-EOG signals observed during experiment and free time analyzed with the method described in session 3.4 and 3.5 is shown in Figure 6.

Using the characteristics of the horizontal 0-0 wave and the pause time τ which determined by calibration to determine normal eye movements. We attempted to detect eye-glance behavior during experiment times using the horizontal 0-0 wave and the pause time τ. A successful value was counted when an eye-glance was detected at least one once during the experiment time. The results of our experiment showed that the detection rates for all test subjects were increased as determined by the horizontal 0-0 wave and the pause time τ ($\tau \pm 0.1 \sim 0.4$), as shown in Table 1.

Especially, eye-glance of the high detection rates for all test subjects were above 90% as determined with using the horizontal 0-0 wave and pause time range ($\tau \pm 0.3$) and ($\tau \pm 0.4$). Because it's desirable to detected eye-glance in a short time, we determined to detect eye-glance with using the horizontal 0-0 wave and ($\tau \pm 0.3$).

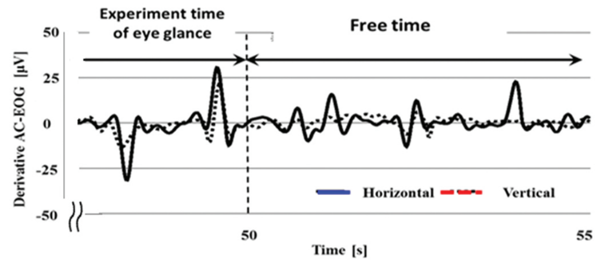

Figure 6: Derivative AC-EOG signal example showing both experiment and free time.

4 Discussion

4.1 The vertical 0-0 wave

We tried to add the information of the vertical 0-0 wave for raising success rate of direction. In other words, offline analyses were performed with the four subjects to compare the new integration method with the method of using three characteristics (as the same time horizontal 0-0 wave and vertical 0-0 wave which the pause time is ($\tau \pm 0.3$). The accuracy of a choice as defined as the success rate divided by the number of choices made. Table 2 shows the accuracies of the choices for all subjects along with the sum of all the displacements. In the case of four possible choices using eye-glance behaviors, the mean accuracy of the choices was above 84% when the three characteristics were used.

The success rate accuracies for all subjects, including the vertical success rate, was reduced by 10% compared to measurements of the horizontal direction and pause time ($\tau \pm 0.3$), as shown in Tables 1 and 2. Especially, with respect to the subject D, including the vertical success rate caused a 35% reduction compared to judgments of the horizontal direction.

4.2 Timing of the vertical 0-0 wave

It is possible that the timing of the vertical 0-0 wave included an error, as shown in Figure 7. The gray zone shows that the timing of the horizontal 0-0 wave, and twice were different, but twice vertical 0-0 wave were the same direction in this example. One of the reasons was that this subject tended to move his neck as well as his eyes vertical direction when using the smartphone for long periods of time. Furthermore, there are individual differences in the neck movements of all test subjects. In particular, this is why Subject D showed a 35% accuracy reduction. However, this tendency is not general for almost the human as shown in Table 2.

Table 1: Detection rate of eye-glance by horizontal 0-0 wave and the pause time τ.

	Pause Time	Subject A	B	C	D	E	F	G	Average
Detection rate (%)	τ±0.1	43.82	77.54	42.54	60.69	67.83	52.90	40.52	55.12
	τ±0.2	75.14	97.53	75.03	78.57	89.11	87.71	72.93	82.29
	τ±0.3	87.82	97.54	90.41	85.88	96.92	94.40	89.21	91.74
	τ±0.4	87.46	97.45	92.45	85.65	96.32	94.00	89.14	91.78

Table 2: The accuracies (%) of choices for all subjects using three characteristics.

	Pause time range(s)	Subject A	B	C	D	E	F	G	Average
Detection rate (%)	τ±0.3	81.32	95.04	85.77	55.03	95.47	92.48	86.52	84.52

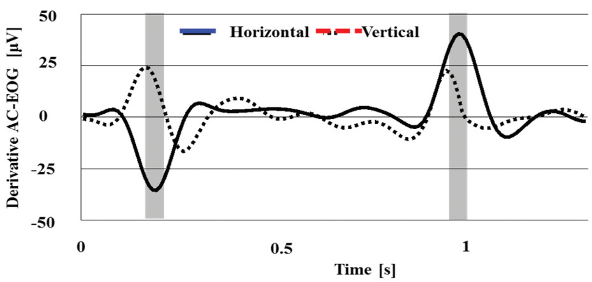

Figure 7: Direction error judgments for single eye glance behavior.

5 Character input with using eye glance

Recent years, the diffusion of smart phones which are designed based on PC-functions is becoming a trend because of its highly compatible features with the Internet. However, even though the miniaturization of information processing units can be technically achieved, the realization of the interface for the smart phones is becoming more and more difficult due to the limitation of physical size of manipulation by fingers. Therefore, the software keyboard and input interface for the smart phones only are needed. In this study, we proposed a screen design for inputting a lot of possible choices on the screen with a few degrees of freedom for input operation for the use of a small screen such as smart phones. We also proposed two kinds of input interfaces which are a contact input interface through a touch panel and a non-contact input interface by eye movements respectively.

5.1 Detail of the guide menu

(1) Set four selection areas to upper left, lower left, upper right, lower right. Such as upper left button (include five choices: A, I, E, U and Mo).

(2) The center of one selection area is four common choices such as Mo (Language mode), Del (Deletion), En (Enter) and Sp (Space).

(3) The center of this guide menu is screen reshuffling button.

(4) All choices are 4(selection area) $\times$ 4 (four choices)+ 4(common choices) =20 choices

(5) This guide menu for only guding information and been changed size freely such as Figure 9.

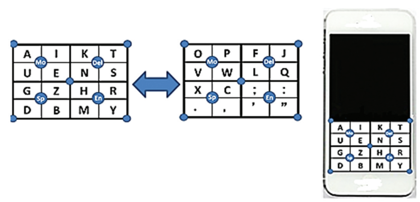

Figure 8: Guide menu for character input.

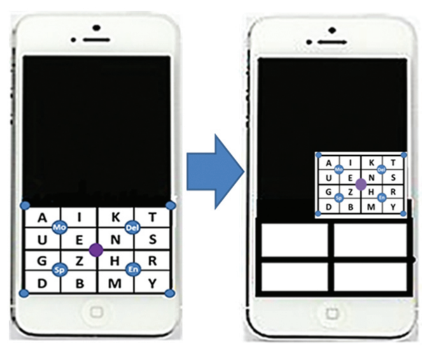

Figure 9: Diversity of the menu.

5.2 Character input with using this guide menu

First of all, we used existing features such as touch panel to input character with using this guide menu. For character input method, we defined to use four selection areas for inputting 16 alphabet choices and 4 common choices with using the following algorithm:

Algorithm 2 Algorithm of character input

1: For inputting alphabet choices, there are 2 steps that pressing selection area of including the aim choice and pressing anther selection area of direction of the aim choice continuously. For an example, inputting alphabet "R" as shown in Figure 10.

2: For inputting common choices, pressing selection area of including the aim common choice such as Mo, Del, En and Sp, and waiting more than 2 seconds.

3: For changing screen of guide menu, pressing the center button of the guide menu.

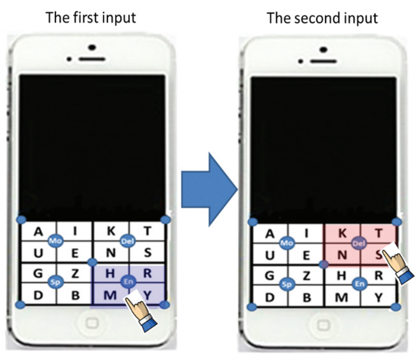

Figure 10: Procedure for inputting alphabet choices.

5.3 Character input with using eye-glance input

In an attempt to create a practical application for use with our eye glance input interface; we designed a guide menu for character input that utilizes eye glance behavior and a small screen, as shown in Figure 8. For our future work, intend to conduct character input experiments using this guide menu and eye-glance input.

6 Conclusions

In this paper, we proposed an eye-glance input interface that allows users to make inputs consistently without prior declarations and discussed a decision algorithm for the interface that utilizes a horizontal 0-0 wave and the pause time τ. And we proposed a screen design for inputting a lot of possible choices on the screen with a few degrees of freedom for input operation for the use of a small screen. During experiments conducted on four test subjects, we achieved the average detection rate of the four subjects was above 90% as measured by the horizontal 0-0 wave and the pause time $(\tau \pm 0.3)$ and $(\tau \pm 0.4)$. However, when the vertical success rate was included, the accuracies of success rate of direction for all subjects were above 84%, and a 10% reduction occurred when the vertical 0-0 wave was added. Our future tasks and goals include using an input guide menu and web camera for a small screen that can be used with the eye-glance interface along with creating an application suitable for a smartphone or tablet.

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