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Study of a Saccade-incident Information Display using a Saccade Detection Device

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Abstract

In recently proposed saccade-based information displays, the observer cannot see an afterimage without moving the eyes appropriately and therefore often cannot see the afterimage correctly. We propose a new display system based on a concise saccade detection technique and the perceptual features of eye movement. In addition, with a system consisting of a wearable sensor (saccade detector) and a ubiquitous display (saccade-based display), we propose an application where many viewers can be accommodated simultaneously (Several viewers can view an image simultaneously (timesharing) with one saccade-based display.) and independently (Several viewers can view different images with one saccade-based display.). In experiments, we compared character-recognition rates to confirm that the detection of the saccade improves the visibility of the saccade-based display. The results indicate that the recognition rate is clearly improved.

Keywords: Saccade-based Display, Ubiquitous Display, Wearable Saccade Detection Device, Character Recognition

1. Introduction

1.1 Saccade-based Display

Many studies have proposed or demonstrated visual information displays that work on the basis of the characteristics of human vision. For a two-dimensional (2D) visual information display, physical (mechanical) high-speed movement of a light dot array (one-dimensional (1D) LED array) has been proposed [1]. The user perceives information in two dimensions when the light dot array is moved in one dimension. Another approach is to not physically move a dot array, but instead change the blinking pattern of an array of lights at high speed. Then when the human does a saccade (high-speed eyeball movement), a 2D image is perceived [2][3][4]. Such an information display method [which we call a saccade-based display (Fig. 1)] greatly reduces the space needed for the device effective. Therefore, we have been studying ways to improve the effectiveness of information display devices using saccades [5][6]

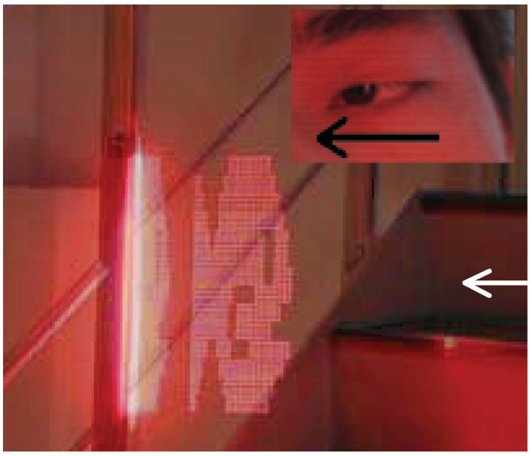

Fig 1. Saccade-based display

1.2 Improvement of saccade-based display

In a saccade-based display, when there is both the observer's ocular motility and one light dot array, a 2D image can be viewed in the space of the light dot array neighborhood. However, if there is a discrepancy between the luminescence timing of the light dot array and the ocular motility, the image can not be viewed. We examined whether this problem could be solved by always displaying information (continuously blinking light source), by using visual stimulation to cause a saccade (cause ocular motility by moving a fixation point), or by measuring a saccade and displaying information synchronously with the saccade

In the first method, the light source is continuously blinking regardless of the observer's ocular motility. When the observer moves the eyeball, a 2D image is drawn on the retina without fail. However, the order of the displayed 2D-image may change or the direction reverse according to the timing of observer's saccade. For example, the observer sees “ROGF” or some other combination of letters, though we want to display “FROG”, or the image reverses when the direction of viewer's saccade changes, so that observer sees “ÐOЯꟻ”. Therefore, this method does not provide and dramatic improvement of the saccade-based display.

The second method is based on saccade inducement. When the object of an observer's gaze is changed, a saccade is generated. This effect can be achieved by adding a blinking light to the saccade-based display, and information is displayed with the same timing as the stimulation for inducing the saccade. Two points defined by a LED [the fixation point (FP) and the target point (TP)] are arranged on either side of a saccade-based display. We illuminate the FP first, and the observer gazes at it. Next, the FP is turned off and the TP is illuminated. Then, the observer's saccade is induced in the reflection. When we blink saccade-based display according to the timing of saccade-inducing, the observer surely perceives display information. However, we must know the time from the TP presentation to saccade start time (usually called "latent time") and display start time. In general, the latent time of a saccade is about 200[ms]. However, the latent time is every time a little different, and varies with the individual. Therefore, the probability of being able to appropriately see is 10[%] or less. For improvement, a method using a stable saccade latent time (called the express saccade [7][8][9]) has been proposed [6]. Nonetheless, the observer is still not able to be see appropriately by as much as 50[%] without training. In addition, we must measure the different latent time for each individual for adjustment. This is approach is therefore still far from practical use.

In the third method, the saccade onset is measured in real time and the saccade-based display is activated at the same time the saccade starts. When the saccade detection accuracy is high, the observer surely perceives 2D information. We consider this method to be the most effective of the three. We examined remote detection of the saccade using the reflexive reflection of the retina [13]. However, this required an expensive, high-speed camera, and range of the measurement was limited by the measurement device. Therefore, we here propose the simple wearable device for saccade detection. In addition, we propose a saccade-based display system that displays 2D information using this device.

1.3 Selective information display with wearable saccade detection device

If we can detect when and who makes saccades, we can selectively present different images to each person using only one light array. Consider the situation in Fig. 2, where persons A and B are observing the display and a saccade detection device continuously detects the wearer's saccade. At time t1, when person A's saccade is detected, a 2D image is presented only to person A by flickering the LED array. On the other hand, person B doesn't move his eyes at this time, so he can see only a single array of LEDs. In contrast, at time t2, person B's saccade is detected and only person B can see a different 2D image. If this display does not output an image synchronized with the timing of the viewer’s saccade, it will be almost impossible for the viewer to perceive the afterimage. That is to say, if the image is presented only to the viewer whose saccade is detected, this display system will be able to handle highly confidential information. Moreover, many viewers can use one display device by timesharing.

In this paper, we propose a new display system based on a concise saccade detection technique and perceptual features during eye movement. We also propose new ubiquitous display systems in which a wearable saccade detection device is combined with ubiquitous saccade-based display.

Section 2 describes our design considerations in the development of the saccade detector device. Section 3 describes the experiments and presents the results. Though displaying characters is important in a situation like that in Fig. 2, the recognition characteristics of characters have not been examined in past research using saccade-based displays. To show the effect of the proposed saccade detector device, we compared the character-recognition rates with/without the saccade detector device. We confirmed that the recognition rate is improved using the saccade detection.

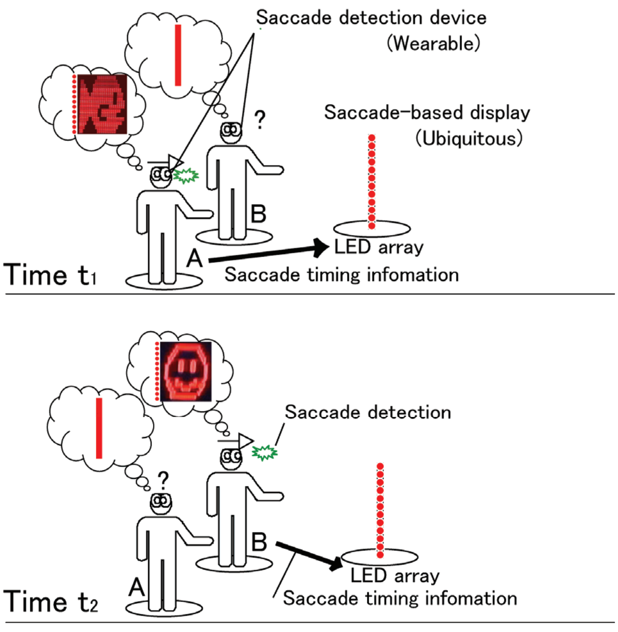

Fig. 2. Saccade-based display with saccade detection

2. Wearable Saccade Detection Device

2.1 Requirements for saccade detection

In a saccade-based display, immediately after the detection of the viewer's saccades, the light array flickers to present 2D images. Therefore, we must consider the temporal relationship between perceived 2D images and the saccade in the saccade detection device design.

The maximum saccade speed is 700[deg/s] and the duration is 50[ms], which are faster and shorter than other ocular motilities. The timing of the saccade onset should be detected with as little delay as possible because delay narrows the display area. As a concrete value, a delay of 5[ms] or less is preferable, which means the sampling rate should be 200 [Hz] or higher. On the other hand, we do not want high spatial resolution like in conventional eyeball movement measuring instruments. Instead, we want high time resolution. In addition, the device should be wearable.

2.2 Conventional eyeball movement measurement

We can take a movie of the eyeball with a camera, and obtain the movement angle of the eyeball through image data processing [11][12]. However, the frame rates are too slow (usually 30-60 FPS). Of course, we could use a high-speed camera [13]. However, to obtain sufficient signal-to-noise ratios for saccade detection, such cameras use high-power light, which could injure the eye.. In addition, we would have to reduce the size of the lens for the device to be wearable, but as lens size is reduced so is the quantity of light. . Then, there is also the need for very strong lighting. Therefore, this method is not realistic either. We have proposed a method of remote saccade detection [10]. However, it is difficult to separate eye movement from face movement without attaching markers on the face. Moreover, the method cannot specify the person whose eyes moved from a group of several observers, which means apposite information can not be displayed for each individual. In addition, we examined conventional eyeball movement measurement methods. The sclerotic reflection method [14] irradiates the eyes with weak infrared rays and detects eye movement from the difference between the reflectivity of the white of the eye and the iris. However, because of noise from outside light influences this method easily, it is disadvantageous in a bright environment. The search coil method [15] requires the use of a special contact lens. Therefore, it is difficult to use it in daily life. The EOG method [16] uses living body signal. The cornea has positive potential of 10-30 μV, so that ocular motility can be observed from electrodes attached around the eyes. This method is affected by external electromagnetic noise and the accuracy is low. However, since our concern here is only detecting the timing of the saccade, we expected that we would be able to extract only saccade timing information by appropriate filter processing and therefore decided to use the EOG method for the saccade detection.

2.3 EOG saccade detection device

For the detection of saccade timing, the weak living body signal obtained by EOG has to be amplified and filtered. . Figure 3 shows the circuit blocks for the amplification and filtering. An instrumentation amplifier amplifies the EOG signal from the electrode, and a high-pass filter eliminates drift and signal that is slower than the saccade. The cutoff frequency is 1 [Hz]. Next, the noise is removed. The most serious problem is electromagnetic radiation noise from the power line. Most of this noise can be removed with a 50-Hz notch filter. (The power supply of North Japan is 50 [Hz] AC, and this is a key factor in the noise.) In addition, the signal is appropriately adjusted for the microcomputer A/D input. The differentiation processes the input signal to the microcomputer, which judges that a saccade has been generated when the differentiation value exceeds a threshold. The delay of the saccade detection increases when this threshold is high. However, when the threshold is low, microcomputer misjudgments are caused by the noise. Therefore, delay time is decided depending on the amount of the signal noise. Figure 4 shows how the electrodes are worn and a close-up on an electrode, and Fig. 5 shows a snap shot of the signal measurement. To decrease misjudgments, we adjust the threshold of the signal (10% or less) in Fig. 5. In our laboratory (an unshielded room in a building), the delay time is about 5 [ms]. We confirmed that this device can detect saccades without delay. In this work, the electrodes were attached directly to the skin around the eyes. However, they could be attached to eyeglass frames for comfort (Fig. 6).

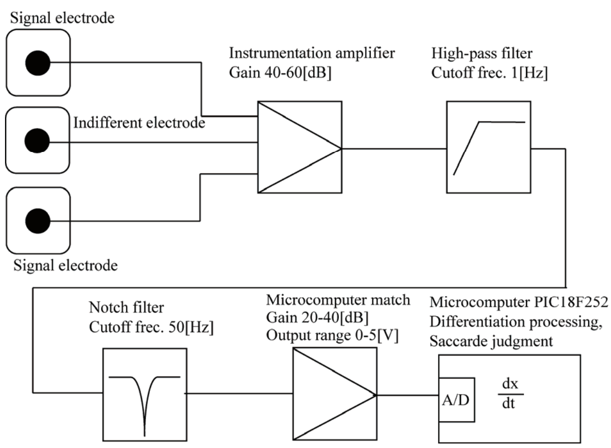

Fig. 3. The processing circuit block.

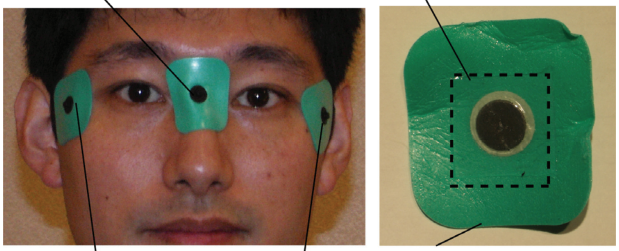

Fig. 4. Wearing the electrodes and a close-up of an electrode

(CLEARODE TE-174RT, FUKUDA DENSHI Inc. The gel sheet has about 2[cm] on a gel side width).

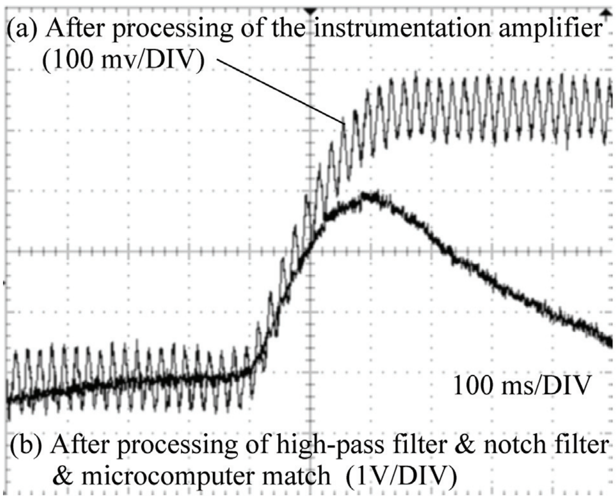

Fig. 5. Snap shot of the signal measurement.

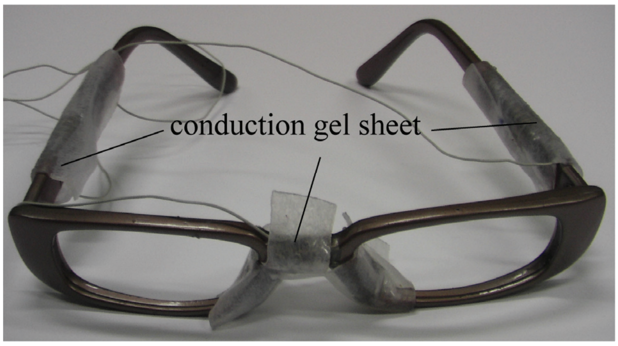

Fig. 6. Electrode glasses.

3. Improvement of character recognition rate by saccade detection

We consider that it is evident that the timing match display using saccade detection has high visibility compared with inducing saccades with a moving fixation point. This is because, when the timing of the inducement is a mismatch in the saccade inducement method, no viewer can see the afterimage. And, the ratio of the mismatch is about 50[%].

Then, we compared the timing match display method using saccade detection [Fig. 7(b)] with the continuous display method [Fig. 7(a)]. Information is surely projected onto the retina in either method. However, the displaying time is momentary. Therefore, we consider that a lot of character information (even if it is the same) might be unrecognizable. (Strange characters may appear due to changes in the timing of eye movement or there may be a continuous afterimage, and so on.)

The duration of the perception image by saccade-based display is short with about 100-150[ms]. We seem that it is easy to understand Fig. 7 (b) than Fig. 7(a). The displayed number of characters of Fig. 7(a) is fewer than that of Fig. 7 (b). And, some characters of Fig. 7(a) collapse sideways. For such reasons, we consider that the timing-match display method might be more advantageous.

The display of character information is important for a visual information presentation device. We consider that the difference of seeing influences the recognition rate of the character in saccade-based display (This device is displayed only momentarily.). Therefore, we compared the character recognition rate for the two methods.

(a) Image continuously displayed

(b) Image displayed with timing match

Fig. 7. Image of the timing-match display method and the continuously displayed method. (This image was taken with the slow shutter camera instead of the eyeball. This image looks like the afterimage to the viewer.)

3.1 Experiments

In this experiment (See Fig. 8), saccades were caused using the movement of TP to FP.

Subjects sat 5 [m] from the front of the saccade-based display with their head in a chin support. They were instructed to look at the FP LED when it was on and to keep looking at the FP even if the LED was off. When TP LED came on, they were instructed to quickly look at the TP and keep looking at it until our cue. After the saccade, they were asked to recite the four displayed numbers. The FP and TP were orange LEDs (diameter 0.25 deg, luminance 16cd/m^2). The saccade-based display was a green LED array (diameter 0.1 deg, luminance 10cd/m^2). The experiment was conducted in a darkened room. In experiment 1, (Fig. 8 (b), upper half), the saccade-based display continuously displayed the four digits. In experiment 2 (Fig. 8 (b), lower half), it displayed four digits only once for 10 [ms] after the detection of saccade onset. Subjects were three males with eyesight of 1.2 or better. Each experiment comprised 40 trials.

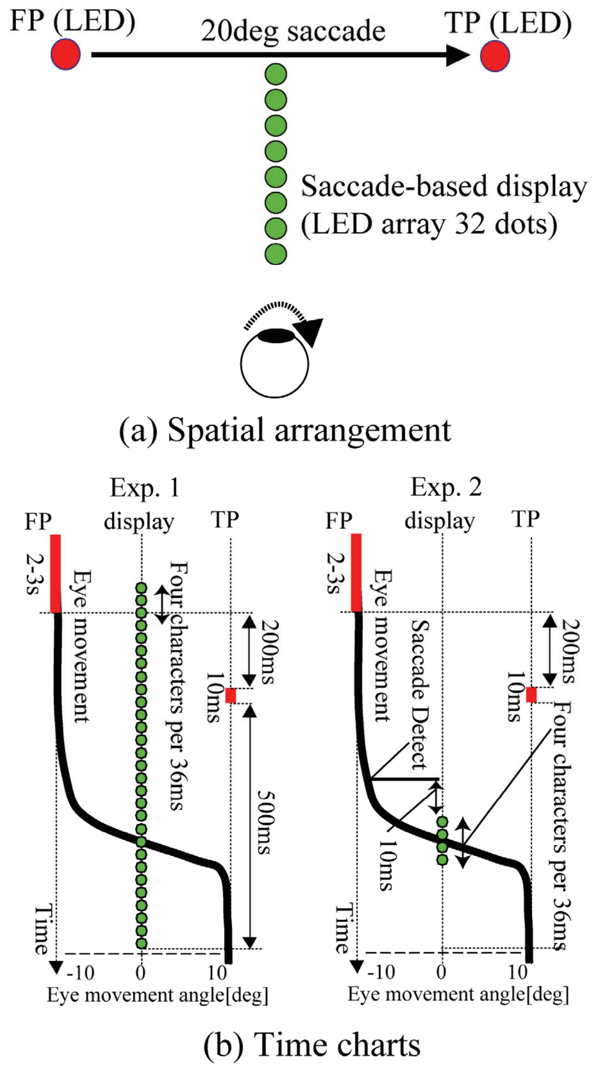

Fig. 8. The experimental condition.

3.2 Results

Fig. 9 shows the results for all subjects, indicating the proportions of the number of correct answers in 40 trials. The band chart shows the correct answer rate for, from the left, all four characters, three characters, two characters, one character, and zero characters in the order corresponding to correctly recited characters. The third line from the top is the result for the continuous display method [like in Fig. 7(a)] Even the subject with the best grade, the percentage of questions answered correctly (The correct answer all of the four characters.) was under 30[%]. The third line from the bottom is the result for the timing match display method [like in Fig. 7(b)]. In all subjects, the percentage of questions answered correctly was over 75[%]. (Note that in one trial subject 3 (TB) was unable to recognize any numbers at all. This is because the detector failed to detect the saccade.) As a result, we consider that the recognition rate of the timing match is higher.

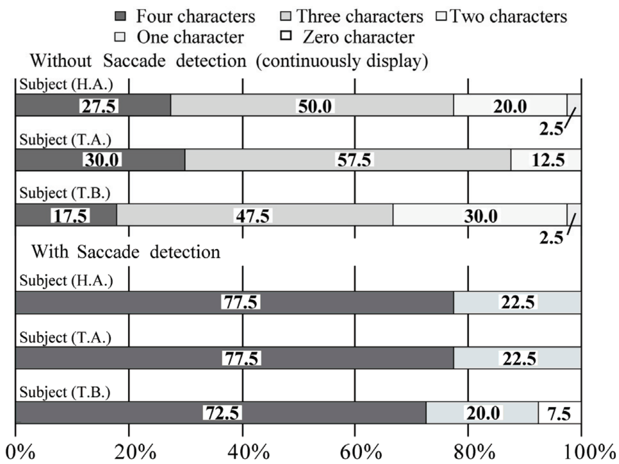

Fig. 9. Character recognition rates with/without saccade detection

3.3 Discussion

From the experimental results, not only timing match but also display of one afterimage is important for accurate character recognition. The afterimage of the saccade-based display lasts only a short time. Therefore, the viewer is looking in the instantaneous field of view. Subjects typically commented that, in the continuous display case, they had understood that the characters had been displayed but could not remember what characters had been shown. This suggests that "seeing" and "recognizing" are different.

We consider the timing match of the saccade to be similar. Therefore, it is important that the viewer sees the same afterimage with stability.

We confirmed that, if the saccade doesn't match the timing of the display perfectly, the afterimage is not seen at all. For example, when the saccade-based display was shown at random intervals, the recognition rate of the subjects who kept moving their eyes was 5% or less. This means only the viewer that installed the saccade detector can be seen.

4. Conclusion

We have found that a wearable saccade detector improves the visibility of a saccade-based display. In addition, using a system consisting of a wearable sensor and a ubiquitous display, we proposed an application where many viewers can use the system simultaneously and independently. We found that the EOG method can be adapted to make it suitable for a wearable saccade detector. A saccade detection system based on the proposed method was designed and developed. Experiments showed that this system is more suitable for reading characters than the usual technique.

We believe that the wearable saccade detector can be applied to other saccade-incident display methods. Human vision has high sensitivity only at the center of the retina. When the human views surrounding environments, eye movements are performed to capture the intriguing images with the sensitive area of the retina. The saccade can be a trigger of the shift of the viewer's attention, and we can display new information according to shifts in eye movement. When we read, we read until the end of a line and move our eyes to the beginning of the NEXT line. However, the next line shifts upward during eye movement in this system. The viewer can read only by making horizontal eye movements to the beginning of the line, which they have just read. Viewers can read efficiently using this system.

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