Full-scale saccade-based display: Public / Private image presentation based on gaze-contingent visual illusion

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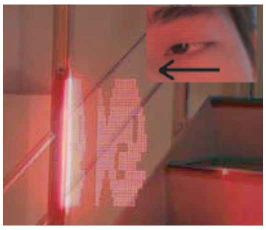
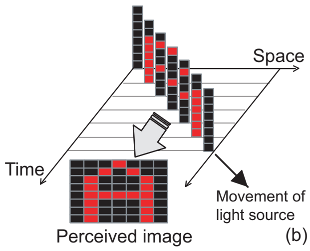
1 Introduction

Pursuing new display techniques based on insights of human visual perception can open up new possibilities for visual information presentation. Here we present the vast refinement of an information display method, which we call a saccade-based display. The saccade-based display can show two-dimensional (2D) images without any screen using only a single line of flickering light emitting diodes (LEDs). The following principle is fundamental to the implementation of this display. It is known that mechanical high-speed movement of a one-dimensional flickering LED array can present 2D images through retinal afterimages (this kind of visual display is commercially available [IMS 2000]) Conversely, when light sources are fixed on a vertical line, and the flashing pattern is changed quickly during a horizontal rapid eye movement called a saccade, 2D images can also be perceived due to spatio-temporal integration in the human vision system as in fig. 1(a). When a vertical line of lights flashes quickly during the horizontal saccade, the flashing pattern is expanded into a spatial pattern by the eye movement. During the eye movement, the vertical light array travels on the retina while changing the flashing pattern. Then, the different vertical images at different retinal locations are integrated into a 2D image as in fig. 1(b). Although the images presented during the saccade can hardly be seen in daily life (e.g. [Latour 1962]), the images with high contrast and high spatial frequency as presented with this display can be recognized [Watanabe et al. 2005b][Watanabe et al. 2005a].

This illusory phenomenon has been used for the visual effects in the field of art and entertainment [Bell 1993][Bur 1989]. For example, Watanabe et al. used this phenomenon on the performing art stages, which was created in collaboration with media performance group "cell/66b" [Watanabe et al. 2004]. On performing art stages, audiences make eye movements at various times triggered by bodily actions and spot lights. If light arrays are flickering fast enough during the eye movements, the members of audience can perceive 2D images, and the shape and width of the images are different among them. Four large LED arrays (1.8m in height) were used on the stage. They were located behind the performers as in fig. 2(a). The LED arrays function not only as illumination, but as a visual display, which can present different 2D images for each audience as in fig. 2(b).

In addition, when we consider this phenomenon as a visual information display principle, this method greatly reduces the space need for the device (one line is enough for 2D image presentation), and it can display visual images even in midair. These features can be applied to an augmented reality visual display that can superimpose various types of information onto real environments, to the field of entertainment, and to light devices for commercial advertising.


(a)



(b)

Figure 1: *(a)Perception of 2D image during saccade eye movement: saccade-based display. (b)Movement of light source in space-time plot.*

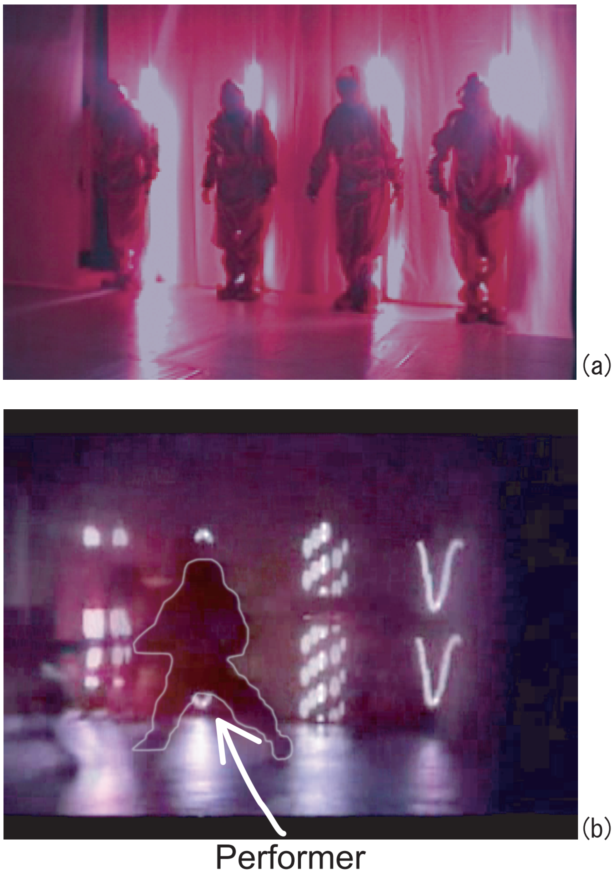


Figure 2: *Application on the performing art stage (this image was captured by rotating the video camera).*

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(Conceptual image)

Figure 3: *Image presentation of several characters.*

2 Full-scale development

The display capability of the saccade-based display was limited to simple characters like in fig. 3. Considering temporal dynamics of the saccadic eye movement and the size of presented image, the duration of the saccade eye movement is around 50 ms, and the horizontal resolution of the image is about 100 pixels. So, the time unit for 1 pixel of the image corresponds to 500 us. In addition, if we manipulate the luminance of the image with PWM (Pulse Width Modulation) method, for example 8 bit luminance depth, the time unit (500 us) is divided by 256. Then, time unit can be about 2 us, which has been beyond the capability of the widely used micro processors. However, recent technological progress of FPGA (Field Programmable Gate Array) enables us to control the time unit within less than 10 us. Consequently, using an optimally-designed FPGA circuit (XILINX Inc., V2P7), we have achieved 70kHz PWM control with 4 bit color modulation (16 scales for each color) for 1 pixel [1], and succeeded in full-scale color image presentation with large LED array (1.8m in height, 128 pixel in vertical resolution) as shown in fig. 4. Single vertical line is scanned in 500 us, and 128 x 128 pixel image is presented. Total presentation time of an image is 64 ms. Even life-size photographic images such as humans and landscapes can be displayed. Although only ready-made image is currently shown with this display, images captured by camera on the moment can be presented in the future. For example, viewers can see his/her own back for a second by capturing from behind and present images with the saccade-based display located in front of them.

3 Characteristics of saccade-based display

As a specific characteristics of the saccade-based display, the flash timing of the light source plays essential role for successful visual information presentation, because 2D images can be perceived only when the timing of the saccade coincides with the flash timing of the light source. If the timing of the saccade does not coincide with the flash timing of the light source, only one-dimensional light will be perceived, instead of a 2D image. In order to overcome this

Figure 4: *Full-scale color image presented with saccade-based display (this image was captured by rotating the video camera).*

drawback, we propose induction methods for PUBLIC information presentation, and a concise saccade detection sensor for PRIVATE information presentation.

4 Public information presentation

When we present visual information to many viewers at the same time, temporal concordance of their eye movements are required. In order to cause this situation, we aimed to induce viewer's eye movement. When a stimulus is presented in a visual field, the viewer's saccade is reflectively generated. This effect can be achieved by illuminating LEDs in the peripheral of the visual field. Then, the viewer's saccade is induced in the reflection. When the saccade-based display flickers according to the timing of the induced saccade, the viewers surely perceive the visual information. In general, the latency time of a saccade is about 200 ms, though it differs every time and varies with the individual. Therefore, we can decide the timing between the light of the inducer and flashing light for image presentation. In addition, auditory and tactile sensory can also be used for eye movement induction. Abrupt sound and touch automatically cause eye movements. For example, sound of breaking glass strongly attracts viewer's attention and eye move-

[1] Since the saccade-based display has a particular feature that a temporal gap is extended into a spatial gap due to eye movement, smaller time unit is required for the luminance depth.

ment. Sounds that cause feeling of motion like a sound of wind, also play a role of an inducer. Using air cannon, feeling of air can also be an inducer. In public situation, we can show 2D images to many viewers simultaneously using these kinds of the eye movement inducers.

5 Private information presentation

5.1 Saccade detection

As described above, only when the viewer's ocular motility and the flicker of the light array occur simultaneously, the saccade-based display can show 2D images in the space of the light array neighborhood. For private image presentation, we propose a novel application of this display technique achieved by combining the saccade-contingent phenomenon with a wearable fast eye-measuring method [Ando et al. 2005]. Viewer's saccade is measured and a single light array is flickered immediately after detecting viewers' saccades, and then, 2D images can successfully be presented. Using this measurement method, the display can surely present information to a specific person. Moreover, if we can detect who makes the saccade, different 2D images can be delivered to different viewers. That is to say, if the image is presented only to the viewer whose saccade is detected, we can selectively present different images to each person using only one light array, and this display system will be able to handle highly confidential information. Moreover, many viewers can use one display device through timesharing, which would be a novel type of visual information display capability. Consider the situation in fig. 5, where persons A and B are observing the display and a saccade detection device continuously detects the wearer's saccade. At time t_1 in fig. 5(a), 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 t_2 in fig. 5(b), person B's saccade is detected and only person B can see a different 2D image. The system consisting of a wearable sensor (saccade detector) and a space-saving ubiquitous display (saccade-based display) would make it possible to selectively present confidential information to the viewers. In the following section, we describe our design considerations in the development of the saccade detector device.

5.2 Design considerations of saccade measurement

Only when the saccade detection accuracy is high, the viewer certainly perceives 2D information. In order to achieve saccade measurement and unfailing presentation, we must consider the temporal relationship between perceived 2D images and the dynamics of the saccade. The maximum saccade speed is more than 700 deg/s and the duration is around 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 the 2D images are perceived only during saccades and the delay narrows the display area. As a concrete value, a delay of 10 ms or less is preferable, which means the sampling rate should be 100 Hz or higher. Although high time resolution is required, we do not want high spatial resolution, because detection of saccades, not measuring eye position, is required.

Recently, we have examined remote detection of the saccade using the retroreflective feature of the retina [Watanabe et al. 2007]. However, this required a high-speed camera, and the spatial range of measurement was limited. Although we could use camera-based

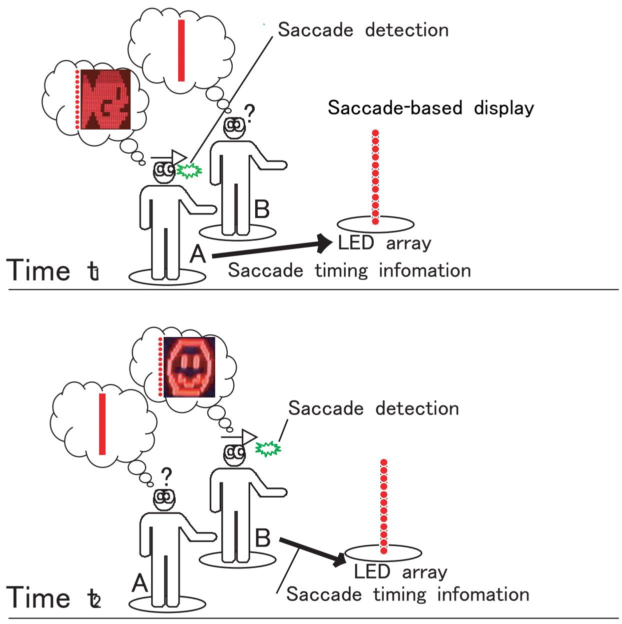

Figure 5: *Selective information presentation at different timings.*

high-speed measurement system [ASL], it is difficult to separate eye movement from face movement without attaching markers to the face and the luminance noises from ambient light influences the acuity of the method. Moreover, the camera method cannot specify the person whose eyes moved from a group of several viewers, which means that visual information cannot selectively be displayed for each individual. Thus, a wearable device is desirable. In vision science experiments, presenting stimuli triggered by saccadic eye movements has been achieved, and a saccade-contingent presentation was accomplished in a virtual reality study [Triesch et al. 2002]. However, they used a limbus eye tracking technique, which forces the viewers' heads to be fixed on a chinrest. Consequently, we used a simple wearable device with an Electro Ocular Graph (EOG) for detecting viewer's saccades and constructed a saccade-contingent visual presentation system based on EOG-based saccade detection and the saccade-based display.

The EOG method uses living body signal. The cornea has positive potential of 10-30 uV, so that ocular motility can be observed from electrodes attached around the eyes. This method is strongly affected by external electromagnetic noise and the spatial accuracy of the measurement is low. However, since our concern here was only the detection of 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. In order to detect saccade timing, the weak living body signal obtained by EOG has to be amplified and filtered. Figure 6 shows (a) how the electrodes are worn and (b) the circuit blocks for the amplification and filtering. Three electrodes, two signal electrodes at the outer corners of the eyes and an indifferent one on the nose, were attached (CLEARODE TE-174RT, FUKUDA DENSHI Inc.). The size of the gel electrodes, the area enclosed by the dotted line on the right in fig. 6(a), was 20 x 20 mm. In order to improve the precision of the measurement, the applied areas were cleaned and defatted with absorbent cotton. The EOG signals from the electrodes are amplified, and a high-pass filter eliminates any drift element in signals that is slower than the saccade. The cutoff frequency of the high-pass filter is 1 Hz. Next, the noise should be removed. The most serious problem

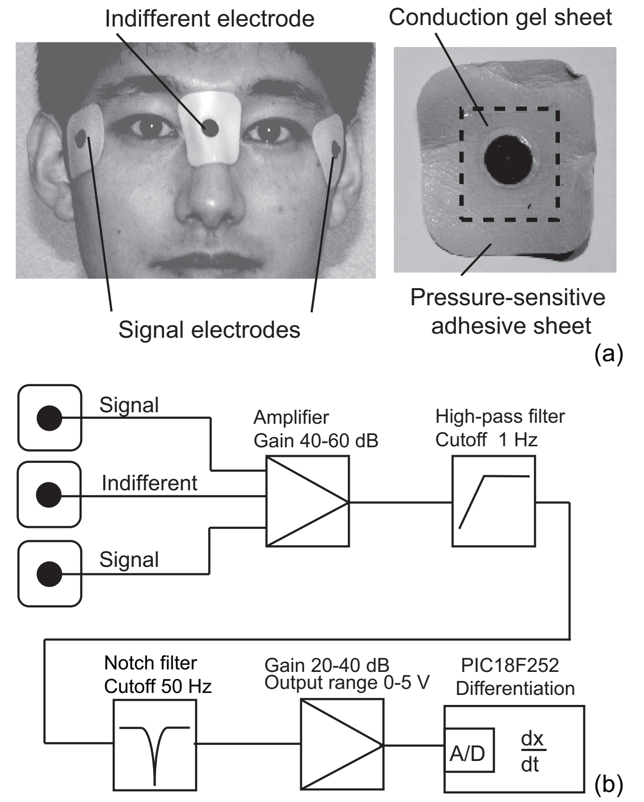

Figure 6: *(a) Wearing the electrodes and a close-up of an electrode. (b) Circuit blocks for the amplification and filtering.*

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 Northern Japan is 50 Hz AC, and this is the main factor in the noise. In addition, the signal is appropriately adjusted for the microcomputer A/D input. The differentiation process is performed in the microcomputer to judge whether a saccade has been generated or not. When the differentiation value exceeds a threshold, we consider that the saccade has started. The delay of the saccade detection increases when this threshold is high. On the other hand, when the threshold is low, misjudgments are caused by the noise. Therefore, delay time is decided depending on the amount of the signal noise. After the threshold of the signal had been adjusted for our laboratory environment (an unshielded room in a building), the delay time was about 5 ms and the accuracy of the detection was 95 percent or more. In this work, the electrodes were attached directly to the skin around the eyes. However, they could be attached to eyeglass frames for comfort as shown in fig. 7.

6 Conclusion

In this paper, we present vast refinement of the information display method, which we call a saccade-based display. Due to recent technological development of blue LED elements and FPGA circuits, full-scale color image presentation have been achieved. In addition, although a drawback of this principle is that the viewer cannot appropriately see the image without moving the eyes, we propose induction methods for public information presentation, and a concise saccade detection sensor for private information presentation. The novel aspects brought up in our study are developments

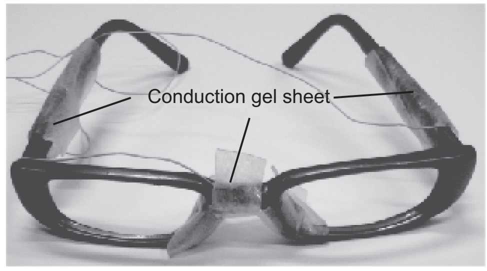

Figure 7: *Electrodes on glasses.*

for realistic image presentation with saccade-based display, and the concept of timing the display to saccades as eye movements are induced or tracked. Although the saccade-contingent phenomenon and eye measuring methods may be previously known and partly established, pursuing the possibility of the visual display technique studied in this paper should be fruitful for investigating new possibilities for designing visual information display devices.

References

ANDO, H., WATANABE, J., AMEMIYA, T., AND MAEDA, T. 2005. study of saccade-incident information display using saccade detection device. In *Proceedings of the 15th International Conference on Artificial Reality and Telexistence*, 119–124.

ASL. *Eye Tracking Expertise*. Applied Science Laboratories, Retrieved Jan. 1, 2007, from http://www.a-s-l.com/.

BELL, B. 1993. *Light Stick*. Exploratorium, Retrieved Jan. 1, 2007, from http://www.exploratorium.edu/.

THE BURNING MAN PROJECT. 1989. *Burning Man*, Retrieved Jan. 1, 2007, from http://www.burningman.com/.

IMS INC. 2000. *Fantazein*, Retrieved Jan. 1, 2007, from http://www.fantazein.com/.

LATOUR, P. 1962. Visual threshold during eye movements. *Vision Research 2*, 261–262.

TRIESCH, J., SULLIVAN, B., HAYHOE, M., AND BALLARD, D. 2002. Saccade contingent updating in virtual reality. In *Proceedings of the symposium on Eye Tracking Research and Applications*, 95–102.

WATANABE, J., TAVATA, T., VERDAASDONK, M. A., ANDO, H., MAEDA, T., AND TACHI, S. 2004. Illusory interactive performance by self eye movement. In *Siggraph2004 Conference DVDROM Sketches*.

WATANABE, J., MAEDA, T., AND TACHI, S. 2005. Time course of localization for a repeatedly flashing stimulus presented at perisaccadic timing. *Systems and Computers in Japan 36*, 9, 77–86.

WATANABE, J., NORITAKE, A., MAEDA, T., TACHI, S., AND NISHIDA, S. 2005. Perisaccadic perception of continuous flickers. *Vision Research 45*, 413–430.

WATANABE, J., ANDO, H., MAEDA, T., AND TACHI, S. 2007. Gaze-contingent visual presentation based on remote saccade detection. *Presence: Teleoperators and Virtual Environments 16*, 2, in press.