Further Crosstalk Reduction Method with Eye-Tracking for Glasses-Free Stereoscopic Display in Both Portrait and Landscape Modes

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ABSTRACT

We propose a crosstalk reduction method with an eye-tracking system for glasses-free stereoscopic displays in both portrait and landscape modes. We can reduce crosstalk by dividing a screen into multiple areas and displaying black images on the subpixels observed simultaneously with both eyes in each divided area.

1 INTRODUCTION

Glasses-free stereoscopic displays can provide the viewers with more realistic images. One of the characteristics that determine the performance of the glasses-free stereoscopic display is crosstalk, which means observing the left eye image with the right eye and the right eye image with the left eye. Crosstalk is a major factor that prevents comfortable stereoscopic vision. Therefore, it is necessary for the performance of the 3D display to reduce the crosstalk.

We previously proposed the glasses-free stereoscopic display using the slanted parallax barrier with the eye-tracking system [1]. The previously proposed system had very high image quality. If we adopted the LC panel as the active parallax barrier, it was possible to switch into two different patterns of barriers correspond to the portrait and the landscape modes. Each barrier pattern corresponding to the two modes had the same barrier pitch and slanted angle, so basically the same eye-tracking algorithm could be applied in sensing the viewing position. Moreover, by dividing the screen into multiple areas and controlling the image positions in each area according to the viewing position, it was possible to keep the stereoscopic vision even if the viewer moved in the depth direction toward the screen [2]. However, as the moving distance from the optimum viewing distance increased, the number of subpixels observed simultaneously with both eyes increased. We call these subpixels “crosstalk subpixels.” As the number of the crosstalk subpixels increases, the effect of stereoscopic vision is reduced. Therefore, the expansion of the viewing area in the depth direction was limited.

Therefore, in this paper, we propose a method to reduce the crosstalk by displaying black images on the crosstalk subpixels. By this method, the crosstalk ratio can be stably suppressed low even if the viewer moves far from the OVD in the depth direction, so the viewing area can be expanded compared to the previous proposed system. To verify the effectiveness of the proposed system, we evaluated the crosstalk ratio at each viewing distance for both portrait and landscape modes in the prototype system.

2 CROSSTALK REDUCTION METHOD

2.1 Concept of Binocular Image Arrangement

In the case of a glasses-free stereoscopic display, binocular images are mixed and displayed on the screen at the same time. Constructing the each one-eye image of the mixed binocular image on the screen with consecutive subpixels is effective for reduction of crosstalk and image position control. For example, as shown in Fig. 1, one pair of binocular images is composed of 14 consecutive subpixels. In the figure, n is the number of one pair of binocular images and the aperture inclination angle θ is $\tan^{-1}(1/6)$.

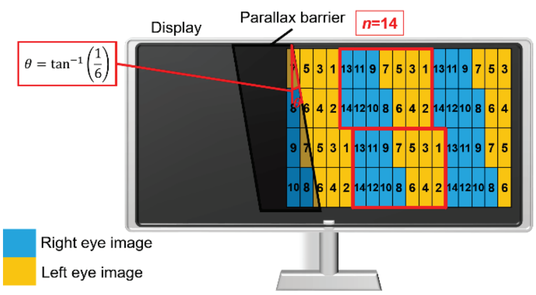

Fig. 1 Example of subpixel number arrangement.

As shown in Fig. 2, we design the parallax barrier that the seven dot spaces corresponding to the seven consecutive subpixels that compose a one-eye image are formed to the width of the interocular distance E at the OVD [1]. The length of this dot space is given by $2E/n$. We use the dot spaces as a reference for determining a control boundary for eye-tracking control. In the figure, since the left eye is located at #4 dot space, the left eye observes #4 subpixels at the center of the barrier aperture. Therefore, the left eye images are arranged at #1 subpixels to #7 subpixels centering on #4 subpixels. The image observed by the left and the right eyes is as shown in Fig. 2. When the viewer moves to the horizontal direction at the OVD, crosstalk occurs. However, it can be similarly controlled by switching the images so that the number of the subpixel corresponding to the number of the dot space where the viewer's one-eye is located is at the center.

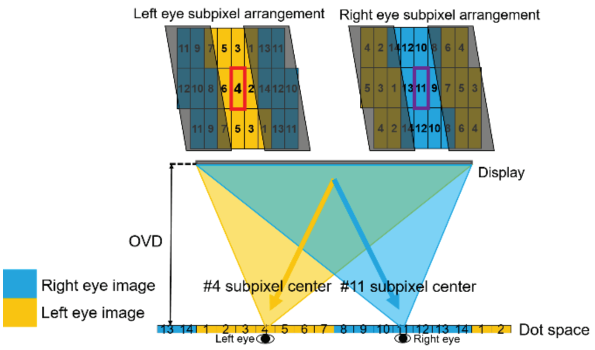

Fig.2 Concept of binocular image arrangement.

2.2 Expansion of Viewing Area in Depth Direction

As shown in Fig. 3, when the viewer moves to the depth direction, the viewing area is expanded by controlling the image processing in each divided area on the screen [2]. d is the optimum viewing distance and z is the viewer's viewing distance. We divide the screen by the extension lines connecting the dot spaces on the viewing side with the position of the viewer's eye. In each divided area on the screen, the center subpixel of the consecutive subpixels of the one-eye image is controlled to match to the number of the corresponding dot space. With this image processing, the one-eye image can be normally observed on the entire screen even in a state away from the OVD. We call this method “divided area control method.”

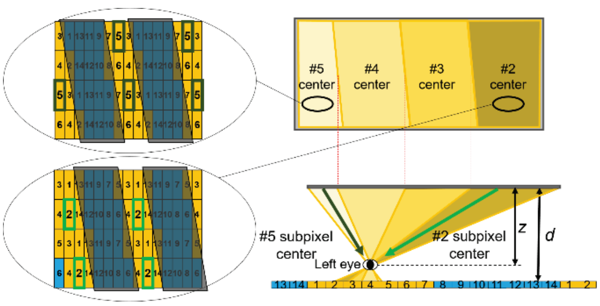

Fig. 3 Expansion of viewing area in depth direction by divided area control method.

Fig. 4 shows the difference between the ideal control state for the right eye and the left eye. The right eye and the left eye are 65 mm apart. Thus, the subpixel that is the center of the right eye image and the subpixel that is the center of the left eye image doesn't shift by 7 subpixels and crosstalk subpixels occur when the viewer moves form the OVD in the depth direction. Therefore, #1 subpixels surrounded by the red closing lines are observed simultaneously with both eyes and the images cannot be properly separated.

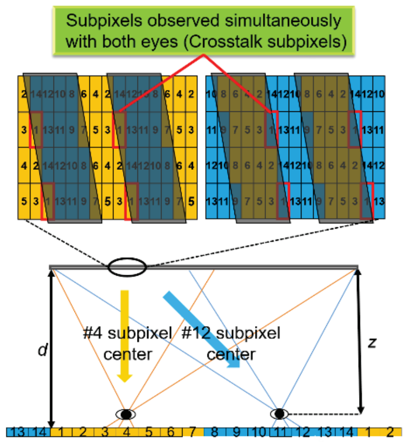

Fig. 4 subpixel observed simultaneously with both eyes (Crosstalk subpixel)

2.3 Crosstalk Reduction Method by Displaying Black Images on Crosstalk Subpixels

Fig. 5 shows the observation state when the viewer moves to the viewing distance less than the OVD. If the viewer is located at the position on the OVD as shown in Fig. 2, the viewer doesn't observe the crosstalk. The viewer observes #4 subpixels with the left eye and #11 subpixels with the right eye at the OVD. However, as the viewer moves to the viewing distance less than the OVD, the screen area is divided, and the number of the subpixel at the center of the aperture changes in each divided area. In the left end divided area of the display in Fig. 5, the viewer observes #4 subpixels with the left eye and #12 subpixels with the right eye. The right eye image should be shifted by 7 subpixels compared to the left eye image, but only 6 subpixels are shifted in Fig. 5. Thus, the interval of the dot spaces between the right eye image and the left eye image according to the viewing position shifts by one dot space compared to the optimum state where the viewer is located at the OVD. In this case, the divided areas by the left eye and the right eye become the same positions that shifted by one dot space, and viewer observes one crosstalk subpixel in all areas on the screen. In the case that the viewing distance is less than the OVD, in Fig. 5, the relationship between the number of the crosstalk subpixels t and viewer's viewing distance z is given by

$$d:E+\frac{2E}{n}t=z:E \quad . \tag{1}$$

From Eq. (1), z is given by

$$z = \frac{nd}{(n + 2t)} \ , \tag{2}$$

where t is a natural number less than $n/2$.

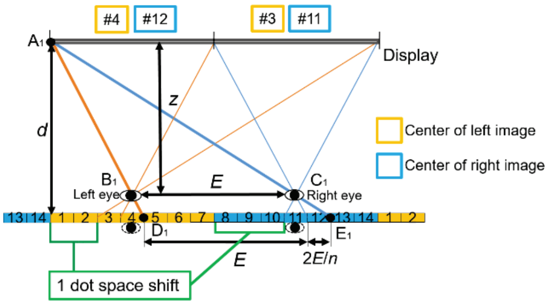

Fig. 5 Number of crosstalk subpixel (*z* < *d*).

Fig. 6 shows the observation state when the viewer moves to the viewing distance more than the OVD. In the case that the viewing distance is more than the OVD, in Fig. 6, the relationship between t and z is given by

$$d : E - \frac{2E}{n} t = z : E \ . \tag{3}$$

From Eq. (3), z is given by

$$z = \frac{nd}{(n - 2t)} \ , \tag{4}$$

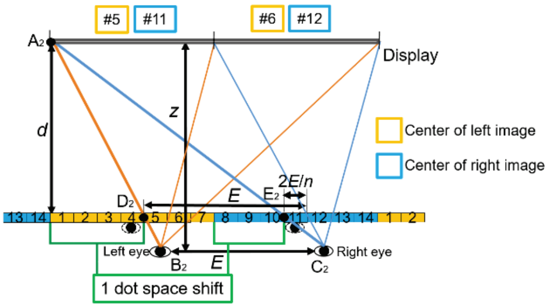

Fig. 6 Number of crosstalk subpixel (z > d).

From Eqs. (2) and (4), the relationship between the viewer's viewing distance and the number of the crosstalk subpixel is given by

$$t(z) = \frac{n|d - z|}{2z} \ . \tag{5}$$

From Eq. (5), the number of the crosstalk subpixels t increases as the viewer moves away from the OVD. In the case that d is 516 mm and n is 14, Table 1 shows the relationship between the number of the crosstalk subpixels and the viewing distance when the viewing distance is less than the OVD, and Table 2 shows that when the viewing distance is more than the OVD.

In this paper, the crosstalk ratio of both eyes reduced by displaying black images on the crosstalk subpixels as shown in Fig. 7. The advantage of this method is that it can be reduced the crosstalk only by processing images. By this image processing, the crosstalk ratio of both eyes can be stably suppressed low, so the viewing distance in the depth direction can be extremely expanded.

Table 1 Relationship between *t* and *z* (*z* < *d*)

	Viewing distance *z*				
	516 mm	451 mm	401 mm	361 mm	328 mm
t	0	1	2	3	4

Table 2 Relationship between *t* and *z* (*z* > *d*)

	Viewing distance *z*				
	516 mm	602 mm	722 mm	902 mm	1203 mm
t	0	1	2	3	4

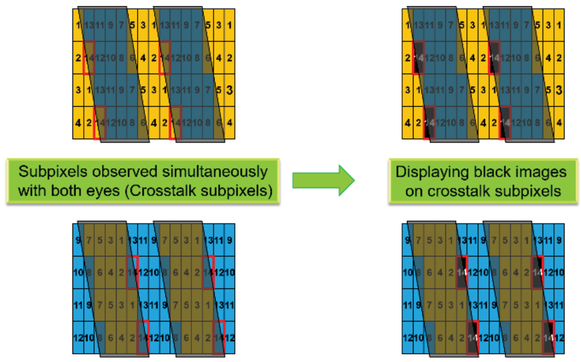

Fig. 7 Displaying black image on crosstalk subpixel.

3 EXPERIMENTAL RESULTS

3.1 Prototype System

In this paper, we made prototype systems using a 24-inch Full HD display. Table 3 shows the specifications of the prototype systems. We designed two parallax barrier for the portrait and landscape modes, and artificially reproduced barrier switching by attaching them to two displays.

Table 3 Specifications of prototype systems

Display resolution	1920 x 1080
Subpixel pitch (H)	0.09225 mm (Portrait) 0.27675 mm (Landscape)
Barrier pitch (H)	0.64256 mm
Barrier aperture ratio	35.7%
Aperture inclination angle	$\tan^{-1}(1/6)$
OVD	516 mm

3.2 Evaluation of Crosstalk Ratio

We measured the crosstalk ratio at each viewing distance for both portrait and landscape modes. The results are shown in Fig. 8 and Fig. 9, respectively. Fig. 8 shows the crosstalk ratio of each viewing distance in the portrait mode, and Fig. 9 shows that in the landscape mode. In order to measure the crosstalk ratio, we captured the white images, black images and black-and-white images displayed on the prototype system at each viewing distance. The black-and-white image is an image synthesized with the right eye image as black and the left eye image as white when measuring the right eye's crosstalk ratio. We calculated the crosstalk ratio using the average subpixel value of the captured images. The red graph shows the crosstalk ratio of the left eye, and the blue graph shows that of the right eye. The broken line shows the measurement result of the previous method, and the solid line shows that of the proposed method.

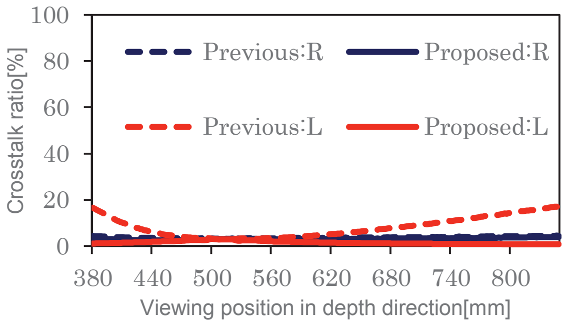

Fig. 8 Crosstalk ratio in portrait mode.

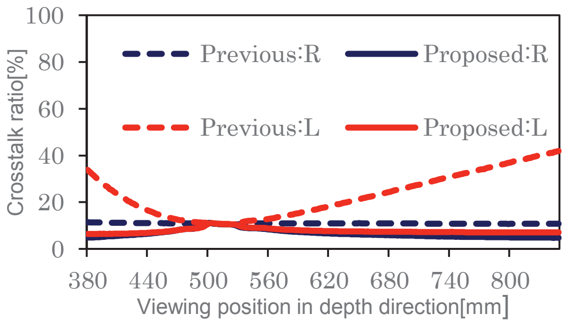

Fig. 9 Crosstalk ratio in landscape mode.

4 DISCUSSION

Even if using the divided area control method, it cannot be avoided that the subpixels observed simultaneously with both eyes (crosstalk subpixels) are displayed according to the viewing distance. In the previous method, the crosstalk subpixels were processed as the right eye images. Therefore, the previous method could reduce the crosstalk ratio of the right eye, but that of the left eye increases as the viewer moved from the OVD in the depth direction. Although it is generally considered that it is possible to obtain comfortable stereoscopic vision if the crosstalk ratio is less than 10%, the crosstalk ratio of the left eye in the previous research largely exceeded this condition. Therefore, in this paper, we reduce the crosstalk ratio of both eyes by displaying black images on the crosstalk subpixels. We verified that the proposed method can reduce the crosstalk ratio of both eyes to less than 10% in a wide viewing area by the prototype systems and the experimental results.

This method reduces the crosstalk by identifying the subpixels that cause the crosstalk and displaying black images on them. However, the crosstalk subpixels don't uniformly occur on the screen. For this reason, black stripe patterns occur. They deteriorate the image quality. Therefore, this method is suitable for images that don't have double images which tires the eyes and that stereoscopic vision is important. For example, this method is very effective for HUD [3] and surgical images because it can display 3D images with excellent depth perception. For viewers, the recognition of black stripe patterns is less burdensome on the eyes than the recognition of double images. Therefore, this method is superior in that the viewer can observe 3D images without burden.

5 CONCLUSIONS

The proposed method in this paper can reduce the crosstalk ratio even when the viewer moves from the OVD in the depth direction by displaying black images on the crosstalk subpixels. In addition, since this technology is applicable to both portrait and landscape modes, it can be applied to tablets and smartphones. This method can reduce crosstalk only by image processing, and it can reduce crosstalk over an infinitely wide range in theory. In currently, it is very important to provide comfortable stereoscopic vision without crosstalk for tablets and smartphones that we spend a lot of time.

We expect that the evaluation of the glasses-free stereoscopic display will be improved, and the new market are expanded with this technology.

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