Two-View Autostereoscopic Display for Two Viewers with Wide Viewing Area by Individual Eye Tracking

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ABSTRACT

We propose the two-view autostereoscopic display using parallax barrier for two people. The feature of this display is individual eye-tracking control for two people to provide high quality 3D image and wide stereoscopic viewing area for them.

1 Introduction

We proposed an autostereoscopic display using parallax barrier [1,2]. The display has wide viewing zone and high image quality by eye-tracking control, but the display can be observed by only one person.

When the number of viewers increases to two, the conventional multi-view display enables two viewers to simultaneously view stereoscopic images by increasing the number of viewpoints, but the image quality degradation is the problem [3]. On the other hand, eye-tracking control to expand the viewing area for two viewers at the same time is impossible with conventional methods. To overcome this problem, our research aims to realize a 3D display that enables eye-tracking control individually. Specifically, the four-view parallax barrier design is introduced, which is assigned to two viewers viewing same stereoscopic image. The four viewpoint areas are wider than the normal interocular distance to give more margin to follow two viewers. For the individual viewer, the viewpoint boundary between the right eye image and the left eye image follows the viewer based on the viewer's interocular center to enable stereoscopic viewing. In this paper, the prototype display was built and the proposed method was evaluated.

2 Previous 3D Display using Parallax Barrier

Here, we describe our previous method of 2-view 3D display using a parallax barrier.

2.1 Previous 3D Display Barrier Design

Figure 1 shows how the parallax barrier is designed in the previous method. The two equations in barrier design is given by

$$E : d = \frac{k}{2} : g, \tag{1}$$

$$d : B_p = (d + g) : k, \tag{2}$$

where E is the interocular distance, B_p is the barrier pitch, g the barrier gap, d is the viewing distance, and k is the binocular image pitch on the display. Barrier design is based on Eqs, (1) and (2).

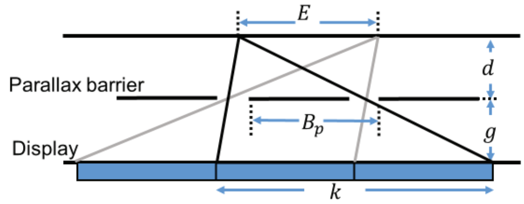


Fig. 1 How parallax barriers are designed in the previous method.

2.2 Previous Eye-tracking Control

First, we describe the horizontal eye-tracking control of the previous method. Figure 2 illustrates the concept of the dot spaces. Pixel numbers are assigned to the subpixels on the display in n-dot cycles, where $n = 16$ in Fig. 2, and the subpixels #1-8 are images for the right eye and the subpixels #9-16 are images for the left eye. The dot spaces is determined by the positions of the pixel arrangement pattern of the parallax image and the parallax barrier and serves as the reference for determining the control boundary for eye tracking. When the parallax barrier is placed in front of the display, the parallax barrier is designed so that the dot spaces is formed on the optimum viewing distance (OVD). Figure 2 shows that the right eye at the dot space #5 on the OVD observes the #5 subpixels at the center of the barrier apertures. The width of the dot space f is given by

$$f = \frac{2E}{n}. \tag{3}$$

In the horizontal eye-tracking control in Fig. 2, when the viewer moves to the right on the OVD, the right eye moves to #4 dot space. The right eye observes the #4 subpixels at the center of the barrier apertures so we change the #4 subpixels becomes as the center of the light eye image.

Next, we describe the eye-tracking control for the depth direction. The eye-tracking control is shown in Fig. 3. The divided areas on the display are determined based on the intersection of the display and the extension line connecting the right eye and the edge of each dot space. In each of the divided areas, the dot which corresponding the dot space number is observed at the center of the parallax barrier aperture. In Fig. 3, the images of the centers of #4 subpixel, #5 subpixel, #6 subpixel, and #7 subpixel are displayed in order from the right side of the display. This control allows the right eye to observe the appropriate image. Since the right eye is usually the dominant eye, this control gives priority to the right eye.

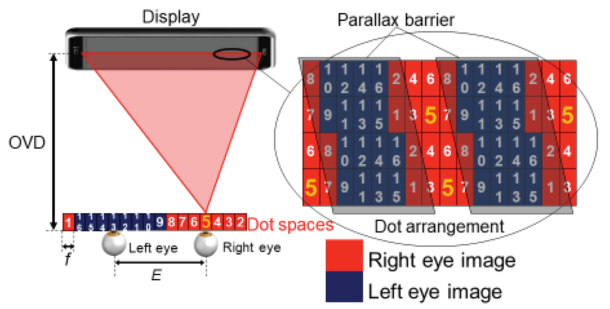


Fig. 2 Concept of dot spaces.

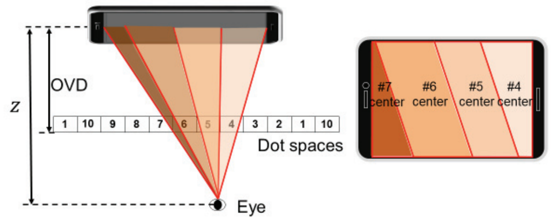


Fig. 3 Concept of divided area control.

2.3 Multi-view Method

The multi-view method is achieved by increasing the number of viewpoints. Figure 4 shows the barrier design when the number of viewpoints is increased to four. The multi-view method also enables stereoscopic viewing by two viewers simultaneously, but basically this method is not suitable for eye-tracking control to expand the viewing area.

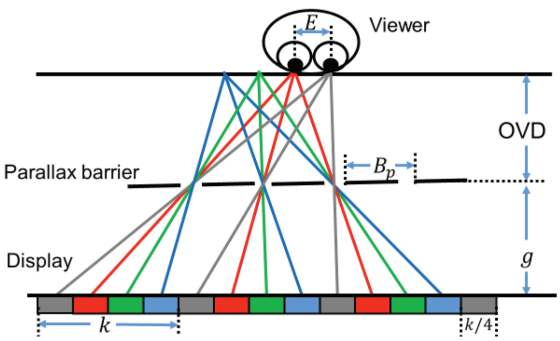


Fig. 4 Barrier design when the number of viewpoints is four.

3 Autostereoscopic Display Trackable for Two Viewers

3.1 Proposed 3D Display Barrier Design

Based on the design method of the two-view 3D display, we proposed the 3D display that can track the two viewers individually at the same time. Figure 5 shows the correspondence between the dot spaces of the conventional and proposed methods. The proposed 3D display for two viewers is based on the conventional four-view method using a parallax barrier. By displaying same two binocular images on four-view image, this enables stereoscopic viewing for two viewers simultaneously. In addition, the interocular distance E in the barrier design is increased to enable eye tracking control. This results in creating margin for the two viewers to move. The details of eye tracking control are described in Sections 3.2 and 3.3. In the proposed method, the interocular distance E in the previous method is used as the observation area E'. If both eyes of the viewer are within the area of $2E'$, stereoscopic viewing is possible.

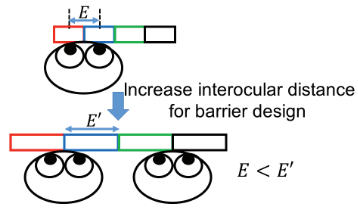


Fig. 5 Correspondence between the dot spaces of the conventional and proposed method.

3.2 Eye-tracking Control for Horizontal Direction

This section describes the eye-tracking control in the horizontal direction. When designing the barrier, the width of the observation area E' is designed to be larger than E, which is the average human interocular distance, thereby it creates a margin and allows to follow the horizontal movement of the two viewers. When the two viewers move horizontally, the two set of parallax images are controlled based on the interocular centers of them. Figure 6 shows the example of horizontal eye-tracking control for one viewer in the proposed method. E' is larger than the interocular distance, and the parallax image of the one viewer is constituted by the 12 dots. So the E' is constituted by 6 dot spaces. The red and blue dot spaces are observation area for the left and the right eyes of the first viewer, and the green and the black dot spaces are for the second viewer. This time, the interocular center is detected and we display black image to the subpixel corresponding to that position as the boundary between the right eye and left eye images. This reduce the crosstalk. In Fig. 6, for example, before the first viewer moves, the left eye image is displayed in pixels #1-#5, the right eye image in pixels #7-#12, and pixel #6 is black. After the movement of the first viewer, the left eye image is displayed in pixels #1-#8, the right eye image in pixels #10-#12, and the pixel #9 is black. This enables stereoscopic viewing even when the first viewer moves horizontally. In this method, the first observation area for the first viewer is limited to the width of the red and the blue dot spaces, and the second observation area is limited to the width of the green and the black dot spaces. However, within these area, two viewers can simultaneously view parallax images from any position. The range of movement for one person depends on the observation area E' in the barrier design. If the width of the observation area E' is increased, it can follow the viewer's movement more widely, but this is accompanied by deterioration in image quality, so optimization is necessary.

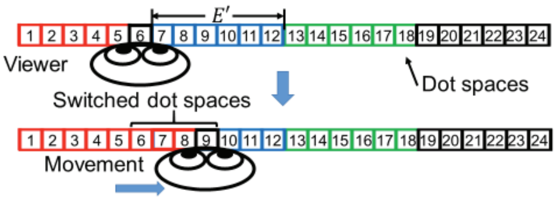


Fig. 6 Eye-tracking control for horizontal direction.

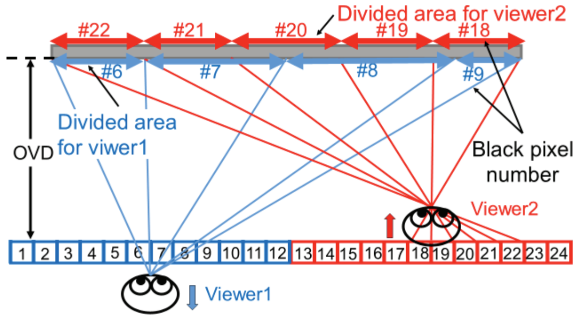
3.3 Eye-tracking Control for Depth direction

This section describes the eye-tracking control in the depth direction. The proposed method uses the viewer's interocular center as the reference as well as the horizontal eye-tracking control. Figure 7 shows the example of eye-tracking control in the depth direction. The divided area of the display image is determined with respect to the viewer's interocular center. In the previous method, the center pixel number of the right eye image is determined for each divided area and the image centered on that pixel number is displayed. In the proposed method, in each divided area, the center pixel number is detected based on the positional relationship between the interocular center and the dot spaces, and that subpixel is displayed in black. With that subpixel as the boundary, the right-eye and left-eye images are composed for the one viewer. For example, as shown in Figure 7, for viewer1, the divided area on the display is divided into four parts, and the center pixel numbers are #6-#9 from the left. In the area with center pixel number #6, #6 pixel is displayed in black, the left eye image is displayed in #1-#5 pixels, and the right eye image is displayed in #7-#12 pixels. When controlling eye tracking for two viewers, the divided areas for the first viewer and the second viewer must be controlled individually. In the example in Fig. 7, there are four or five display patterns with one viewer, but with two viewers, there are seven display patterns on displayed image.

4 Experiments and Results

4.1 Prototype System

The prototype system consists of a high-resolution display and a parallax barrier. Table 1 shows the specifications of the prototype system. In this prototype



Viewer1

No.	Left eye	Right eye	Black
#6	#1-#5	#7-#12	#6
#7	#1-#6	#8-#12	#7
#8	#1-#7	#9-#12	#8
#9	#1-#8	#10-#12	#9

Viewer2

No.	Left eye	Right eye	Black
#18	#13-#17	#19-#24	#18
#19	#13-#18	#20-#24	#19
#20	#13-#19	#21-#24	#20
#21	#13-#20	#22-#24	#21
#22	#13-#21	#23-#24	#22

Fig. 7 Eye-tracking control for depth direction.

system, the observation area E' of one viewer was designed to be 15 cm, giving priority to principle confirmation. As shown in Fig. 8, since it is impossible for two viewers to stand side by side in a 30 cm width, it is assumed that they will observe with discrete sidelobes instead of continuous sidelobes. The observation area for one viewer consists of 31 dots, and the dot at the interocular center position is displayed in black. The 31 dots are used to prevent coloration due to periodic patterns. In this design, the aperture inclination angle is $\tan^{-1}(1/12)$ to achieve OVD of 1 m.

Table1 Specifications of prototype system.

Display	Apple Pro Display XDR
Barrier size	263 mm × 203 mm
Barrier aperture ratio	8.1 %
Aperture inclination angle	$\tan^{-1}(1/12)$
OVD	1112 mm
Dot space pitch	9.56 mm
n (subpixel number)	62
Observation area width	30 cm

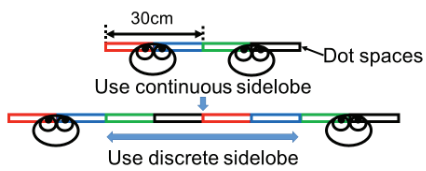


Fig. 8 Two people observe with discrete sidelobe.

4.2 Eye-tracking Control

This section describes the experimental method to verify the effect of horizontal eye-tracking control. Instead of a viewer, a camera is placed OVD away from the display and directed perpendicularly to the display surface, and the camera takes pictures at the position of the right eye and the left eye. From equation (3), the dot space width f is 9.68 mm and the observation area of the prototype display is 300 mm, so the camera moves horizontally 300 mm to capture the image. In addition, the shooting interval is set to 1 mm. We obtain the pixel values of the entire display area of the captured image and calculate the average pixel value for each captured image. There are three types of displayed images: all-white image, all-black image, and composite (parallax) image. For the composite images, the right eye is displayed in black and the left eye image in white when measuring the crosstalk ratio of the right eye, and the right eye image is displayed in white and the left eye image in black when measuring the crosstalk ratio of the left eye. The image is displayed according to the position of the viewer (camera). The crosstalk ratio is calculated based on the captured images. The crosstalk ratio CT is given by

$$CT = \frac{P_{vc} - P_{vb}}{P_{wv} - P_{vb}} \times 100 \qquad (4)$$

where P_{vb} is the average pixel value of the black image, P_{vw} is the average pixel value of the white image, and P_{vc} is the average pixel value of the composite image.

Fig. 9 shows the theoretical and experimental values of the relationships between the amount of movement and the crosstalk ratio of right and left eyes.

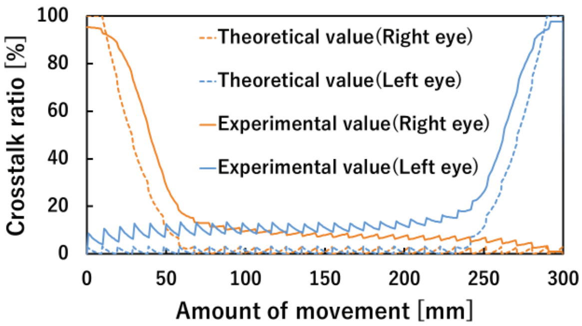


Fig. 9 The theoretical and experimental values of the relationships between the amount of movement and the crosstalk ratio.

5 Discussion

To verify the effectiveness of the proposed method, the prototype system was fabricated and evaluated. Figure 10 shows that the crosstalk ratio of right eye clearly increases because the right eye image is displayed with one dot when the amount of movement is around 0 mm. Conversely, however, the left eye has less crosstalk. Thus, at the edge of the observation area, the difference in crosstalk between the right and left eye is large. Therefore, the observation area that has stereoscopic viewing should be judged comprehensively by the crosstalk of the right eye and the left eye. As shown in Figure 9, the crosstalk ratio for the right eye increases sharply when the amount of movement is smaller than around 60 mm, and the crosstalk ratio for the left eye increases sharply when the amount of movement is larger than around 240 mm. This means that stereoscopic viewing is possible in the range of 60 mm to 240 mm at the amount of movement. The reason why the line is not smooth is that the dot space width f is large (9.56 mm) and the image is not switched if the viewer moves slightly. The crosstalk ratio is generally high because the parallax barrier was fixed by hand in a simplified manner in this experiment, resulting in a shift in the inclination angle of the parallax barrier and a non-uniform barrier gap g with the display pixels. On the other hand, since the crosstalk is based on the pixel values of the entire image display area, the entire image display area is not displayed uniformly due to these problems, and we think that this has a negative effect on the crosstalk. In this paper, we measured the crosstalk ratio for only one viewer and showed the its effectiveness of the proposed method. The eye-tracking control is considered to be effective because the same process is performed even when the number of viewers is increased to two. Therefore, the proposed method allows two people to observe stereoscopic images even if they move on the horizontal direction individually.

6 Conclusions

We developed the two-view autostereoscopic display using parallax barrier for two people and confirmed its effectiveness. Experimental results show that the viewers can move about 180 mm horizontally. The wide horizontal stereoscopic viewing area for two viewers is realized by using individual eye-tracking control. The effect of eye-tracking control in the depth direction will be confirmed in the future. Since this method reduces crosstalk compared to multi-view display, it is possible to display images with good separation. In addition, if the barrier pitch can be reduced by design, higher image quality can be achieved than with multi-view display. In the future, we target to optimize this method so that its advantages can be realized.

References

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