Two-View Autostereoscopic Display Independent of Differences of Interocular Distance and Viewing Condition

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ABSTRACT

We propose the method of compositing stereoscopic images on a two-view autostereoscopic display that can deal with the changes in interocular distance due to the individual differences and the changes in viewing condition. The proposed method reduces crosstalk by using the positions of each eye to composite stereoscopic images.

1 Introduction

The two-view autostereoscopic display [1] can provide high resolution than other methods, but it has the disadvantage of the very narrow viewing zone. To overcome this problem, we proposed the method to composite an optimal parallax image corresponding to the position of the viewer obtained by the depth camera [2,3]. However, the previous method simplifies the process by using the average interocular distance and compositing images corresponding to the center position of both eyes. As a result, crosstalk caused by individual differences in interocular distance and changes in viewing condition, such as facial tilt and rotation, was occurred. The crosstalk caused by individual differences in interocular distance is an important factor that must be eliminated.

In this paper, we propose a method to composite a parallax image by using positions of both eyes to expand the viewing zone. We use the black images to the crosstalk subpixels, which can be determined from the positions of each eye. We can achieve an autostereoscopic display that is independent of individual differences in interocular distance and changes in viewing condition. In this paper, we made a prototype system and evaluated the proposed method.

2 Expansion of Viewing Zone Based on Eye Tracking in the Previous Method

First, we assign a number to each subpixel of the display. The number of consecutive parallax images in a set is denoted by n, and the numbers from 1 to n is regularly assigned. This number assignment is uniquely determined by the barrier pitch, the barrier inclination angle θ, and n. A dot space is assumed at the OVD (Optimum Viewing Distance) for each subpixel assigned a number. The dot space indicates which subpixel an eye observes centered on through the aperture of the parallax barrier. For example, if the eye is in the dot space 3, the eye observes up to $n/2$ subpixels centered on the #3 subpixel through the aperture of the parallax barrier. However, if the number of subpixels observed by one eye is even, the number of subpixels to be observed as the center is two, so the dot space with lower number is regarded as the dot space in which the eye is. Figure 1 shows the number assignment and the dot space when $\theta = \tan^{-1}(1/6)$ and $n = 16$. In this case, the right eye observed centered on the #4 and #5 subpixels, but we regard the center as the #4 subpixel. The relationship between the width of the dot space f and the interocular distance E is given by

$$f = \frac{2E}{n}. \tag{1}$$

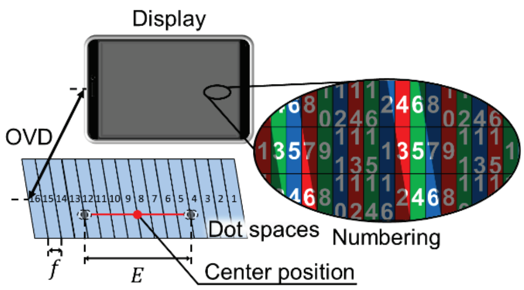

Fig. 1 The number assignment and the dot space.

2.1 Parallax-image Composition in the Previous Method

In the previous method, we used the center position of both eyes and the average human interocular distance $\bar{E}$ to simplify the process. First, we explain parallax-image composition when the viewer moves horizontally and vertically. When the center position of both eyes is in a dot space i on the OVD, the right eye is in a dot space from i to $i - n/2 + 1 \pmod n$ and the left eye is in a dot space from $i + 1$ to $i + n/2 \pmod n$. Therefore, the parallax image is composited with $n/2$ subpixels right from the #i subpixel as the right-eye image and $n/2$ subpixels left from the #i subpixel as the left-eye image. Figure 2 shows an example of parallax-image composition when $n = 16$ and the center position of both eyes is in the dot space 8. In this case, the parallax image is composited with #1 to #8 subpixels as the right-eye image and #9 to #16 subpixels as the left-eye image.

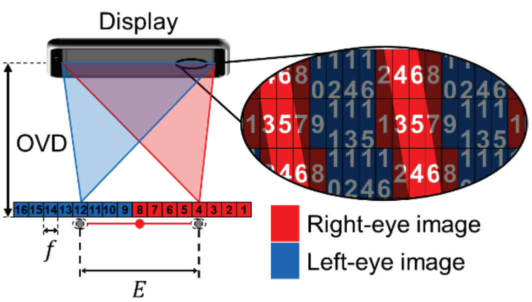

Fig. 2 Parallax-image composition in horizontal and vertical direction in the previous method.

Next, we explain the parallax-image composition when the viewer moves back and forth. When the viewer is positioned away from the OVD as shown in Fig. 3, the display is virtually divided by each dot space. The position where the straight line through the center position of both eyes and both ends of each dot space intersects the display is the boundary where the displayed image is switched. Each divided area has a different dot space in which the center position of both eyes exists, so the parallax image is composited accordingly.

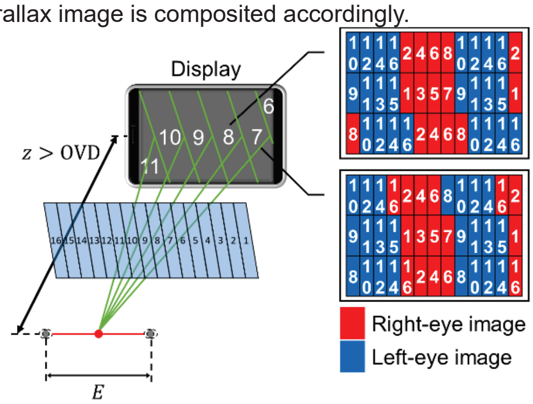

Fig. 3 Parallax-image composition in depth direction in the previous method.

In the previous method, it can deal with movement in any direction if the viewer's interocular distance is equal to the average interocular distance and the viewer is parallel to the display surface. When the viewer is not parallel to the display surface, as shown in Fig. 4, the person will observe the wrong subpixels because of the control using the center position of both eyes.

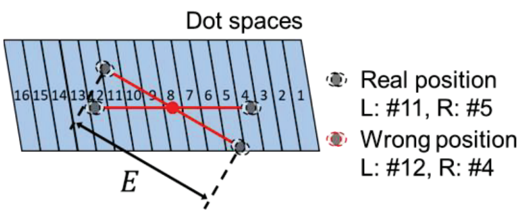

Fig. 4 Crosstalk in the previous method.

3 Parallax-image composition independent of interocular distances and viewing conditions

An actual interocular distance obtained by the depth camera is denoted by E'. First, we explain parallax-image composition when the viewer moves horizontally and vertically on the OVD, using the case where E' is larger than $\bar{E}$ as an example. As shown in Fig. 5, if the right eye is in a dot space i and the left eye is in a dot space j. Let A_r be the aperture ratio of the parallax barrier, then each eye observes $A_r \times n$ subpixels each centered on that dot space number. Therefore, a parallax image is composited with $A_r \times n$ subpixels centered on the $\#i$ subpixel as the right-eye image and $A_r \times n$ subpixels centered on the $\#j$ subpixel as the left-eye image. If the number of dot spaces between i and j is smaller than $A_r \times n$, there are subpixels that are simultaneously observed by both eyes and subpixels that are not observed by either eye. The former subpixels cause crosstalk, so the subpixels are made black. In addition, the subpixels on the opposite barrier edge corresponding to the black subpixels are also made black to reduce moiré. And the latter subpixels are made black. Similarly in the case where E' is smaller than $\bar{E}$, crosstalk and moiré can be reduced by using the same process.

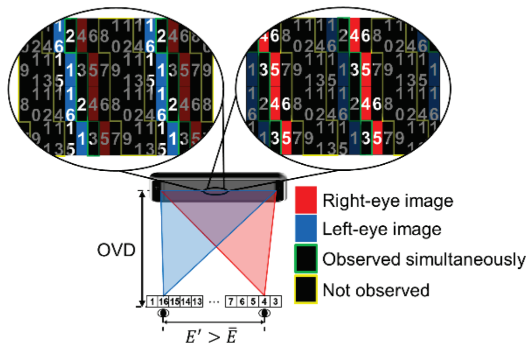

Fig. 5 The example of parallax-image composition in horizontal and vertical direction in the proposed method ($n = 16, i = 4, j = 16, A_r = 25$ %).

Next, we explain the parallax-image composition when the viewer moves back and forth from the OVD. The previous method divides the display based on the center position of both eyes. However, in the proposed method we divide based on each eye position. In this way, we can divide the display more finely than the previous method, which further reduces crosstalk across the entire display.

If each eye is in the position shown in Fig. 6, In the area (2), the right eye observes 4 subpixels centered on the #4 subpixel and the left eye observes 4 subpixels centered on the #7 subpixel. #6 subpixel is observed by both eyes, on the other hand #1, #2, and #10 to #16 subpixels are not observed by either eye. Therefore, #1, #2, #6, and #10 to #16 subpixels are made black. In addition, #3, #5, #7, and #9 are also made black to reduce moiré. This process is also applied to other areas to make the subpixels that cause crosstalk or moiré invisible across the entire display. Table 1 shows the observed subpixels, the subpixels without black image, and the number of subpixels to be displayed for each area at the positions of each eye in Fig. 6. As shown in Table 1, the number of subpixels displayed in each area is different, so the differences in luminance occur in each area. We adjust the luminance of other areas to match the luminance of the areas with the fewest number of subpixels being displayed. As a result, the luminance is kept constant across the entire display.

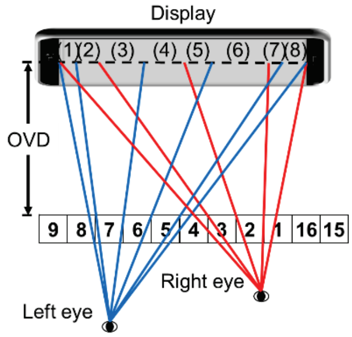

Fig. 6 The example of parallax-image composition in depth direction in the proposed method ($\theta = \tan^{-1}(1/6)$, $n = 16$, $A_r = 25$ %).

Table 1 Observed subpixels, subpixels without black image, and the number of subpixels to be displayed.

<table>
<tr><th rowspan="2">Area</th><th colspan="2">Observed subpixels</th><th colspan="2">Subpixels without black</th><th rowspan="2">The number of displayed subpixels</th></tr>
<tr><th>Left eye</th><th>Right eye</th><th>Left eye</th><th>Right eye</th></tr>
<tr><td>(1)</td><td>7~10</td><td rowspan="2">3~6</td><td>8,9</td><td>4,5</td><td>4</td></tr>
<tr><td>(2)</td><td rowspan="2">6~9</td><td>8</td><td>4</td><td>2</td></tr>
<tr><td>(3)</td><td rowspan="2">2~5</td><td>7,8</td><td>3,4</td><td>4</td></tr>
<tr><td>(4)</td><td rowspan="2">5~8</td><td>7</td><td>3</td><td>2</td></tr>
<tr><td>(5)</td><td rowspan="2">1~4</td><td>6,7</td><td>2,3</td><td>4</td></tr>
<tr><td>(6)</td><td rowspan="2">4~7</td><td>6</td><td>1</td><td>2</td></tr>
<tr><td>(7)</td><td rowspan="2">1~3,16</td><td>5,6</td><td>2,3</td><td>4</td></tr>
<tr><td>(8)</td><td>3~6</td><td>5</td><td>2</td><td>2</td></tr>
</table>

4 Experimental Results

4.1 Prototype System

The prototype display consists of the tablet display with the parallax barrier and the depth camera. Table 2 shows the specifications of the prototype system.

Table 2 Specifications of prototype system.

Display resolution	2732×2048
Barrier pitch (H)	0.25540 [mm]
Barrier aperture ratio	25 [%]
Barrier inclination angle	$\tan^{-1}(1/6)$
OVD	370 [mm]
Interocular distance	63 [mm]
Dot space width	7.25 [mm]
n	16

4.2 Experimental Configuration

The crosstalk ratio is used to evaluate the prototype system. The experimental system consists of the monochrome camera, the X-Z stage, and the prototype system. In the experiment, the camera with an aperture set to pupil size (4 [mm]) is used instead of the eye. The camera is adjusted to be parallel to the display surface and placed in a specific position. In this state, a prototype system displaying an all-black image, an all-white image, and a parallax image (right-eye: white, left-eye: black) is photographed. However, in the proposed method, a parallax image (right-eye: white, left-eye: white) is used instead of an all-white image. The crosstalk ratio at that location is calculated by analyzing these three images. The crosstalk ratio (CTR) used to evaluate the previous and proposed methods is given by

$$CTR = \frac{\overline{P_{bw}} - \overline{P_b}}{\overline{P_w} - \overline{P_b}} \times 100\ [\%], \qquad (2)$$

where $\overline{P_w}$ is the average pixel value when the prototype system displaying an all-white image was photographed, $\overline{P_b}$ is the average pixel value when the prototype system displaying an all-black image was photographed, and $\overline{P_{bw}}$ is the average pixel value when the prototype system displaying a parallax image was photographed.

4.3 Experimental Results on Changes in Interocular Distance

The camera is positioned the OVD away from the prototype system. The position of the camera is the left eye position. The center position of both eyes was fixed, and the interocular distance was varied from 30 [mm] to 100 [mm] in 1 [mm] increments, and the crosstalk ratio was calculated. Figure 7 shows the theoretical values of the previous and proposed methods in this experiment, and Fig. 8 shows the actual experimental results. Theoretical values for both methods were calculated by simulation using the program. In the previous method, the crosstalk ratio increases as the difference from the interocular distance increases. The proposed method can suppress the crosstalk ratio to within 5 [%] from the interocular distance of 30 [mm] to 89 [mm]. Even with the proposed method, the crosstalk ratio is high for interocular distances longer than 90 [mm].

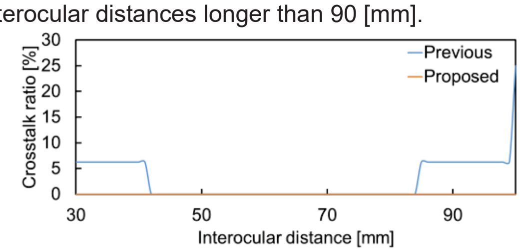

Fig. 7 Theoretical crosstalk ratio on changes in interocular distance from 30 [mm] to 100 [mm].

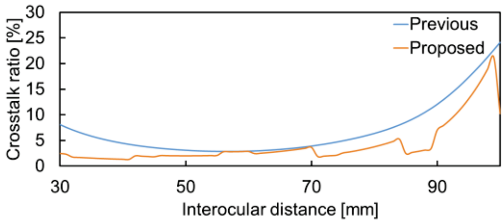

Fig. 8 Experimental crosstalk ratio on changes in interocular distance from 30 [mm] to 100 [mm].

4.4 Experimental Results on Changes in Viewing Distance

The observation angle was fixed at $30°$ and the viewing distance was varied from 261 [mm] to 361 [mm] in 2 [mm], and the crosstalk ratio at the left eye position was calculated. Figure 9 shows the theoretical values of the previous and proposed methods in this experiment, and Fig. 10 shows the actual experimental results. Theoretical values were calculated by simulation using the program. Comparing the previous method with the proposed method, the proposed method always has a lower crosstalk ratio. In addition, the crosstalk ratio tends to increase as the viewing distance diminishes with the previous method, whereas this is not the case with the proposed method.

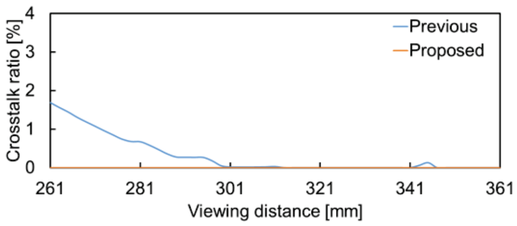

Fig. 9 Theoretical crosstalk ratio on changes in viewing distance from 261 [mm] to 361[mm].

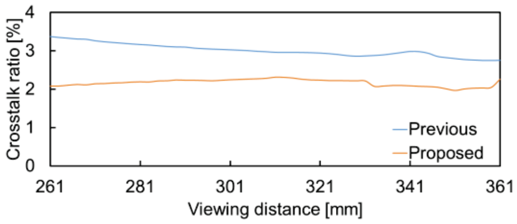

Fig. 10 Experimental crosstalk ratio on changes in viewing distance from 261 [mm] to 361[mm].

5 Discussion

When the interocular distance is over 90 [mm], the crosstalk ratio in the proposed method increases rapidly. Exponential increase is caused by small $\overline{P_w}$ in Eq. (2). The crosstalk ratio becomes more sensitive to changes in $\overline{P_{bw}}$ as $\overline{P_w}$ becomes smaller, so even small changes in $\overline{P_{bw}}$ has a great effect on crosstalk. Under the present experimental conditions, the left eye is in the dot space 2 and the right eye is in the dot space 5 when the interocular distance is 90 [mm]. In the proposed method, subpixels that are observed simultaneously and subpixels that are not observed by either eye are made black, so the #1 subpixel, which is originally observed by the left eye as the center, are made black. As a result, the area of the white image that could be observed at the left eye position became extremely small. Therefore, $\overline{P_w}$ also became small, and it caused the sharp increase in the crosstalk ratio. In addition, if the number of black subpixels increases by changes in interocular distance or viewing condition, light rays for stereopsis cannot be delivered to each eye. We concluded that the limit of interocular distance is 89 [mm] for the prototype system. Comfortable stereopsis is not possible if the interocular distance is longer than 90 [mm], but this is not a problem in practical use.

6 Conclusions

The proposed method can achieve to suppress crosstalk which the previous method cannot reduce. In the proposed method, the parallax-image composition uses the position of the viewer's each eye instead of the center position of both eyes and average interocular distance. The proposed method has achieved to suppress crosstalk to less than $2/3$ of that of the previous method at the distance $\pm 30\%$ from the average interocular distance. Therefore, the proposed method can reduce the crosstalk caused by individual differences in the interocular distance and changes in apparent interocular distance due to viewing condition.

Two-view eye-tracking control technology can provide stereoscopic images with high resolution and low crosstalk. Furthermore, this method suppresses degradation of stereoscopic performance caused by individual differences in the interocular distance and enables comfortable stereopsis with the very wide range. Since average interocular distance is used in the design of 3D displays, it has not been possible to display 3D images corresponding to individual differences in the interocular distance of viewers. The proposed method enables 3D image display that corresponds to the viewer's interocular distance.

References

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