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A full-HD super-multiview display with a deep viewing zone

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Abstract

We expand the viewing zone of a full-HD super-multiview display based on time-division multiplexing parallax barrier. A super-multiview display is a kind of light field displays that induces focal accommodation of the viewer by projecting multiple light rays into each pupil. The problem of the conventional system is the limited viewing zone in the depth direction. To solve this problem, we introduce adaptive time-division, where quadruplexing is applied when the viewer is farthest, quintuplexing is applied when the viewer is in the middle, and sextuplexing is applied when the viewer is nearest. We have confirmed with a prototype system that the proposed system secures a deep viewing zone with little crosstalk as expected

Introduction

Vergence-accommodation conflict has been one of the major problems to be solved to realize a natural 3D vision. When images for the left eye and the right eye are projected onto each eye, the depth can be perceived by binocular convergence. Focal accommodation, however, does not work correctly because the eye's focus is adjusted to the screen instead of the 3D image in the air or on the back of the display. This conflict causes visual fatigue of the viewer.

One of the conventional methods to solve the problem of vergence-accommodation conflict is volumetric display technology. The oldest volumetric display is based on the varifocal optics using a vibrating mirror [1]. A varifocal lens that changes its focal distance fast enough can attain the same volumetric effect [2]. Besides the varifocal optics, volumetric displays can also be realized by rotating a screen [3] or by layering translucent screens [4]. Volumetric displays, however, cannot express occlusion or specular light.

To overcome the drawback of volumetric displays, anisotropic projection surfaces [5,6] or multiview display technologies [7,8] can be combined with volumetric displays to express specular light and focal depth effect simultaneously. Though there have been several trials to improve the image quality of multiview volumetric displays [9-13], resolutions of the presented images are low since more than 50 views have to be presented to secure practical viewing zones.

Another approach to avoid vergence-accommodation conflict, is super-multiview display technology [14-17]. Super-multiview displays induce focal accommodation of the viewer by projecting multiple light rays into each pupil. Because two or more viewing zones cover the pupil, proper focal accommodation is required so that the image on the retina may not become a double image. However, this solution also requires around 50 or more views to secure a practical viewing zone, which requires an extraordinary computational power to run the system. Though the number of views can be decreased by using head tracking to show super-multiview images only around the pupils [18], high resolution is hard to realize because directional light rays are generated by using lenticular lenses.

On the other hand, several autostereoscopic displays that attain full resolution of the display panel have been proposed. One way to realize full resolution autostereoscopy is time-division multiplexing parallax barrier [19,20]. The whole information of the stereo pair is divided into two frames by resolution, where one frame shows half of the resolution of each view as usual, and the next frame shows the other half by shifting the phase of the barrier pattern and the image pattern. In addition, head-tracking technology widens the viewing zone [21-24]. By monitoring the position of the viewer, the image or the barrier pattern is adjusted accordingly to move the sweet spot so that it always follows the position of the viewer and keeps correct stereoscopy.

To ensure a wider viewing zone, Zhang et al. have proposed time-division quadruplexing parallax barrier [25-27]. In this system the same image is delivered to 2 of the 4 viewpoints, which suppresses emergence of crosstalk when each of the viewer's eyes is positioned between the two viewpoints showing the same image. To suppress moiré caused by the layered panels, a directional diffuser should be used so that the 3 primary colors are evenly mixed. When the color filters are aligned in the horizontal direction, which holds for most of the commercial display panels, a horizontal diffuser causes mixture of the left-eye image and the right-eye image, which destroys stereoscopy.

To overcome this problem, Okada et al. have proposed a time-division quadruplexing slanted barrier system with a slanted directional diffusion so that the moiré may be erased without destroying stereoscopy even when the color filters are aligned in the horizontal direction [28]. With this optical alignment, the barrier can be shifted by subpixel unit. Subpixel-based control can also be used to change the slit width adaptively [29].

Recently we have developed a full-HD super-multiview display based on time-division multiplexing parallax barrier [30]. 18 views are realized by time-division sextuplexing, where the orders of color filters in the two LCD panels are reversed to realize 3 fold views. 9 views are generated around each eye to attain a super-multiview condition. The problem of this system is the limited viewing zone in the depth direction.

In this paper we expand the viewing zone of the super-multiview display based on time-division multiplexing parallax barrier so that it may be applied for practical use.

Previous Study

Binocular stereoscopy causes eyestrain due to the vergence-accommodation conflict as shown in Figure 1. When the left-eye image and the right-eye image are projected onto the left eye and right eye respectively, the depth of the 3D image can be perceived by binocular convergence. Focal accommodation of the eyes, however, is adjusted to the two images on the screen instead of the 3D image in the air. This conflict causes visual fatigue of the viewer.

Super-multiview displays can induce focal accommodation of the viewer by projecting multiple light rays into the pupil as shown in Figure 2. Under this condition, proper focal accommodation to the image in the air is required so that the image on the retina may not be a double image.

Super-multiview displays require a large number of viewpoints to constitute contiguous viewing zones including the left eye and the right eye. In general, the viewing zone twice as wide as the interpupillary distance is prepared to secure stable stereoscopy. As the average interpupillary distance is 63 mm and the average radius of pupil is 5 mm, about 25 viewpoints have to be prepared. When the super-multiview display is implemented on a flat panel display with a lenticular lens on top of it, required resolution of the flat panel display is 25 times as fine as the image to be presented.

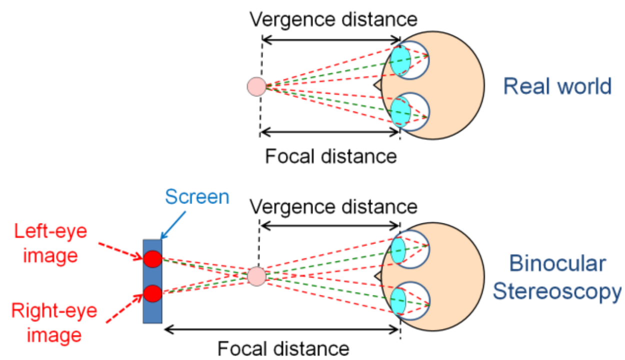

Figure 1. Vergence-accommodation conflict.

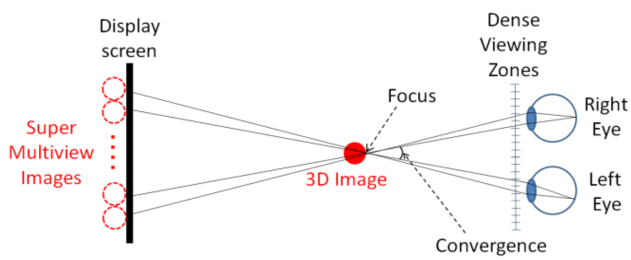

Figure 2. Principle of super-multiview display.

Takaki et al. proposed a system to reduce the resolution required for the flat panel display by eye-tracking as shown in Figure 3 [16]. The system reduces the number of viewpoints by generating the viewing zones near the tracked eye positions. This system, however, uses spatial multiplexing with lenticular lenses, which lowers the resolution of the presented image.

Time-division multiplexing parallax barrier is an effective method to attain an autostereoscopic display without loss of resolution. We apply this method to realize a super-multiview display.

When we use a pair of LCD panels whose refresh rate is 180 Hz to realize time-division sextuplexing parallax barrier, 6 views are reproduced at 30 Hz interlaced. More views are generated with the same refresh rate by using two LCD panels so that they may face the opposite direction. In this way the order of color filter is reversed and the light rays of different colors are directed to different orientations. Since each color produces a different directional light to realize 3 fold views, 18 views are realized in total. Then 9 different views can be delivered to the left image, while the other 9 views can be delivered to the right image. Figure 3 shows the principle of this system. Here 9 left eye images are shown at pixels L1-L9 and 9 right-eye images are shown at pixels R1-R9.

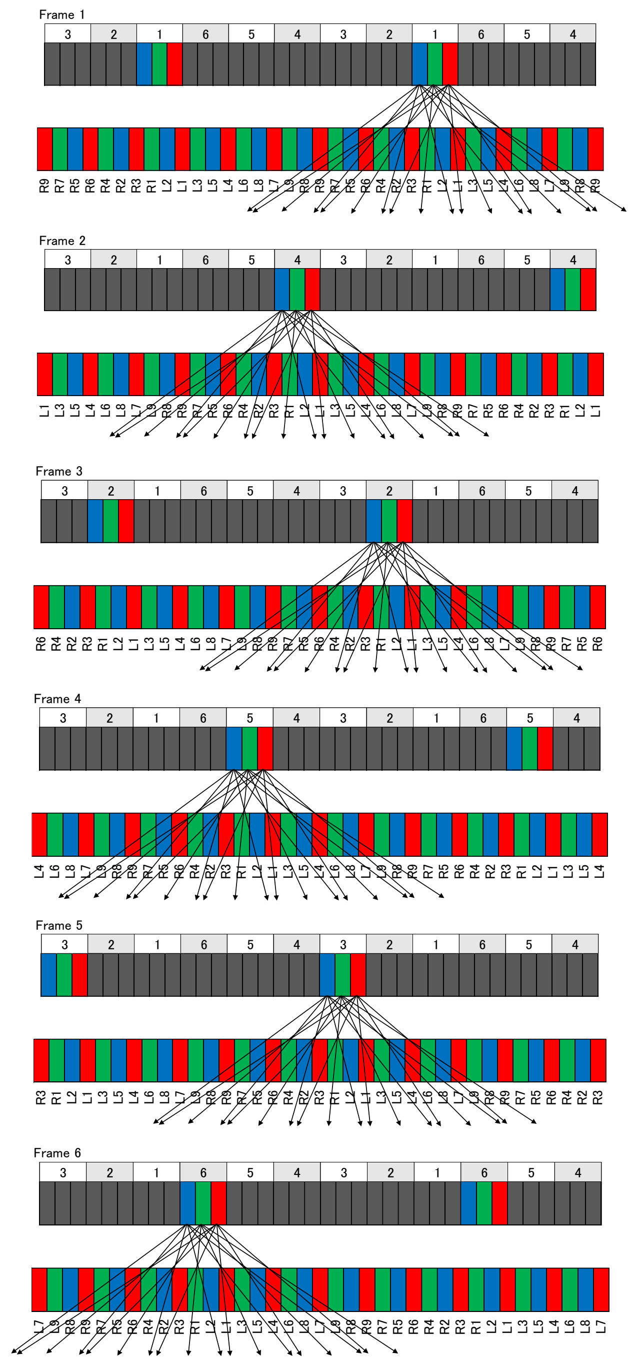

Figure 3. Super multiview with time-division sextuplexing parallax barrier.

In the first prototype system [30], a pair of 24 inch LCD panels, which had 1920×1080 pixels were used. The width of each subpixel p was 0.092 mm. To remove moiré, all 3 colors of each pixel should enter the pupil. Since the average pupil size is 5 mm, the viewing zone of each light ray should be around 1.7 mm or less. The distance between the two panels d was 60 mm. Therefore the width of each viewing zone v is given by $v = pD/d = 1.4$ [mm] when the distance D between the display and the observer is 900 mm as shown in Figure 4.The alignment of viewing zones at $D = 900$ [mm] are shown in Figure 5. As the width of the viewing zone for each eye w is given by $w = 1.4 \times 9 = 12.6$ [mm] and the average inter-pupillary distance P is 63 mm, two different set of images are observed by each eye.

Stereoscopy is maintained even if the viewer moves by shifting the barrier pattern to reflect the position of the viewer obtained by head-tracking. The problem here, however, is that the viewing zone w is too narrow. Also w is dependent on D, which means that one of the eyes can soon go out of the proper viewing zone when the viewer moves in the depth direction.

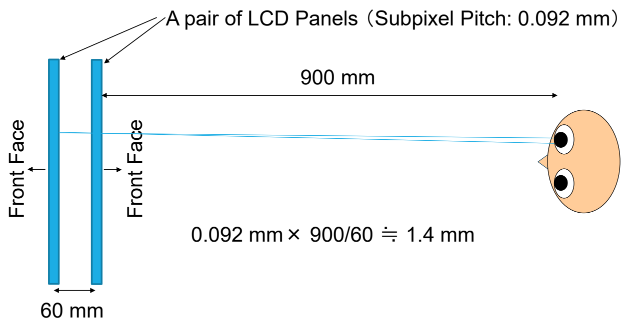

Figure 4. Optical setup of the prototype system [30].

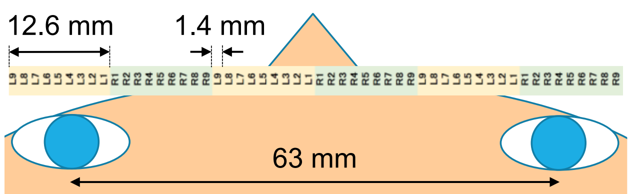

Figure 5. Viewing zone of the prototype system [30].

Proposed Method

To expand the viewing zone in the depth direction, we introduce two modifications. First, the distance between the two panels are narrowed to expand the width of each viewing zone. Super-multiview is maintained while two or more views enter the pupil. When only two views are observed, however, moiré stands out. To remove moiré, a weak diffuser is added in front of the panel in the back. Note that the diffusion here should be weak enough to maintain alternation of views in the horizontal direction.

Figure 6 shows the case where the interval of the panels is 30 mm. In this case stereoscopy is maintained when the distance between the front panel and the observer is around 750 mm as shown in Figure 7. Here the width of the viewing zone for each eye is given by $w = 2.3 \times 9 = 20.7$ [mm].

When the viewer moves in the depth direction, however, one of the eyes go out of the proper viewing zone here again. To overcome this problem, we change the number of time-division depending on the viewer's position.

Figure 8 shows the case where time-division quintuplexing is applied when the distance between the front panel and the observer is 900 mm. In this case $v = 2.76$ [mm], which is larger as the observer is farther from the screen. The width of the viewing zone for each eye w is maintained here by decreasing the number of views for each eye, which is attained by reducing the number of time-division.

Figure 9 shows the case where time-division quadruplexing is applied when the distance between the front panel and the observer is 1125 mm. In this case $v = 3.45$ [mm] and $w = 3.45 \times 9 = 20.7$ [mm]. Thus stereoscopy is maintained even when the viewer moves in the depth direction.

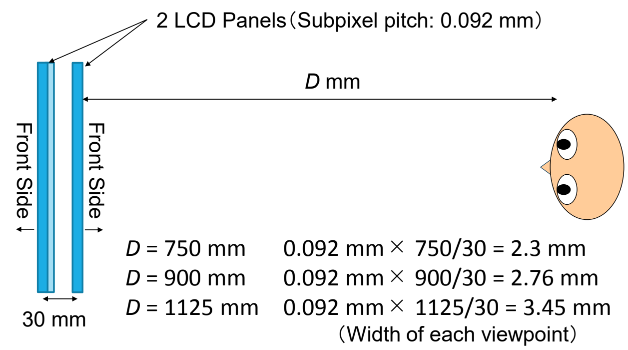

Figure 6. Optical setup of the proposed system

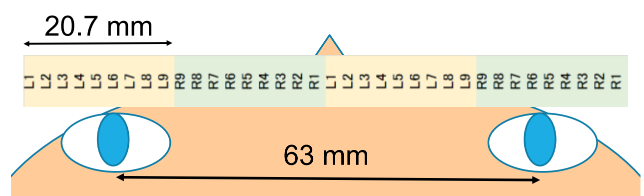

Figure 7. Viewing zone of sextuplexing time-division when D = 750.

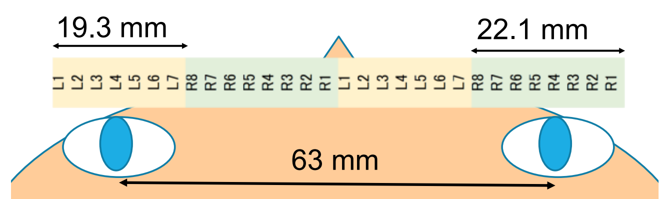

Figure 8. Viewing zone of quintuplexing time-division when D = 900.

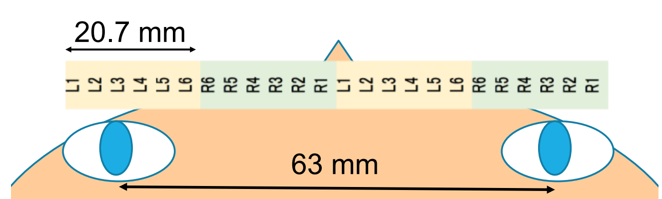

Figure 9. Viewing zone of quadruplexing time-division when D = 1125.

Experiment

The prototype system we made based on the principle described above is shown in Figure 10. To verify the principle, we carried out a simple experiment where a white image is shown to the left eye and a black image is shown to the right eye. Pictures are taken at the two viewpoints 63 mm apart from each other. The pictures at different depths (750 mm, 900 mm, and 1125 mm) are shown in Figures 11 through 13 respectively.

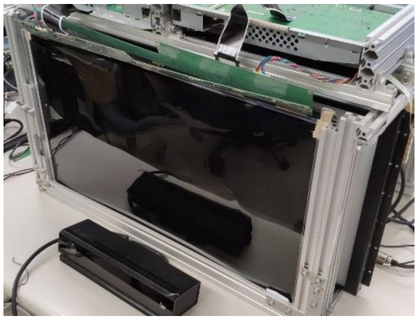

Figure 10. Picture of the prototype system.

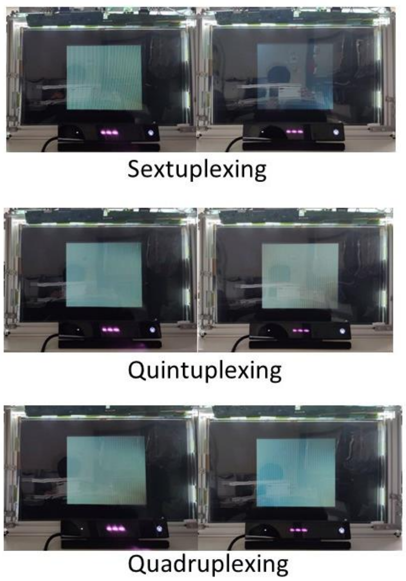

Figure 11. Observed images when D = 750.

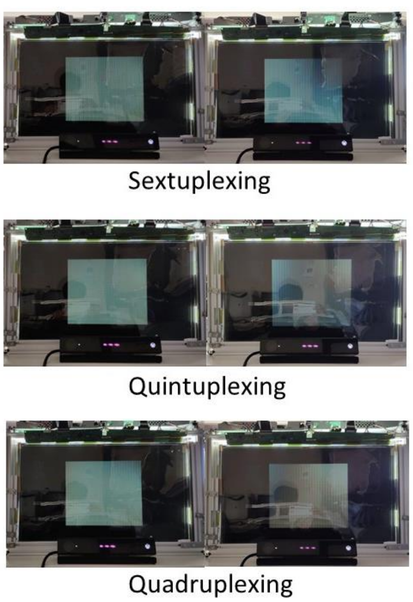

Figure12. Observed images when D = 900.

When D = 750, black and white images are best separated when time-division sextuplexing is applied as shown in Figure 11. When D = 900, black and white images are best separated when time-division quintuplexing is applied as shown in Figure 12, though crosstalk remains, which is due to the imbalance in the width of the viewing zone for the left eye and the right eye. When D = 1125, black and white images are best separated when time-division quadruplexing is applied as shown in Figure 13. Thus stereoscopy is maintained by changing the number of time-division as the viewer moves in the depth direction.

Figure 14 shows the pictures to confirm the super-multiview effect, which are taken at D =750 mm. Here a thin cone is shown 100 mm in front of the screen on the left and another thin cone is shown 100 mm behind the screen on the right. As shown in the figure, the back cone is blurred when the front cone is in focus, while the front cone is blurred when the back cone is in focus. Thus it is confirmed that the focal effect is reproduced in this prototype system.

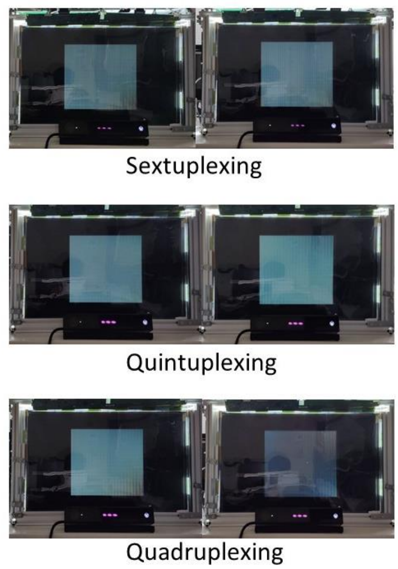

Figure 13. Observed images when D = 1125.

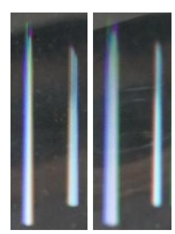

Figure 14. Pictures taken by changing the focus.

Conclusion

In this paper we have proposed a full-HD super-multiview display with a deep viewing zone to maintain stereoscopy by use of adaptive time-division multiplexing parallax barrier. First, the distance between the two panels are narrowed to expand the width of each viewing zone. To remove moiré, a weak diffuser is added in front of the panel in the back. Then daptive time-division multiplexing is introduced, where quadruplexing is applied when the viewer is farthest, quintuplexing is applied when the viewer is in the middle, and sextuplexing is applied when the viewer is nearest. We have confirmed with the prototype system that the proposed system secures a deep viewing zone as expected.

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