A Super-Multiview Display by Time Division and Color Multiplexing with Achromatic Lenses

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ABSTRACT

We measure the effect of achromatic lenses in place of conventional lenses to make dense light field based on time-division and color multiplexing. We confirm that the viewpoints corresponding different colors are aligned in order and the quality of observed image is improved by using achromatic lenses.

1 INTRODUCTION

Most of the conventional stereoscopic displays realize stereoscopic vision by displaying two different images with parallax for the left eye and right eye. However, just showing binocular parallax causes vergence-accommodation conflict.

Binocular convergence and focal accommodation are the two major physiological factors that constitute human depth perception. Under a natural environment, the focusing point of each eye matches the depth of binocular convergence. When the viewer is observing a 3D image given by a standard stereoscopic display, however, the focus of the eye is adjusted onto the screen while the binocular convergence is adjusted to the 3D image away from the screen. This discrepancy is called vergence-accommodation conflict, which is one of the main causes of eye fatigue or sickness specific to stereo vision.

A super-multiview display is one of the methods to solve the problem of vergence-accommodation conflict [1-4]. Super-multiview displays project multiple images to each eye by displaying multiview images at intervals smaller than the size of the pupil. In other words, they generate dense light fields around the eyes. In order to prevent the image from being blurred when two or more light rays going through an aerial 3D point are projected onto the retina, the focusing position is induced to that point, which eliminates vergence-accommodation conflict. To realize a practical super-multiview display, however, a huge number of views are required to be displayed to cover a wide viewing zone.

To realize super-multiview display, Takaki et al. proposed a super-multiview near-eye display system that combines a high speed SLM and a two-dimensional light source array [5]. However, the images generated by the method are monochromatic. To avoid loss of color, Kakeya et al. have proposed a method that combines time-division and color multiplexing [6]. This method is composed of a pair of Fresnel lenses and two LCD panels that runs at a high refresh rate and achieves a high resolution full-color super-multiview display with horizontal and vertical parallax. However, since the above method uses a Fresnel lens, the effect of chromatic aberration is significant.

In this paper, we propose use of achromatic lenses in place for Fresnel lenses and evaluate its image quality.

2 CONVENTIONAL RESEARCH

One of the causes of eye fatigue that occurs in binocular stereopsis is vergence-accommodation conflict, as shown in Figure 1. When you see a thing in the real world, focusing and binocular convergence are adjusted to the same depth. When the viewer sees a stereoscopic image given by a traditional 3D display, the focus of the eyes should be induced to the display screen to see the image clearly, while the binocular convergence is induced to the 3D image away from the screen. This difference often causes eye strain of the viewer.

Super-multiview displays have been proposed as one of the methods to solve the vergence-accommodation conflict. As shown in Figure 2, super-multiview displays project two or more images onto a single eye. In order to prevent the image from being doubled, the focal point is induced to the intersection of the light rays. When the focal accommodation is properly induced, the vergence-accommodation conflict disappears.

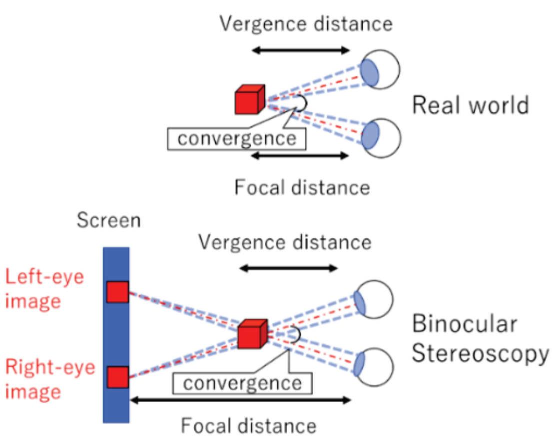

Fig .1 Vergence-accomodation conflict.

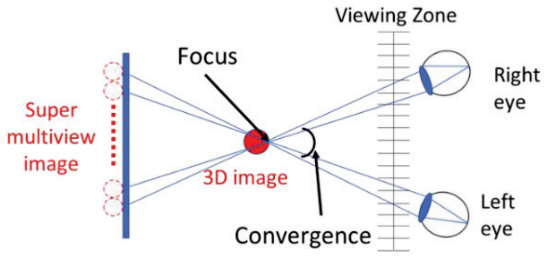

Fig. 2 Principle of super-multiview display.

To realize a super-multiview display, a huge number of images for continuous viewpoints have to be generated.

Among several super-multiview display systems previously proposed, Takaki et al. have proposed a super-multiview near-eye display system that combines a high speed SLM and a two-dimensional light source array. This system generates 21 viewpoints with both horizontal and vertical parallax by projecting different image patterns to each viewpoint, while the images that can be presented are monochromatic [5].

As a different super-multiview display method, Kakeya et al. have proposed a system that uses a parallax barrier to prevent resolution loss and provide full color images [7]. This system uses time-division multiplexing parallax barrier [8-14] and two LCD panels to face the opposite directions. 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 when sextuplexing parallax barrier is applied. This system, however, can show only horizontal parallax.

Watanabe et al. have proposed a full-color super-multiview display with both horizontal and vertical parallax by using time-division and color multiplexing [6]. The proposed system is composed of a pair of Fresnel lenses and two LCD panels that runs at a high refresh rate as shown in Figure 3. Suppose that lens 1 with focal length f_1 and lens 2 with focal length f_2 are arranged as shown in the figure, where the distance between the rear panel and the lens 1 is f_1, the distance between the lens 2 and the front panel is d_1, and the distance from the front panel to the observation point is d_2. Then the relationship $d_1 + d_2 = f_2$ holds and the image on the rear panel is projected to the pupil with the magnification ratio of f_2/f_1.

In the proposed system, the rear panel generates the viewpoints so that the image for each viewpoint may be depicted with different colors. They also apply time-division multiplexing to increase the number of viewpoints. The principle of the proposed system is shown in Figure 4. Here time-division quadruplexing is applied so that 12 viewpoints may be generated. Thus 4 x 3 viewpoints with horizontal and vertical parallax are generated.

At each frame, 3 images corresponding to the viewpoints generated by the color pattern on the rear panel are shown on the front panel with 3 different colors. By alternating the images on the front panel synchronously with the pattern on the rear panel, 12 different images are delivered to 12 different viewpoints. Though the image for each viewpoint is monochrome, a color image is observed by the viewer since multiple light rays are projected onto the retina. It is confirmed that this method can induce focal accommodation of the viewer.

Since the above system uses Fresnel lenses, chromatic aberration emerges, which blur the distinction of viewpoints.

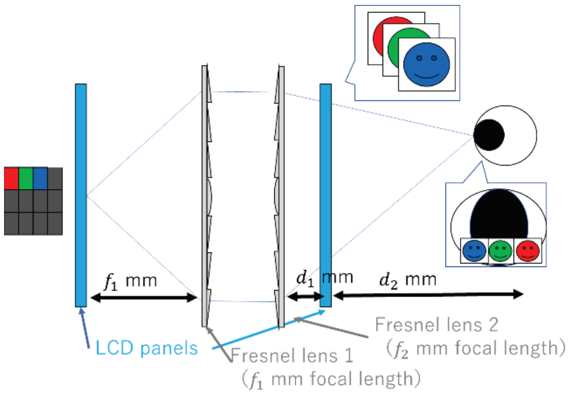

Fig .3 Principle of the proposed method.

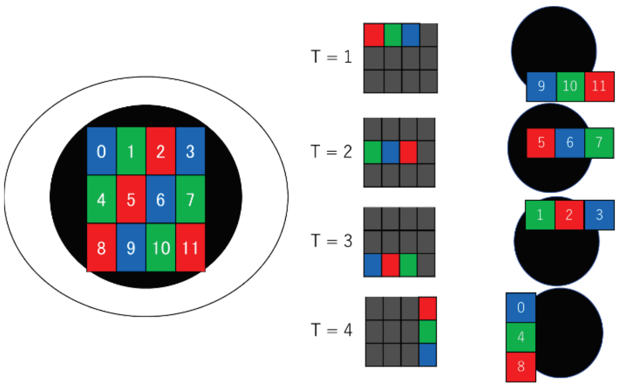

Fig.4 The color pattern on the rear panel and the viewpoints generated around the eyes. The position is rotated by 180 degrees due to the real image generation by the lenses.

3 EXPERIMENT

Because of the color aberration, the viewpoints generated by red, green, and blue backlight are shifted in the depth direction. Therefore, the size of the viewpoints changes, which can deteriorate the quality of super-multiview image. We test use of achromatic lenses in place of conventional lenses and confirm its effect to overcome this problem

The viewpoint pattern when Fresnel lenses are used is shown in Figure 5. The design of the experimental system was $f_1 = 250\ f_2 = 500, d_1 = 70$ [mm]. As shown in Figure 5, the sizes of red, green, and blue area are different due to the large effect of chromatic aberration, Achromatic lenses reduce the effects of chromatic aberration. We test use of a single achromatic lens and a pair of achromatic lenses to generate the viewpoints. The optical designs for each case are shown in Figures 6 and 7. In this optical design, the viewpoint patterns displayed on the rear LCD panel is projected at the observation position with equal magnification.

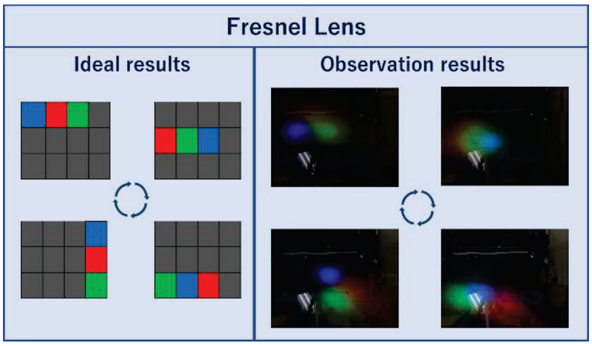

Fig .5 Photographed viewpoint patterns using Fresnel lens.

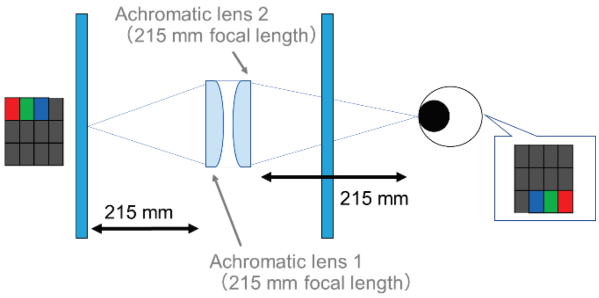

Fig. 6 Optical design with two Achromatic lenses.

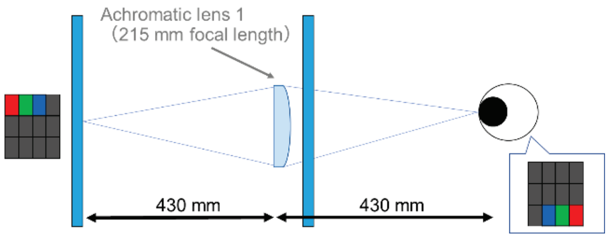

Fig. 7 Optical design with a single Achromatic lens.

4 RESULT

The viewpoint pattern when using achromatic lenses is shown in Figure 8. By comparing Figure 8 with Figure 5, it is clear that the use of achromatic lenses generates the viewpoints with the same size, though refraction due to the small pixel apertures in the front LCD panel broadens the light.

To confirm the effect of the aberration correction for super-multivew imaging, photos are taken from the center of the above viewpoint to observe the super-multivew image generated with the proposed method. Figure 9 shows the photos taken with different focusing while the two asterisks are shown in front and on the backside of the display with parallax. Two conditions with weak and strong parallax are tested.

As shown in the figure 9, the image is clearer when we use an achromatic lens in place of the conventional lens.

This is considered to be the effect of equally aligned viewpoints and the ability to project all viewpoint patterns at the observation point. Though it is harder to focus when the parallax is larger, the same tendency that is maintained. In the case of an achromatic lens, the image is clearer, but the vertical lines are doubled. The reason for this is thought to be that light from the viewpoint pattern diffracts and forms a diffracted light at the observation point.

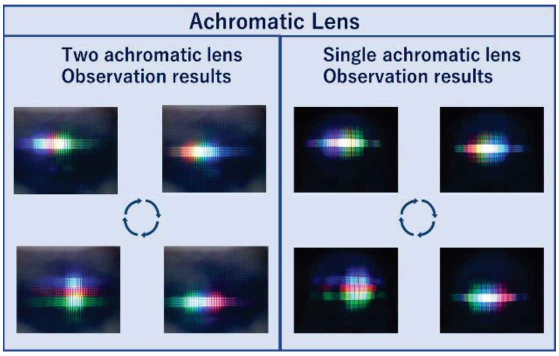

Fig. 8 Photographed viewpoint patterns using Achromatic lens.

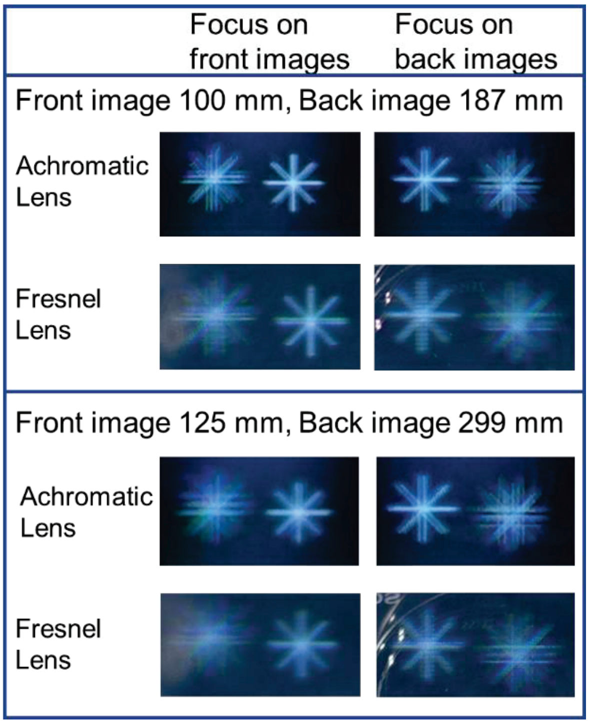

Fig. 9 Displayed images taken for each lens used.

5 CONCLUSIONS

In this paper, we have measured the effect of achromatic lenses in place of conventional lenses to make dense light field based on time-division and color multiplexing. We have confirmed that the viewpoints corresponding different colors are aligned in order with the same viewpoint size. The quality of observed image is also improved by using achromatic lenses, with clearer image.

In future work, we plan to measure the effect of human focal accommodation to the super-multiview image when the color aberration is removed by use of achromatic lenses.

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