Static Color Moiré Reduction Technology for Flat Panel Integral 3D Display

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ABSTRACT

In this paper, we describe a technique to reduce the color moiré that is peculiar to flat panel integral 3D displays. By adopting a static and thin optical element, we succeeded in preventing the occurrence of problems caused by the time-division color moiré reduction method and in maintaining the thin form factor of the display. By using a wavelength-selective polarizing element and polarization diffractive elements, R, G, and B subpixels that are separated and arranged adjacent to each other are optically collected in one place, and each subpixel is converted into a white pixel. We also demonstrate that by mounting this element on an integral 3D display system, it is possible to reduce the color moiré with a thin and static configuration.

1 Introduction

In the integral 3D display method[1], which uses a flat panel display to display elemental images, color moiré due to the structure of the color filter becomes a visual obstruction (Fig.1), and it is necessary to develop a technique for reducing color moiré [2,3]. We have proposed a method for optically synthesizing multiple flat panel display devices [4] and a method for using dynamic subpixel wobbling [5] with a liquid crystal polarization controller (LCPC) and birefringence optical elements or polarization diffractive elements (PDEs). These have the advantage of being able to simultaneously reduce color moiré and improve display resolution. However, there were problems, such as the system becoming bulky and the effective frame rate decreasing. In this paper, we show that by using a wavelength-selective polarization conversion element (WSPC) and PDEs, it is possible to optically collect red (R), green (G), and blue (B) subpixels that are separated and arranged adjacent to each other in one place and make each pixel a white spot. We also demonstrate that by mounting this optical element on an integral 3D display system, it is possible to reduce the color moiré with a thin and static configuration, although there is no resolution improvement effect.

2 Method of static color moiré reduction

This section describes the details of the static color moiré reduction method. As shown in Fig.1, the cause of the color moiré in the integral 3D display is the sampling of the display panel subpixel structure with the lens array.

This method presupposes that the display panel has a striped subpixel structure. The light emitted from the display panel was converted into linearly polarized (LP) light using a polarizing plate. For example, it can be used without a polarizing plate when a cross-nicol liquid crystal display (LCD) panel is used, because the output light polarization is already LP. The WSPC installed next converts only the R wavelength region of the linearly polarized visible light into right-handed circular polarization (RHCP) or left-handed circular polarization (LHCP), and the remaining G and B wavelength regions into circularly polarized light with a reverse rotation to R, that is, LHCP or RHCP. In a WS-PDE[6] arranged at the last stage, the light in the wavelength region of B becomes 0th-order diffracted light on both the incident side and the emitting side surfaces, resulting in the light in the wavelength region of B traveling straight without being affected by the element. On the other hand, regarding the wavelength regions of R and G, in the case of RHCP, the light is +1st-order diffracted on the incident side surface and −1st-order diffracted light on the

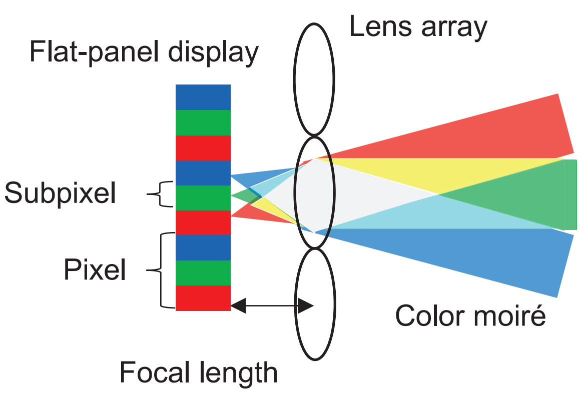


Fig. 1 Occurrence of color moiré.

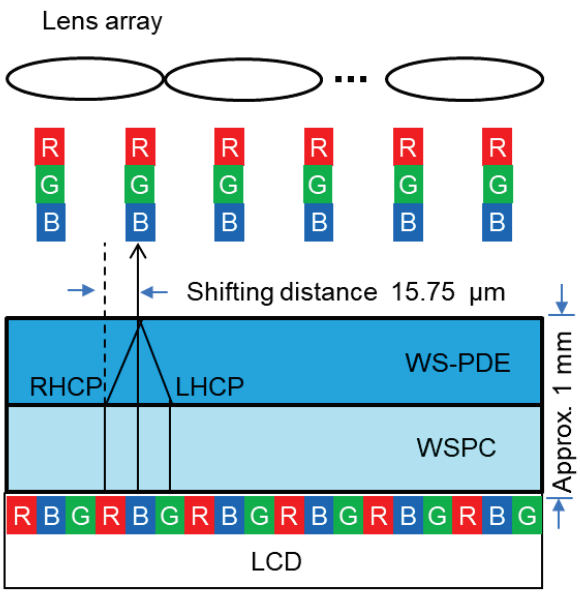


Fig. 2 Schematic cross-sectional view of experimental optical system.

outgoing side surface. In contrast, in the case of LHCP, the −1st-order diffracted light on the incident side surface and +1st-order diffracted light on the outgoing side surface. Therefore, the light in the wavelength region of R, which is RHCP, and the light in the wavelength region of G, which is LHCP, laterally shift in opposite directions as they pass through the element. Consequently, when the subpixels are arranged in the order of R, B, and G per pixel, the subpixels of R and G are shifted to the positions of the subpixels of B, resulting in a white pixel. This makes it possible to prevent the occurrence of color moiré patterns in a static and thin configuration.

3 Results

An experiment to reduce the color moiré was performed using an experimental optical system, as shown in Fig.2, based on the method described in the previous section. Table 1 lists the configuration of the experimental setup.

3.1 Experimental results of optical subpixel shift

An experiment was conducted by applying the WSPC and WS-PDE described in the previous section to an LCD panel for smartphones, as shown in Table 1. The thickness of the WSPC and WS-PDE was 0.5 mm, and the 1st-order diffraction angle was set such that the shift amount was 15.75 μm in the wavelength of G. Figure 3 shows the experimental results without the lens array. The result is generally as expected, with the R, G, and B subpixels overlapping in one place. However, it can also be observed that the light remains weak in places where it is expected to be black, e.g., the area surrounded by a white frame in Fig.3 (b).

3.2 Experimental results of color moiré reduction

A color moiré reduction experiment was conducted using a display panel, optical elements, and lens array, as described in the previous section. The entire white image is shown in Fig.4. The display was captured with a digital still camera for measurement to obtain the image data.

Table 1 Configurations of experimental setup

LCD panel	Pixel pitch	31.50 μm
	Subpixel pitch	15.75 μm
	Resolution	2160 (RG/BR/GB) × 3840 pixel
	Panel size	68.04 × 120.96 mm
Lens array	Pitch	0.5 mm
	Focal length	3.0 mm
	Arrangement	Orthogonal

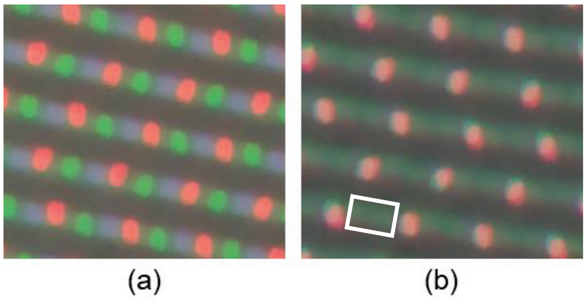
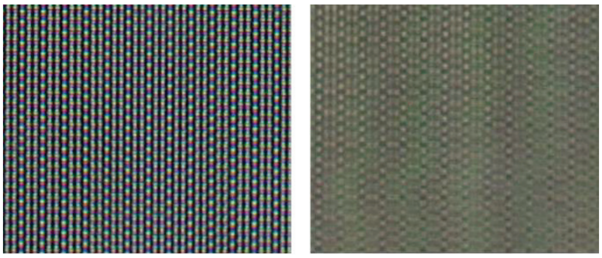


Fig. 3 Experimental results of optical subpixel shifting. Micrographs of LCD panel surface without (a) and with (b) subpixel shift.

Figure 5 shows the result of drawing the RGB values in the same image as in Fig.4 on the CIE 1931 xy chromaticity diagram. The capturing gamma was set to one because the image data is linear with respect to the luminance of the display. The black-painted area is the range of chromaticity without a subpixel shift, whereas the gray-painted area has a subpixel shift. Because the image used for the measurement was white, the chromaticity was expected to converge to one point, as indicated by the central circle. The chromaticity was observed to approach white, and the color moiré was noticeably reduced because of the effect of the subpixel shift. The area of the residual color moiré in the chromaticity diagram when the subpixel shift was performed was 5.9% of the area when it was not performed. Visually, the effect was suppressed to the extent that it was almost unnoticeable. The color moiré reduction performance of this method is sufficiently high compared with the dynamic subpixel wobbling methods proposed in the past [5]. This is because the area of the residual color moiré in the chromaticity diagram when the dynamic subpixel wobbling methods was performed was 28% of the area when it was not performed. It was confirmed that the color moiré pattern can be reduced with a static and thin configuration. However, luminance moiré occurred.



(a) (b)

Fig. 4 Enlarged images of displaying entire white. Without (a) and with (b) subpixel shift.

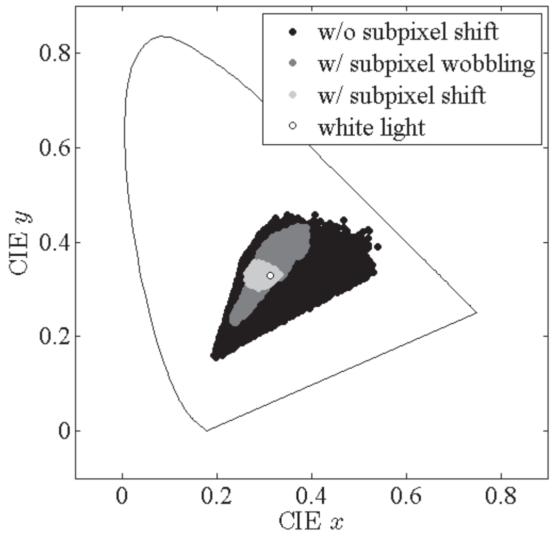


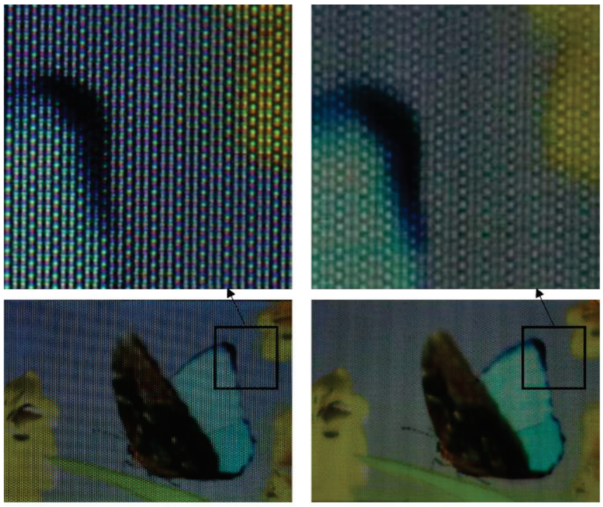
Fig. 5 Chromaticity diagram of the color moiré.

A 3D image-reproduction experiment was conducted, as shown in Fig.6. It was confirmed that the color moiré was effectively reduced; however, the color reproducibility and resolution deteriorated.

4 Discussions

While the R, G, and B subpixels overlapped in one location, as shown in Fig.3, it was also observed that the light remained weak in other locations. As shown in Fig.5, even with a subpixel shift, it did not match perfectly with white light, and deterioration in color reproducibility was observed, as shown in Fig.6. There are two possible causes for this: first, crosstalk occurs due to insufficient suppression of 0th-order diffracted light in the R and G shifts; second, the difference in the wavelengths of R and G, the desired amount of shift for R is not achieved precisely.

In addition to the reason described above, it is presumed that the reason for the decrease in resolution is that the positions of the shifted subpixels do not match the sampling positions of the elemental images. It is anticipated that improvements can be made by displaying information regarding the correct sampling position to which it is shifted for each subpixel. Moreover, it was



(a) (b)

Fig. 6 Experimental results of 3D image display. Without (a) and with (b) subpixel shift.

confirmed that although the color moiré can be reduced, luminance moiré occurs. This is because the phases of the RGB color moiré become the same owing to the shift, which is considered to be due to the decrease in the aperture ratio of the pixel and the increase in the ratio of the black matrix. It is effective to insert an appropriate Gaussian defocus filter and arrange the lens array at an angle to the pixel structure of the display panel to shift the moiré frequency to a high-frequency range [7].

5 Conclusions

In an integral 3D display, by adopting the method of collecting the subpixels of R, G, and B in one place to create white pixels, as shown in this paper, it is possible to create a static and thin configuration to prevent the occurrence of color moiré. Experiments have shown that the color moiré can be reduced to 5.9% in terms of the area ratio of the chromaticity diagram, confirming a higher effect than the methods proposed in the past. However, it has been confirmed that the prototype optical element suffers from deterioration in color reproduction performance and resolution owing to crosstalk, and the occurrence of luminance moiré due to the expansion of the black matrix area.

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