Analysis on the effect of color dispersion compensating layer in the three-dimensional/two-dimensional convertible display based on parallax barrier

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Abstract

In a three-dimensional/two-dimensional convertible parallax barrier display, an additional layer compensating the color dispersion for three-dimensional display can distort displayed image in the two-dimensional mode. We analyze the effect of the color dispersion compensating layer on two-dimensional image by computer simulations.

1. Introduction

A parallax barrier system is an autostereoscopic three-dimensional(3D) display system with a great possibility of commercialization. The parallax barrier system projects each pixel to one of the left or right eye, creating binocular parallax.[1] Recently, considerable effort is concentrated on developing the 3D/two-dimensional(2D) convertible display system by using liquid crystal(LC) active parallax barrier.[2] One problem of 3D/2D convertible display system based on parallax barrier is the color dispersion in the 3D mode.

In the liquid crystal display(LCD) panel, one pixel consists of RGB sub-pixels as shown in Fig. 1. Since RGB sub-pixels are spatially separated, the light from each sub-pixel is projected to different direction by the parallax barrier. Accordingly, the color of 3D image is dispersed at the observation plane. The viewing zone where the observer can see 3D image without color distortion is significantly narrowed to the superposed area of the light from sub-pixels.[3,4] Many researchers make their effort to compensate the color dispersion by adding a compensating layer in the parallax barrier configuration.

One notable point is the performance in the 2D mode. Since the color dispersion compensating layer itself is static, it can affect the quality of the 2D images as well as the 3D images. Considering the importance of the performance in the 2D mode, any layer degrading the 2D image quality is not acceptable. Therefore it is essential to analyze the effect of the color dispersion compensating layer on the 2D image quality. In this paper, we simulate the effect of compensating layer on the 2D image.

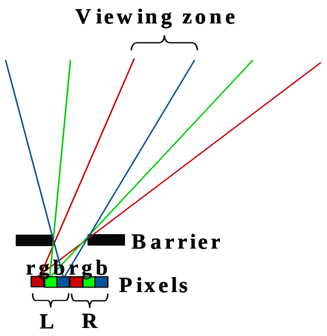

Figure 1. Color dispersion in the parallax barrier

2. Assumption on compensator

Suppose a configuration shown in Fig. 2. The additional layer compensates the color dispersion in the 3D mode by making the projecting direction of RGB sub-pixels be the same. Or, equivalently, the compensating layer shifts the R and B sub-pixels to G sub-pixel, superposing RGB sub-pixels at the same position as shown in Fig. 3.

Since each slit corresponds to two pixels(left and right view), the R and B sub-pixels of these two

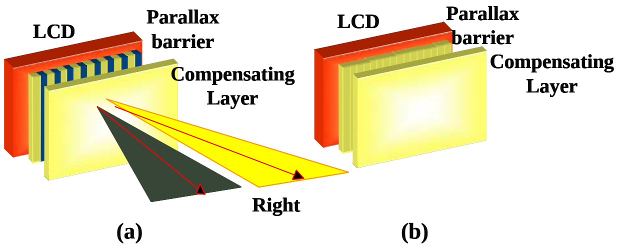

Figure 2. Compensator in front of the parallax barrier(a)3D mode(b)2D mode

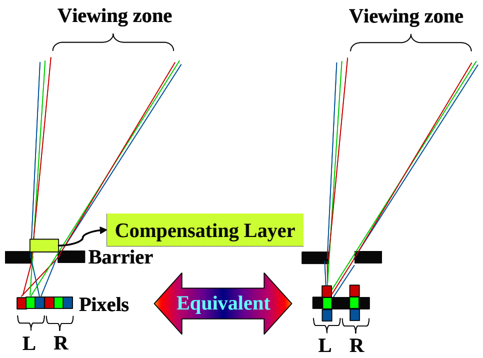

Figure 3. Assumption on the optical properties of the compensator

corresponding pixels can be assumed to be shifted to G sub-pixels by the compensating layer.

One thing we should note here is the role of the compensating layer on the pixels that do not correspond to the designated slit; i.e. pixels in 'A' area in Fig.4. Since the observing direction is arbitrary in the 2D mode, these pixels can be seen through undesignated slit, and thus will be affected by the compensating layer. We consider two cases here. In case 1, these pixels(pixels in 'A' area) is assumed not to be shifted at all by the compensating layer as shown in Fig. 4(a). In case 2, these pixels experience the same shift as the two pixels corresponding to the designated slit as shown in Fig. 4(b).

The other notable thing is compensating efficiency which is defined by the ratio of the intensity of the diffracted light to the intensity of the total light. If the efficiency is 1, then the result will be the best in 3D mode. However when the

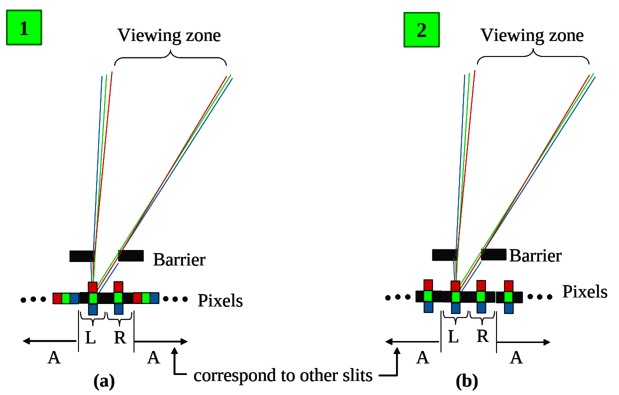

Figure 4. (a) The compensator dose not shift pixels in 'A' area. (b) The compensator shifts all pixels.

compensating efficiency is high the 2D image is changed more compared with the case in which the efficiency is low. Thus we need to find the optimal efficiency of the compensating layer. Hence, here, we simulate 3D and 2D modes with different efficiencies of compensating layer.

3 Simulation result

3.1 The effect of the compensating layer on the displayed images

3.1.1 3D mode

First, we simulated 3D mode and the result is shown in Fig. 5. We assume the efficiency of the compensating layer is 1. Boxed areas indicate the region where the observer experiences no color dispersion. Without the compensating layer, the image has severe color dispersion as shown in the first row of Fig. 5. In case 1 and case 2, we see that the compensator plays its role. There are no color dispersion between the 0 mm and the 65 mm(width between human eyes) in case 1 and case 2. Moreover

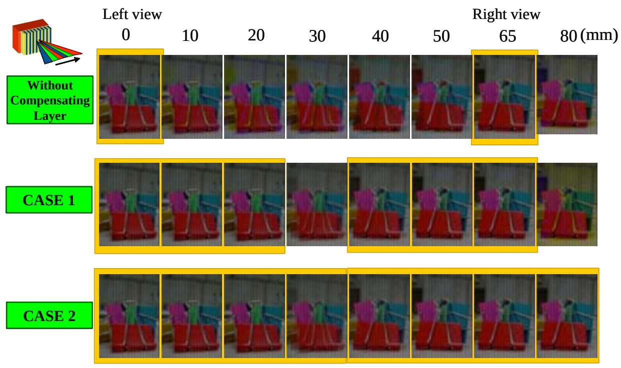

Figure 5. Variation of 3D image along the *x* axis

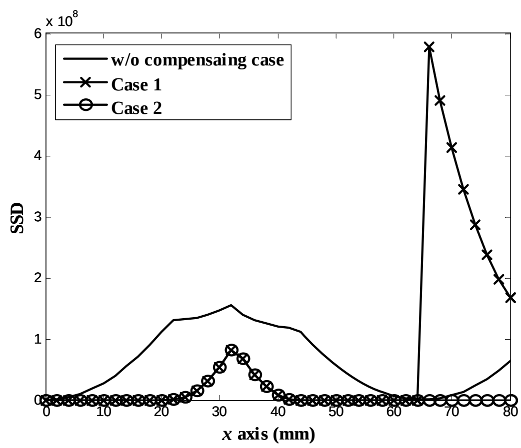

Figure 6. SSD of 3D image along the *x* axis

in case 2, there is no color dispersion over 65 mm. The reason is that all of the RGB sub-pixels are shifted by the compensating layer in case 2. Figure 6 shows the sum of squared difference (SSD) between the observed image and the corresponding left or right view image which can be a measure of the image distortion due to color dispersion. The SSD is

$$SSD = \sum_{M,N} \left(I_x(m,n) - I_{left}(m,n) \right)^2 \quad 0 \le x \le 32.5mm \qquad (1)$$

$$SSD = \sum_{M,N} \left(I_x(m,n) - I_{right}(m,n) \right)^2 \quad 32.5 \le x \le 80mm \qquad (2)$$

where $I_x(m,n)$ is intensity of *m*th row and *n*th column pixel.

The value of SSD around 32.5 mm point is caused by the fact that the left viewing image and the right viewing image are shown simultaneously.

3.1.2 2D mode

Figure 7 shows the simulation result in the 2D mode. We also assume the compensating efficiency of the compensating layer is 1. There is no problem when the compensating layer is not applied. In case 1, however, we see distorted image at 13° and 19°. The reason is that we see the shifted pixels(pixels corresponding to the designated slit) and the unshifted pixels in 'A' area at the same time. In case 2, all sub-pixels are shifted as shown in Fig. 4(b). Therefore the distortion of the 2D image is negligible.

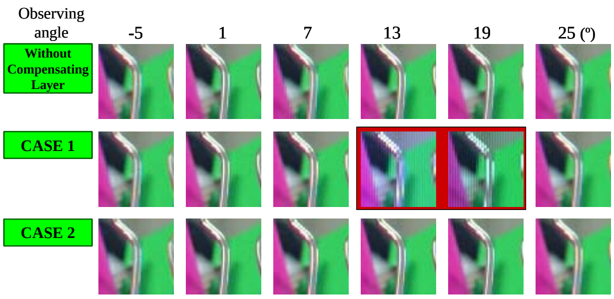

Figure 7. Variation of 2D image along the *x* axis

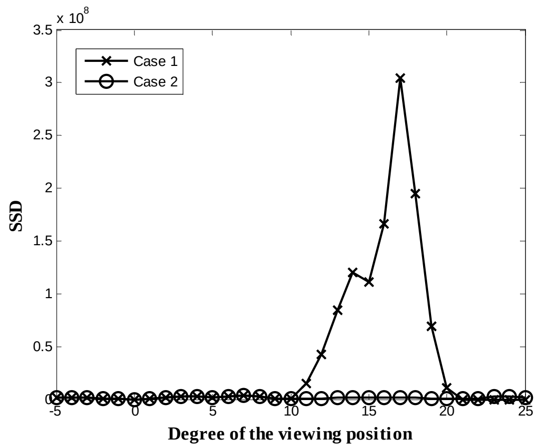

Figure 8. SSD of 2D image along the *x* axis

Figure 8 shows the SSD between the case of no compensating layer and other cases. In case 1, serious distortions are carried out in 11° ~20°. Unlike case 1 in case 2, the distortions of the 2D images are negligible.

3.2 Variation according to compensating efficiency

3.2.1 3D mode

Figure 9 shows the simulation result in the 3D mode in case 1 and case 2 according to the compensating efficiency at fixed viewing position(x=20 mm). Figure 10 shows the SSD between the left viewing image and the observed image according to the compensating efficiency at fixed viewing position(x=20 mm and x=80 mm). The graph shows interesting results. Between 0 mm and 65 mm the SSD values of case 1 and case 2 are same. However out of the range, i.e., at

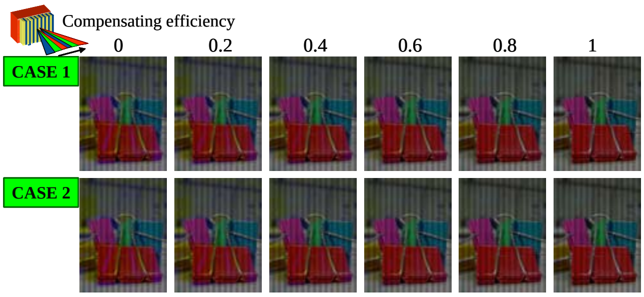

Figure 9. Variation of 3D image corresponding to compensating efficiency

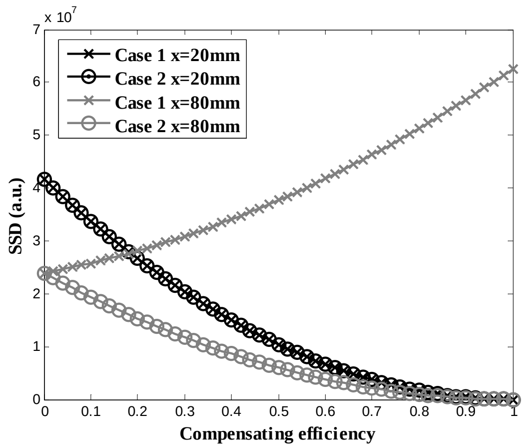

Figure 10. SSD of 3D image corresponding to compensating efficiency

x= 80 mm, the image distortion in case 1 becomes more serious as the compensating efficiency increases. Unlike case 1, in case 2 the image distortion decreases with high compensating efficiency.

3.2.2 2D mode

Figure 11 shows the simulation result in the 2D mode in case 1 and case 2 according to the compensating efficiency at fixed viewing position (15^o). The SSD is calculated between the images of the no compensating layer case and the images of the case 1 or 2 at two viewing angles as shown in Fig. 12. At 30^o the distortion of case 1 and case 2 can be negligible. However at 15^o in case 1, as the compensating efficiency approaches 1, the distortion of the images becomes more serious. Unlike case 1, in case 2 the values of SSD are negligible irrelevant to the compensating efficiency. Therefore in case 1, high compensating efficiency can induce serious distortion on 2D image.

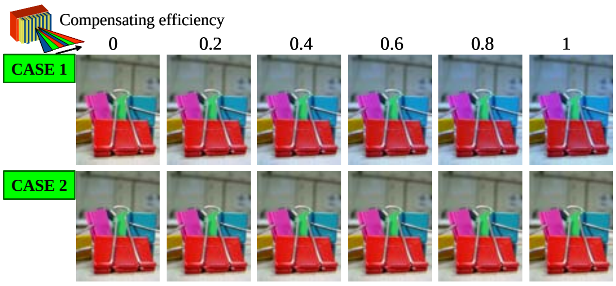

Figure 11. Variation of 2D image corresponding to compensating efficiency

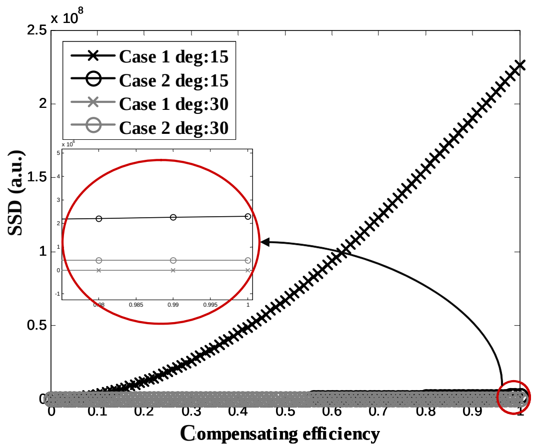

Figure 12. Variation of 2D image corresponding to compensating efficiency

4. Conclusion

We simulated two kinds of cases with the different compensating efficiency of the compensating layer. The result says that the viewing zone in the 3D mode becomes wide with the color dispersion compensating layer. The amount of distortion of the 2D image depends on the property of the color dispersion compensating layer. First consider the compensating efficiency is 1. When only two pixels corresponding to the slit are shifted(Fig. 4(a)), the color distortion problem is restricted in the small area(10^o~ 20^o) as shown in Fig. 8. When all of pixels are shifted(Fig. 4(b)), there is no significant distortion. Then consider the image with the different compensating efficiency. As the compensating efficiency approach 1, the compensating layer makes good 3D performance in viewing zone. However distortion of 2D image is more serious when compensating efficiency is high in case 1. This result of the simulation is useful for designing the compensating layer and improving its performance.

Acknowledgment

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