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Portrait and landscape mode convertible stereoscopic display using parallax barrier

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Abstract

We propose a tablet type stereoscopic display. It features moire free and low crosstalk ratio. The proposed system consists of parallax barriers, a tablet type liquid crystal display (LCD) and stereo cameras. A tablet type display has two display modes, portrait and landscape. It is necessary to realize same viewing distance both portrait and landscape modes. Therefore, it is difficult to observe high quality stereoscopic image by using tablet type display. In proposed system, the same parallax barriers are used both portrait and landscape modes. Therefore, viewing distance of the system is constant regardless of whether the LCD is portrait or landscape.

We constructed the prototype system to verify the effectiveness of the proposed system. We used 15.6 inch 4K display as an LCD for tablet. By realizing new stereoscopic image arrangement that was different from between in portrait and landscape modes, we can see stereoscopic images with the slanted barriers with the same specifications. We confirmed that viewing distance is constantly 207.375 mm and moire patterns are not generated on its image. Additionally, max crosstalk ratio is 6.56 % at portrait mode and 14.00 % at landscape mode.

1. Introduction

Recently, binocular stereoscopic displays have been used in various fields such as healthcare, design and entertainment. But, there are few cases that binocular stereoscopic method is used for a portable tablet display as a mobile phone. The tablet display has two display modes, portrait and landscape. Each arrangement of sub-pixels are different. Therefore, it is difficult to observe a stereoscopic image at the same optimum viewing distance in both display modes. In addition, it is necessary to show a glass-free stereoscopic image with no moire and low crosstalk ratio.

We propose a binocular stereoscopic display system that the optimum viewing distance is same in both portrait and landscape display modes with no moire and low crosstalk ratio. In the proposed system, image quality does not deteriorate like a multi-view display [1]. There are some methods to display a stereoscopic image such as using glasses, a lenticular lens and so on [2]. Among them, a parallax barrier method is used in this research. We can observe the stereoscopic images with no glasses through the parallax barrier. By making the parallax barrier of liquid crystal display (LCD), it is possible to change two kinds of barriers depending on the two modes of portrait and landscape. The proposed system consists of a tablet LCD, switchable parallax barriers made of LCD and stereo cameras. Apertures of the parallax barrier have inclination to remove moire and improve image quality in this research. Stereoscopic images can be observed at the same viewing distance in both display modes. It is realized by designing the two kinds of switchable parallax barriers with the same specifications. The proposed system tracks the viewing position of an observer with the stereo camera. By only controlling the stereoscopic image positions displayed on LCD depending on the observer's eyes position, the stereoscopic image can be observed in large viewing area. Therefore, complex control such as movable parallax barrier [3] is not necessary.

In this paper, we show the principle of a binocular stereoscopic display using a parallax barrier whose optimum viewing distances are equal in both portrait and landscape modes. In section 2, we show the optimum parallax barrier design method, the controlling method of composite images by eye-tracking and the configuration of the proposed system. In section 3, we show the prototype system and its evaluation results. In section 4, we discuss the conclusion. Some methods for removing moire [4] and expanding viewing area using head tracking [5][6] were reported but there were no paper describing to both portrait and landscape modes.

2. Binocular Stereoscopic Display Using Parallax Barrier

2.1 Parallax Barrier Design Method for Moire Free and Low Crosstalk

In this section, we show the parallax barrier design method that viewing distance is same in both portrait and landscape modes with no moire and low crosstalk ratio.

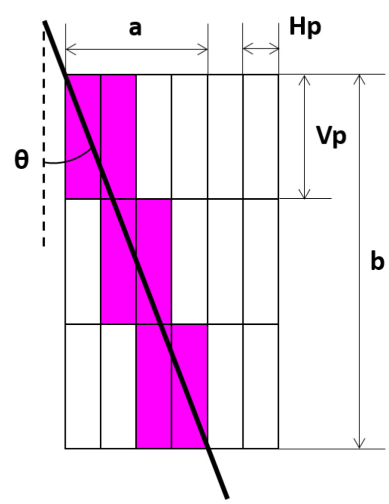

Figure 1. Positional relationship between sub-pixels and a parallax barrier inclination. θ is the inclined angle of the barrier aperture, a and b are the number of sub-pixels become a norm of θ. Hp and Vp are the sub-pixel pitch.

LCD's sub-pixels have the black matrix. If the barrier aperture is parallel to sub-pixels, the intensity of observed lights is uneven due to the positional relationship between the barrier aperture and the black matrix, therefore, moire occurs. In the proposed system, the barrier apertures have inclination to remove moire. The positional relationship between the sub-pixels and the barrier inclination is shown in Fig. 1, and the inclined angle of the barrier aperture θ is given by

$$\theta = tan^{-1}(a \times Hp/b \times Vp). \qquad (1)$$

In Fig. 1, the pink dots are crossed by the line showing the barrier inclination angle. This expresses the minimum number of dots observed from the aperture of the parallax barrier at the same time. In order to realize Moire-free condition, Fig. 2 shows the minimum necessary viewing area through the barrier aperture depending on the inclination of the barrier. As shown in Fig. 2, the barrier apertures' pitch should be set to Hp/b, then, the area observed from the barrier aperture of b rows is equal to the area of one sub-pixel. Therefore, the effect of the black matrix can be ignored and the observers can observe the intensity of lights evenly regardless of the position of their eyes. This means that moire caused by the black matrix does not occur at any viewing position. If the barrier aperture pitch is equal to the integral multiple of the viewing area in Fig. 2, it is possible to design the moire-free parallax barrier.

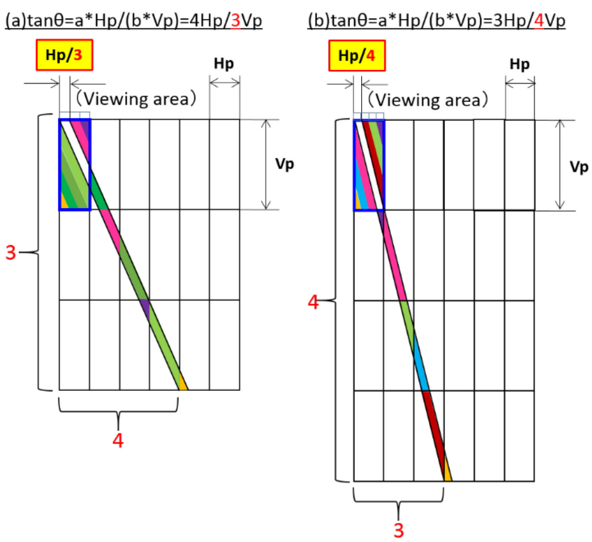

Figure 2. The example of the viewing area through the barrier aperture. If the barrier aperture pitch is equal to the integral multiple of the viewing area, the light from one sub-pixel is allocated in the vertical direction. 2(a) shows an example when the inclination is 3:4, and 2(b) shows an example when the inclination is 4:3.

Next, we show the design method of the barrier pitch based on OVD. The positional relationship between an observer and the proposed system is shown in Fig. 3. Eqs. (2) and (3) are written by a similar relationship shown in Fig. 3.

$$E : d = k/2 : g \qquad (2)$$

$$d : Bp = (d + g) : k \qquad (3)$$

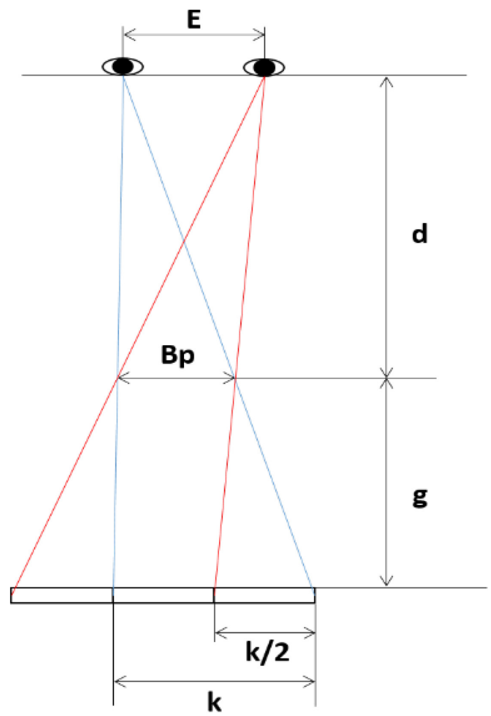

Figure 3. The positional relationship between an observer and the proposed system. E is the interocular distance, d is the optimum viewing distance, g is the gap distance between the parallax barrier and the LCD, Bp is the barrier pitch and k is the horizontal pitch of one set of stereoscopic images on LCD.

In Eq. (2), the interocular distance E and the gap between the parallax barrier and the LCD g are constant. The k is the horizontal pitch of one set of stereoscopic images on LCD and k can be determined freely under the constraint condition that k is the even multiple of the sub-pixel pitch. Therefore, the optimum viewing distance (OVD) d can be determined freely, then the barrier pitch Bp is determined automatically because all the variables other than Bp are determined in Eq. (3).

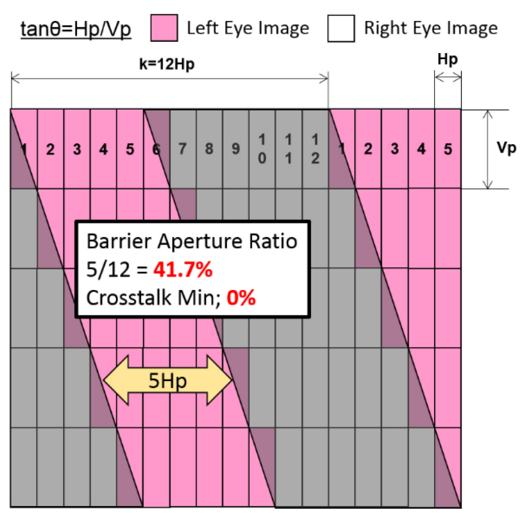

Figure 4. The example of the aperture pitch determining method. The barrier apertures pitch is determined so that the minimum crosstalk ratio is 0 %.

Finally, the barrier aperture pitch is determined and is designed based on Fig. 2. In this case, the inclination of the barrier is $a = b = 1$. The barrier aperture pitch is determined so that the minimum crosstalk ratio is 0 %. The example of the aperture pitch determining method shown in Fig. 4. The pitch of one set of stereoscopic images on the LCD is 12 Hp, and the left and right images are arranged every 6 Hp, then if the barrier apertures pitch is 5 Hp, the minimum crosstalk ratio is 0 %.

In this design, the crosstalk is reduced to 0 % with the high slanted barrier aperture ratio of 41.7 %.

2.2 Eye Tracking System

The viewing space of the binocular stereoscopic display is very narrow, so the viewing space is enlarged by eye tracking [7] in the proposed system. An observer's eye position is measured by the stereo camera and the viewing space is enlarged by controlling the stereoscopic image position on the LCD depending on the observer's eye position, controlling the stereoscopic image position by eye tracking is shown Fig. 5.

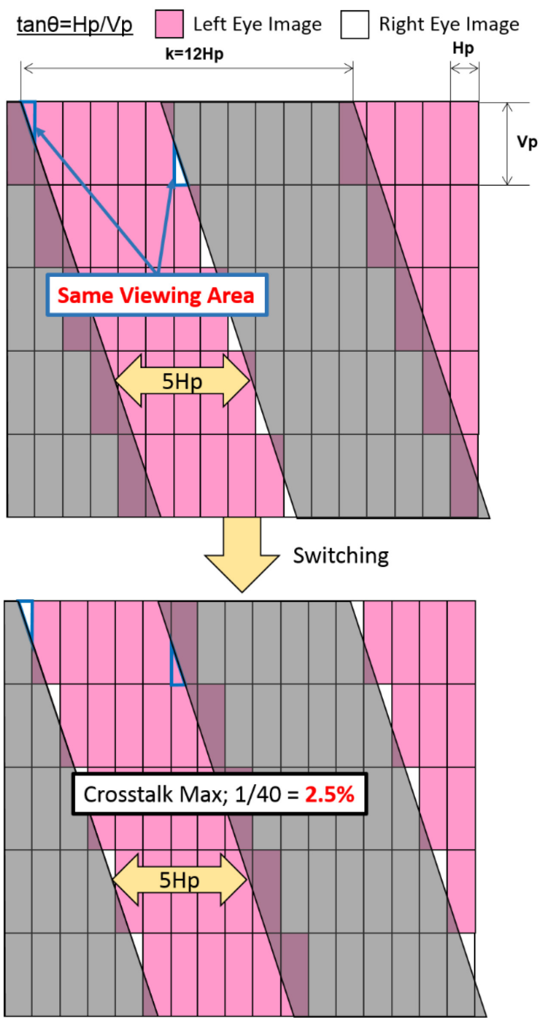

Figure 5. The image switching method by the eye tracking. When the areas of the reverse image and the normal image located at the aperture edge are same, the image displayed on the LCD is switched. Then, the maximum crosstalk ratio is 2.5 % in this example.

When the observer's eye position is shifted in the horizontal direction from optimum viewing position, the reverse image appears from the barrier aperture. When the reverse image size in a dot and the normal image size in a dot located at the aperture edge have the same size, the image displayed in the dot is switched. Then, the crosstalk ratio is maximum at the position of switching the image. For example, the maximum crosstalk ratio becomes 2.5 % in Fig. 5.

2.3 Proposed System of Same OVD in Two Modes

The configuration of the proposed system is shown in Fig. 6.

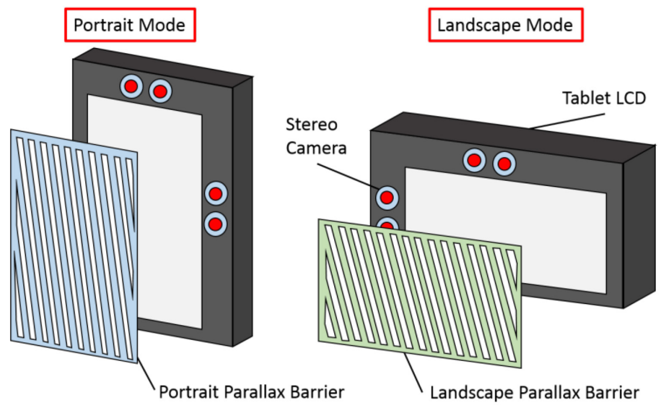

Figure 6. The configuration of the proposed system. Two kinds of barriers appearing on the tablet LCD can be realized by patterning the ITO electrodes on both sides of the LCD that configures the barrier. The parallax barrier can be turned on-off depending on portrait or landscape modes.

When the tablet LCD is placed landscape mode, the arrangement of the sub-pixels rotates by 90 degrees. But, the parameters of the parallax barrier should be equal for both portrait and landscape modes. Therefore, it is necessary to change the composition of the stereoscopic composite image displayed on the LCD in portrait or landscape modes. The composition of the stereoscopic composite image is shown in Fig. 7.

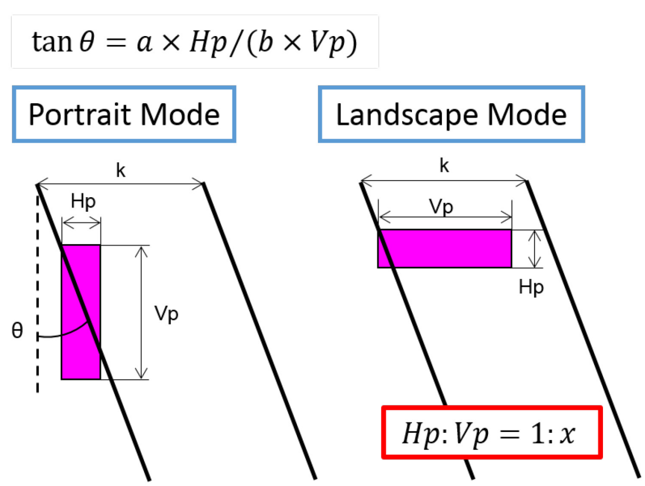

Figure 7. The composition of the stereoscopic composite image. The ratio of Hp and Vp depends on the LCD used. But, in most cases Hp : Vp = 1 : 3.

In Fig. 1, *PDp* is the number of the sub-pixels (pink dots) crossed by the line expressing the inclination of the barrier aperture in portrait mode. *PDp* is written as

$$PD_p = a + b - 1. \quad (4)$$

This expresses the minimum number of dots observed from the aperture of the parallax barrier at the same time.

N is the number of the sub-pixels for displaying one pair of left and right eye images in portrait mode. It is necessary that *N* and *PDp* satisfy the relationship of the Eq. (5).

$$N/2 \geq PD_p \quad (5)$$

Similarly, *PDl* is the number of the sub-pixels crossed by the line expressing the inclination of the barrier aperture in landscape mode. *P* is the number of the sub-pixels for displaying one pair of left and right images in landscape mode. *PDl* and *P* are given by

$$PD_l = a + b \times x \times x - 1, \quad (6)$$

$$P/2 \geq PD_l. \quad (7)$$

Then, *k* is the horizontal pitch of one set of stereoscopic images on LCD in portrait mode and *k* is written as

$$k = N \times Hp/b. \quad (8)$$

Similarly, *k* should be the barrier pitch in landscape mode and *k* is given by

$$k = P \times Hp/b \times x. \quad (9)$$

Therefore, Eq. (10) is defined by Eqs. (8) and (9).

$$N \times x = P \quad (10)$$

In the usual case, *x* is 3. It is necessary for the landscape mode to compose the dot number of one set of stereoscopic image 3 times as large as the portrait mode.

3. Experimental Results

3.1 Prototype System

We constructed the prototype system to verify the effectiveness of the proposed system. The prototype system consists of a 4K LCD and parallax barriers. The specification of the parallax barrier and the prototype system are shown in Fig. 8 and Table 1.

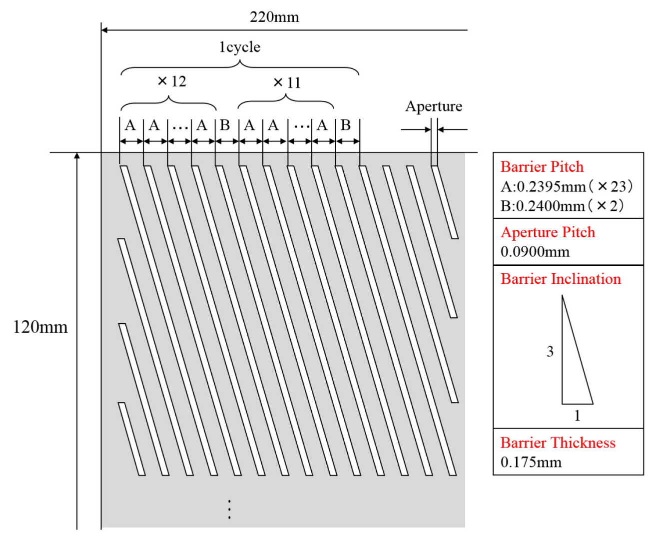

Figure 8. The specification of the parallax barrier used for the prototype system. The accuracy of the barrier pitch is limited. Therefore, two barrier pitches are cycled to achieve the ideal barrier pitch.

Table. 1 The Specifications of the Prototype System

Display resolution	3840H × 2160V
Sub-pixel pitch	0.03 mm
Optimum viewing distance	207.375 mm (for Tablet)
Distance between LCD and barrier	0.395 mm
Interocular distance	63 mm
Ideal barrier pitch	0.23954 mm

As a result of the calculation shown in Fig. 3, the parallax barrier pitch was 0.23954 mm but due to the accuracy of the barrier pitch it was impossible to achieve the ideal barrier pitch. Therefore, the ideal barrier pitch was achieved in one cycle by arranging two barrier pitches alternately [8] as shown in Fig. 8. The appearance of the prototype system is shown Fig. 9.

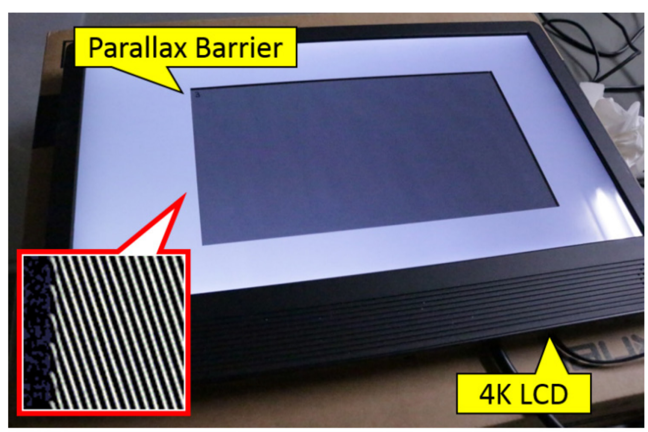

Figure 9. The appearance of the prototype system. The prototype system consists of a 4K LCD and parallax barriers.

3.2 Evaluation of Moire and Crosstalk Ratio

We evaluated moire and crosstalk ratio of the prototype system. Regarding the crosstalk, in order to equalize the eye tracking control in both portrait and landscape modes, it is assumed that each sub-pixel is controlled in portrait mode and three sub-pixels of RGB are controlled collectively in landscape mode. Theoretical crosstalk ratios of both portrait and landscape modes are shown in Figs. 10 and 11.

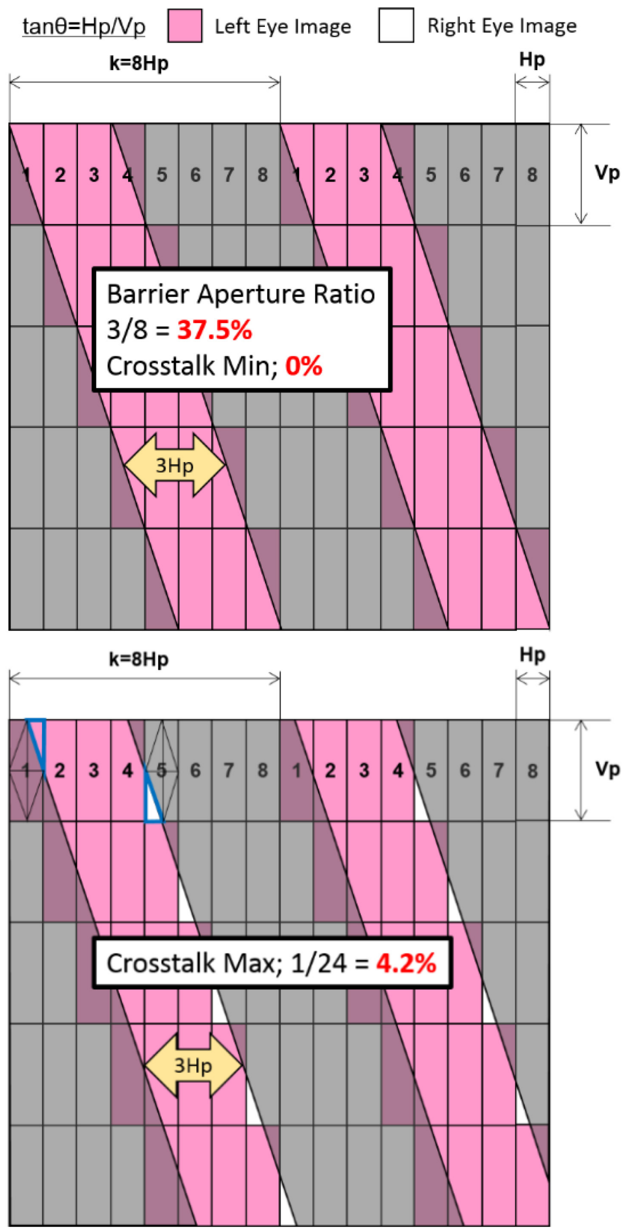

Figure 10. The minimum and maximum crosstalk ratio in portrait mode. The minimum crosstalk ratio is 0 %. The maximum crosstalk ratio is 4.2 % when the sub-pixel 1 and 5 have same size observed through the barrier aperture.

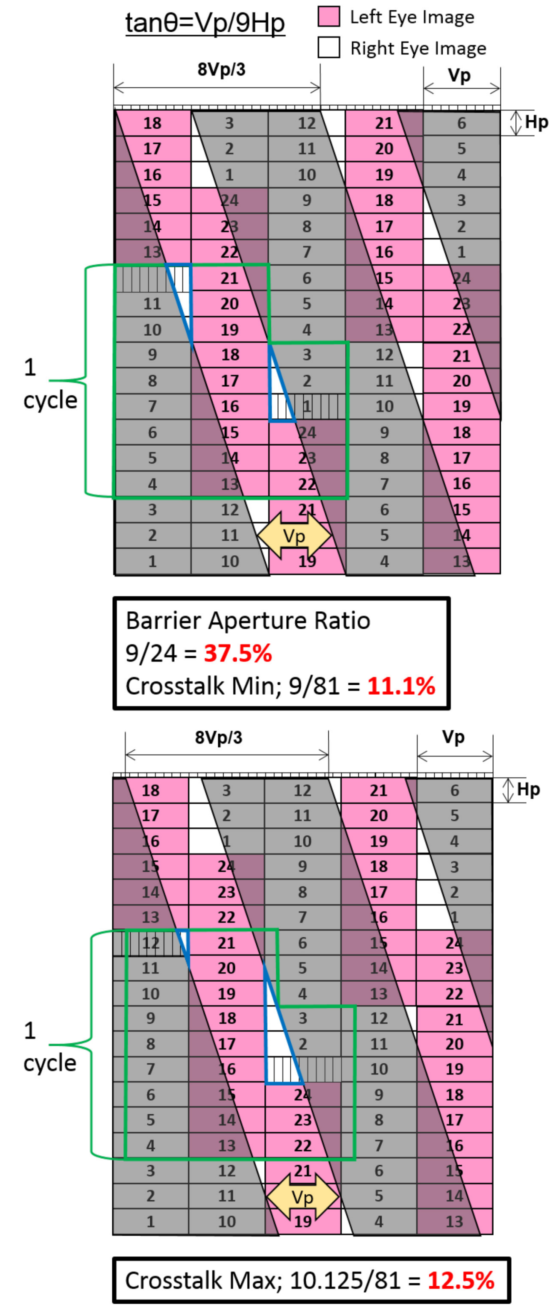

Figure 11. The minimum and maximum crosstalk ratio in landscape mode. The minimum crosstalk ratio is 11.1 % when the sub-pixels 1 to 3 and 10 to 12 have same size observed through the barrier aperture. The maximum crosstalk ratio is 12.5 % when the sub-pixels 1 to 3 and 13 to 15 have same size.

As shown in Fig. 10, the minimum crosstalk ratio in portrait mode is 0 %. When the sub-pixel 1 and 5 have same size observed through the barrier aperture, the crosstalk ratio in portrait mode is maximum, 4.2 %. Similarly, the minimum crosstalk ratio in landscape mode is 11.1 % when the sub-pixels 1 to 3 and 10 to 12 have same size observed through the barrier aperture. The maximum crosstalk ratio in landscape mode is 12.5 % when the sub-pixels 1 to 3 and 13 to 15 have same size. The black matrix exists in the outer peripheral part of the sub-pixels. Therefore, it is considered that the actual crosstalk ratio is less than half of the theoretical values.

We measured moire and crosstalk occurring in the prototype system. The prototype system and a luminometer were used for measurement. We used three special images that were white image for both eyes, black image for both eyes and composite image (white image for right eye and black image for left eye). These three images were displayed, and the light intensity at optimum viewing distance was measured at different horizontal position with the luminometer. The light intensity of the white image was graphed to confirm if moire is occurring. Further, we compared the light intensity of the composite image with the one of the white and black images. The crosstalk ratio was confirmed by calculating the ratio of the white and black images included in the composite image. The measurement result in portrait mode is shown in Fig. 12, landscape mode is shown in Fig. 13.

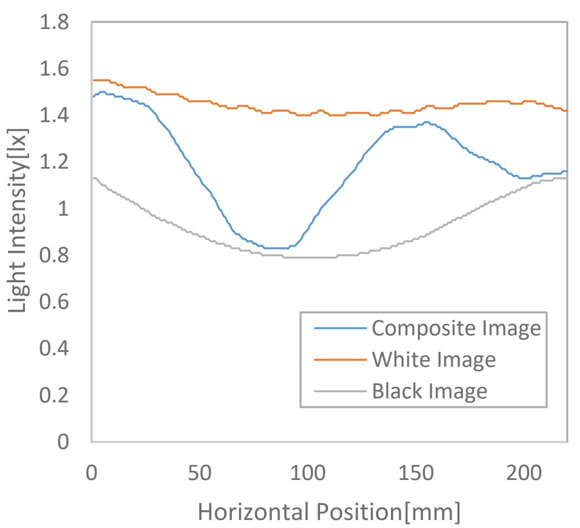

Figure 12. The light intensity measurement result in portrait mode.

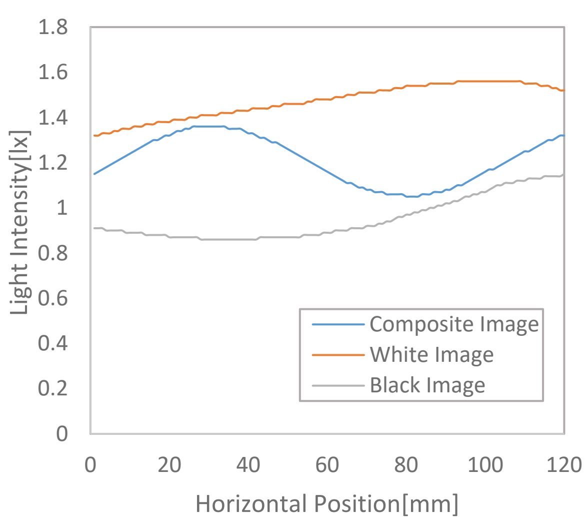

Figure 13. The light intensity measurement result in landscape mode.

In Fig. 12, it is confirmed that the light intensity of the white image was a sinusoidal waveform. The amplitude of this waveform was about $\pm$ 0.02 lx. This light intensity was 1.4 % of the average light intensity 1.45 lx. Therefore, it was confirmed that little moire occurred in portrait mode. Further, the minimum crosstalk ratio was 4.84 %, the maximum crosstalk ratio was 6.56 % in portrait mode.

Similarly, it was confirmed that the light intensity of the white image was distributed evenly as shown in Fig. 13. Therefore, moire did not occur in landscape mode. Further, the minimum crosstalk ratio was 11.11 %, the maximum crosstalk ratio was 14.00 % in landscape mode.

We compared the measured crosstalk ratio with the theoretical value. In portrait mode, the measured crosstalk ratio was higher than the theoretical value for both minimum and maximum. In landscape mode, the minimum crosstalk ratio was almost equal to the theoretical value, and the maximum crosstalk ratio was higher than the theoretical value. The reason why the crosstalk ratio rises is considered that there are errors of the parallax barrier apertures due to the limit of the accuracy because the parallax barriers were made of resin. Furthermore, the sagging of the liquid crystal panel is intense and the gap between the panel and the barrier are not uniform partially. As a result, the OVD of the prototype system contains an error partially.

4. Conclusion

We proposed a binocular stereoscopic display system that the optimum viewing distance was same in both portrait and landscape modes with no moire and low crosstalk ratio. Image quality does not deteriorate like a multi-view display. It is possible to enlarge the viewing area only by eye tracking and image processing. Therefore, complex control such as movable parallax barrier is not necessary. Apertures of the parallax barrier have inclination to remove moire and improve image quality. We found an equation that the barrier pitch was determined automatically by setting the optimum viewing distance. Further, we proposed the conditional equation about the arrangement of the sub-pixels to achieve the same viewing distance for both portrait and landscape modes.

We constructed the prototype system to verify the effectiveness of the proposed system. The prototype system consists of a 4K LCD and parallax barriers. In the prototype system, the 4K LCD's sub-pixel pitch is 0.03 mm, optimum viewing distance is 207.375 mm, the parallax barrier pitch is 0.23954 mm and its aperture pitch is 0.09 mm. The theoretical minimum crosstalk ratio is 0 % and the theoretical maximum crosstalk ratio is 4.2 % in portrait mode. The theoretical minimum crosstalk ratio is 11.1 % and the theoretical maximum crosstalk ratio is 12.5 % in landscape mode. However, it is considered that the actual crosstalk ratio is less than half of the theoretical values by existence of black matrix.

We evaluated moire and crosstalk ratio of the prototype system. As a result of the light intensity measurement, the minimum crosstalk ratio was 4.84 %, the maximum crosstalk ratio was 6.56 % and little moire occurred in portrait mode. The minimum crosstalk ratio was 11.11 %, the maximum crosstalk ratio was 14.00 % and moire did not occur in landscape mode. The crosstalk can be reduced easily by lowering the aperture ratio of the barrier.

As a future plan, we will construct an eye tracking system based on the prototype system that can follow the change of the distance between the observer and the LCD [9].

This technology can be applied to tablets and smart phones that are currently mainstream. Therefore, we consider that this technology is a very prospective in future expansion of glass-free 3D display market.

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