Perception of Flickers on High Resolution Time-Division Multiplexing Parallax Barrier

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ABSTRACT

We evaluate perception of flickers given by time-division multiplexing parallax barrier displays under different image resolutions. Perceived flicker can depend on the refresh rate and the resolution of display panels. It is confirmed that a high image resolution reduces perceived flickers even when the refresh rate is relatively low.

1 Introduction

Though autostereoscopic displays, which do not require the viewers to wear special goggles, have already been commercialized, they are not used widely because of the poor image resolution compared with stereoscopic displays using goggles. To overcome this problem, several autostereoscopic displays that attain full resolution of the display panel have been proposed so far.

One solution is to use a directional backlight composed of a light guide film and a pair of light sources [1-3], where autostereoscopy is realized by time-division of images on the display panel and the directionality of backlight. The drawback of this method is the fixed viewing zone due to the fixed directionality of backlight. To enlarge the viewing zone, directionality of backlight has to be controlled to follow the motion of the viewer, which requires thick optical systems [4-10]

An easier and more compact way to realize full resolution autostereoscopy is time-division multiplexing parallax barrier [11,12]. The pixels of a stereo pair are divided into two frames by resolution, where one frame shows half of each view and the other frame shows the other half by shifting the phase of the barrier pattern and the image pattern. Since this system requires a pair of LCD (Liquid Crystal Display) panels layered with a short interval, the system can be thin and compact.

In addition, head-tracking technology widens the viewing zone [13-16]. By monitoring the position of the viewer, the image or the barrier pattern is adjusted accordingly to move the viewing zone so that it always follows the position of the viewer and maintains correct stereoscopy.

To ensure a wider viewing zone, Zhang et al. have proposed time-division quadruplexing parallax barrier [17-20], where the same image is delivered to two of the four viewpoints, which avoids 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 is placed between the two panels so that the three primary colors may be evenly mixed.

When the color filters are aligned in the horizontal direction, which holds for most of the display panels commercially available, a horizontal diffuser causes mixture of the left-eye and the right-eye images, which destroys stereoscopy. To avoid this problem, Okada et al. have proposed a time-multiplexing 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. With this optical alignment, the barrier can be shifted by subpixel or sub-subpixel unit [21].

Though the theory on the viewing zone without crosstalk has been established [22,23], evaluation of perceived flickers due to time-division multiplexing has not been carried out systematically. The purpose of this paper is to evaluate perceived flickers under different time-divisions and image resolutions.

This paper is organized as follows. In Section 2, we review the mechanism of stereoscopy with time-division multiplexing parallax barrier. We evaluate perceived flickers under different image resolutions and refresh rates in Section 3. The paper is concluded in Section 4.

2 Background

Zhang et al. have proposed time-division quadruplexing parallax barrier, which holds a wider viewing zone for each viewpoint with less crosstalk [17-20]. As shown in Fig. 1, they proposed a 4-view system to show 2-view images. When a left-eye image "L" is shown at pixels A and B, and a right eye-image "R" is shown at pixels C and D, we obtain four viewpoints aligned as "LLRR" (Fig. 2). With this configuration, 3D images without crosstalk are observed when the left eye is positioned between points A and B, and the right eye is positioned between the points C and D.

Based on this system, shift of slits by sub-subpixel unit has been introduced as shown in Fig. 3, which realizes finer control of barrier slits to reduce crosstalk [21]. This fine shift is enabled when the slits are slanted and diffused in that direction, which also reduces moiré caused by the layered panels without destroying stereoscopy.

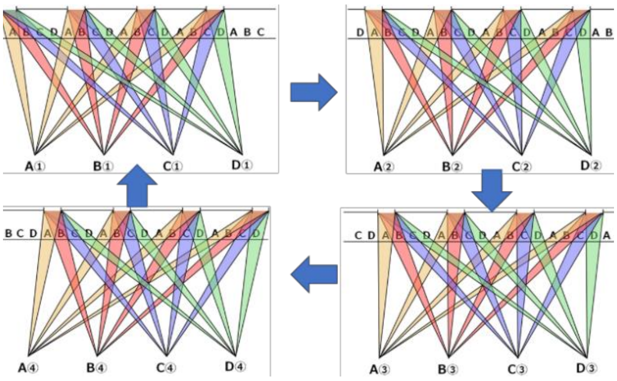

Fig. 1 Time-division quadruplexing parallax barrier. (Blue arrows indicate the order of time sequence.)

The number of time division is not limited to four. When the number of time-division is larger, the viewing zone without crosstalk is enlarged, while the presented image becomes darker and the flicker can stand out. The perceived flicker also depends on the refresh rate of the display panel. Though the flicker becomes less distinct as the refresh rate becomes higher, crosstalk caused by time-division increases due to the limit in the response time of liquid crystal when the refresh rate is excessively high.

In the following discussion, we measure perceived flickers under different conditions to find the acceptable range of flickers.

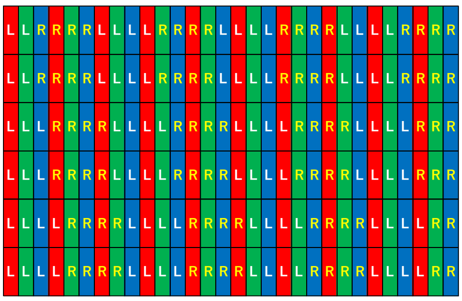

Fig. 2 Interleaved left-eye and right-eye images

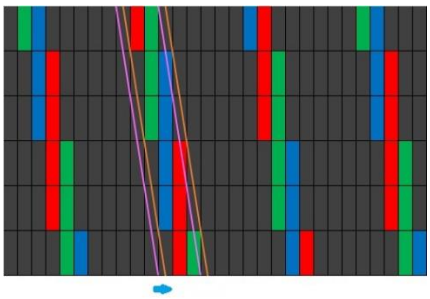

Fig. 3 Shift of slits by half-subpixel.

3 Experiments and Results

An important factor that may influence perception of flickers is the image resolution. As the pixel pitch of the image becomes finer, flickers are expected to be less noticeable. On the other hand, the merit of time-division multiplexing can disappear when the resolution of the presented image exceeds that of the eyes.

As a control experiment, we tested perception of flickers with a Full-HD (1920 x 1080 pixels) time-multiplexed parallax barrier display composed of two 24-inch LCD panels (AUO M240HW01-V8, pixel pitch 0.276 mm) placed with 6 mm interval. A 310 Watt LED backlight was used in this experiment. We used a light reduction film to keep the white luminance down to 43 cd/m2 so that it may be equal to that of the 4K display we use for comparison.

Eight subjects (seven males and one female in their twenties and thirties with corrected eyesight 6/9 or higher) were asked to compare the flicker of a stereoscopic image ("Bycicle1" from Middlebury datasets [24]) under different refresh rates and to answer whether he or she perceived any difference. The number of time-division was fixed to four. The distance between the display and the subject was 600 mm (stimulus area was 54 horizontal degrees and 29 vertical degrees). The experiment started from comparison between 120 Hz and 100 Hz and went down stepwise to 85 Hz and 60 Hz. The options of answers were no different (=), slightly different (> or <), and apparently different (>> or <<). No one reported any perceived flickers at 120 Hz. The results of the experiment are shown in Table 1.

Table 1 Comparison of flickers under different refresh rates with a Full HD time-multiplexed display.

Subject	120 Hz	100 Hz	85 Hz	60 Hz	
A		=	<	<<	
B		=	=	<<	
C		=	<	<<	
D		<	<	<<	
E		=	<	<<	
F		=	=	<<	
G		<	<<	<<	
H		=	<	<<	

As this table shows, most subjects perceived no difference of flickers between 120 Hz and 100 Hz, which means that 100 Hz or a higher refresh rate is practical for time-division quadruplexing parallax barrier. When the refresh rate was 85 Hz or lower, most subjects perceived slight or apparent difference of flickers.

Next we carried out the same experiment with a time-division multiplexing parallax barrier display with a higher image resolution. We used a 4K (3840 x 2160 pixels) display system composed of two 27-inch LCD panels (AUO M270QAN02.2, pixel pitch 0.155 mm) placed with 3 mm interval. A 580 Watt LED backlight was used in this experiment. The white luminance was 43 cd/m2. The picture of the 4K autostereoscopic display system is shown in Fig. 4.

Fig. 4 4K Autostereoscopic display used in the experiment.

The same eight subjects given the same IDs were asked to compare the flicker of the same stereoscopic image (“Bycicle1” from Middlebury datasets 25)) under different refresh rates. Also, two more subjects (male in their twenties with corrected eyesight 6/9 or higher) were added in this experiment. The number of time-division was fixed to four. The distance between the display and the subject was 600 mm this time also. (Stimulus area was 29 horizontal degrees and 16 vertical degrees, which was changed inevitably to use the same image on a display with a different pixel pitch. Since the flicker here comes only from high frequency stripes with no change of average luminance on the whole screen, this difference influences little on perception of flickers.)

The experiment started from comparison between 98 Hz and 82 Hz and went down to 60 Hz and 30 Hz. No one reported any perceived flickers at 98 Hz. The options of answers were the same as in the previous experiment. The results of the experiment are shown in Table 2.

As this table shows, most subjects perceived no difference of flickers between 98 Hz and 82 Hz, which means that 82 Hz refresh rate is still practical for time-division quadruplexing parallax barrier. This result indicates that the refresh rate can be decreased without increasing perceived flickers when the pixel pitch of the display is finer. When the refresh rate was as low as 60 Hz, most subjects perceived apparent difference of flickers.

When the pixel pitch becomes finer, image resolution loss due to the static barrier slits can be unnoticeable. In that case the merit of time-division multiplexing parallax barrier disappears. To confirm whether time-multiplexing is still meaningful for a 4K stereoscopy, we asked the same ten subjects to compare the image resolutions between the time multiplexed mode and the static barrier mode under different refresh rates. The presented image, the display, and the conditions used in the experiment were the same as in the previous experiment.

The results of the experiment are shown in Table 3. As this table shows, almost all subjects answered that time-multiplexed barrier offered higher image resolution than the static barrier. When the refresh rate was 30 Hz, however, more than half the subjects answered that the static barrier is better. When the refresh rate was as low as 30 Hz, the moving barrier was apparently perceivable and distinct, which annoyed the viewers.

The results of the experiments indicate that the critical fusion frequency in the temporal domain depends on the spatial frequency of slits. The flicker becomes less noticeable at lower refresh rates even when the frequency of slits in the spatial domain is not fine enough to be unperceivable, which suggests that temporal fusion has a cooperative mechanism with spatial fusion.

Table 2 Comparison of flickers under different refresh rates with a 4K time-multiplexed display.

Subject	98 Hz	82 Hz	60 Hz	30 Hz	
A		=	<<	<<	
B		<	<<	<<	
C		=	<<	<<	
D		=	<<	<<	
E		=	=	<<	
F		=	<<	<<	
G		>	=	<<	
H		=	<<	<<	
I		=	<<	<<	
J		=	<<	<<	

Table 3 Comparison of image resolution between time-multiplexed and static barrier. “T” means that the subject answered time-multiplexed mode is better, “S” means static mode is better, and “=” means the same.

Subject	98 Hz	82 Hz	60 Hz	30 Hz
A	T	T	T	=
B	T	T	T	=
C	T	T	T	S
D	T	T	T	S
E	T	T	T	S
F	=	=	T	S
G	T	T	T	S
H	T	T	T	S
I	T	T	T	=
J	T	T	T	S

4 Conclusion

In this paper, we have evaluated perception of flickers given by the time-division multiplexing parallax barrier displays under different image resolutions. The result of the experiment shows that a high image resolution reduces perceived flickers even when the refresh rate is relatively low, while the time-multiplexing parallax barrier still offers a higher resolution image than the static barrier when a 27 inch 4K display is used.

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