PROCEEDINGS OF THE INTERNATIONAL DISPLAY WORKSHOPS, VOL. 27, 2020

3D1-4L

(Late-News Paper)

Crosstalk Reduction for Parallax Barrier Stereoscopic Display Based on High-speed Viewpoint Tracking and Projection

Cheng Luo[1], Takashi Nomoto[1], Hao-Lun Peng[1], Yoshihiro Watanabe[1]

ra.t.aa@m.titech.ac.jp

[1] Tokyo Institute of Technology, 4259-G2-31, Nagatsuta, Midori-ku,
Yokohama, Kanagawa 226-8502, Japan

Keywords: parallax barrier, crosstalk, viewpoint tracking, high-speed display

ABSTRACT

We propose a parallax barrier stereoscopic display based on a high-speed viewpoint tracking and projection to reduce the crosstalk. We also employ a pixelwise image warping method to improve the allowable maximum speed of viewpoint movement without any crosstalk. The developed system can achieve the frame rate of 500 fps and latency of 7-8 ms. This performance reduced the crosstalk drastically even when the viewpoint movement speed was roughly 2 m/s.

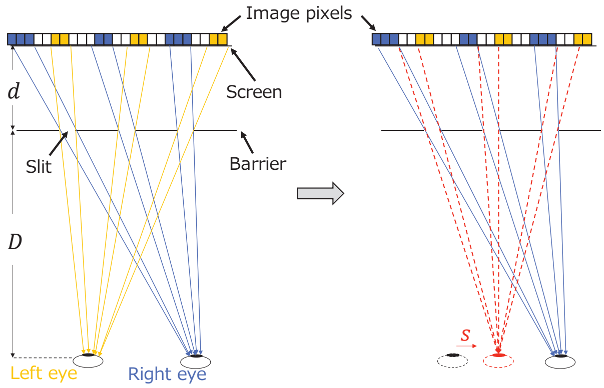

Fig. 1 Parallax barrier model

1 INTRODUCTION

The technology of glasses-free stereoscopic display has numerous applications and is employed in a variety of fields, such as entertainment and education. There are various known principles for such display; here, we focus on the stereoscopic method involving the use of a parallax barrier [1,2]. In a parallax barrier, different images are shown to each eye without the need for wearing three-dimensional (3D) glasses; this enables the humans capable of perceiving a 3D image.

However, crosstalk interference, which is the interference between each eye, is a common problem associated with 3D content visualization. The subject may see a combination of the image that is intended for one eye and a part of the image intended for the other eye, resulting in the total image appearing doubled or ghosting [3]. Crosstalk is also an essential factor for determining the performance of the glasses-free stereoscopic display. It should ideally be less than 5% [4,5]. However, it is difficult to meet such requirement when the observer moves his viewpoint to the display dynamically.

On the other hand, such a viewing style with dynamic viewpoint movement is expected to be important for the immersive experiences such as projection-type virtual reality displays, augmented game or any other similar applications [4,6,7].

It is possible to reduce the crosstalk in such dynamic situation by integrating a viewpoint-tracking system into the parallax barrier device [8,9]. The viewpoint-tracking system enables us to obtain the position information for the eyes in real-time and thus calculate the relative position of the eyes with respect to the display; the information obtained is used to warp the image presented on the display so that even a moving viewer can always see the correct image, without experiencing any crosstalk. However, this solution is still difficult to achieve 0% crosstalk especially when the viewpoint moves fast [10,11]. The first reason is the system latency from the viewpoint movement to the display. If the system latency becomes large, the crosstalk occurs easily even when the viewpoint moves slowly [12].

As the second reason, we also focus on the image warping method. In some related papers, a simple warping method is used [13,14]. In this method, when the correct image and the incorrect image are observed the same amount, replace the pixels of the left eye image and the right eye image. However, this method limits the allowable viewpoint movement speed for the small crosstalk.

To overcome such limitations, we propose a parallax barrier stereoscopic display achieving low system latency for the view-dependent image control. This system is realized by our high-speed tracking, high-speed projection and high-speed image generation. In addition, we also use a pixel-wise-based image warping method to improve the allowable maximum speed of viewpoint movement for the small crosstalk.

2 PROPOSAL

2.1 System Latency Analysis

This section describes the relationship between the allowable viewpoint movement speed and the system

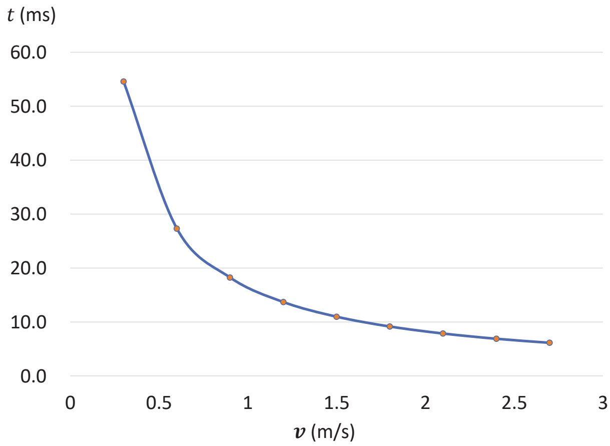

Fig. 2 Relation between viewpoint movement speed v and required system processing latency t

latency. Fig. 1 shows the configuration to derive the relationship. In this figure, the yellow and blue lines denote the lines of sight of the left eye and right eye, respectively. The human eye can see the image displayed on the screen through the slits on the parallax barrier. When the viewpoint starts to move to the right, and the left eye reaches the position of the red dotted line, the previous image for the right eye will be seen by the left eye from next moment. Therefore, crosstalk will occur. Based on this reason, the upper limit of the required system latency t for each frame can be determined from the moving distance s and the viewpoint movement speed v ($t < \frac{s}{v}$).

Fig. 2 shows the relationship between the viewpoint movement speed v and the required system latency t which is based on pixel-wise-based image warping method described in next section. The distance between viewpoint and barrier D is 800 mm. The distance between screen and barrier d is 30 mm. The width of the slit in the barrier is 1.2mm and the pixel width is about 0.3mm. In particular, if the slit width becomes small, allowable speed can become large [15]. However, it sacrifices the resolution and brightness. Therefore, we keep it large in this calculation as much as possible.

As shown in Fig. 2, crosstalk does not occur when the system latency t is below the blue line. It is evident that the faster the viewpoint moves; the shorter is the time required by the system processing latency. For example, in a recent research, a high-speed projector-camera system was developed [16]; the latency was 8 ms. If we were to use such a system and require the absence of crosstalk, the acceptable maximum speed of viewpoint movement can be 2 m/s.

2.2 Image Warping Method

Fig. 3 shows a comparison between employed pixel-

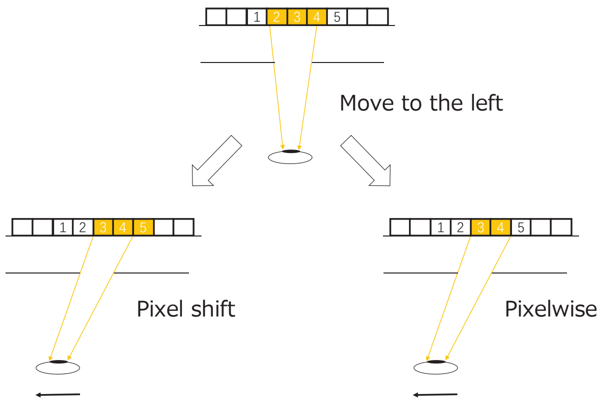

Fig. 3 Comparison of the image warping method

wise-based method and the simple method described in Section 1. When the viewer moves the viewpoint to the left, the simple method replaces pixel 1 with pixel 5. As an extra pixel, pixel 5 induces no problems when the viewpoint moves slowly; however, when the viewpoint moves fast enough, the extra pixel will make the crosstalk happen since the moving distance of viewpoint for each frame increases and the pixel 5 will be easily included in the visible range of the other eye.

In contrast, the pixel-wise-based method controls each pixel accurately, based on the eye position obtained by viewpoint-tracking and the relative position of the screen. Compared to the simple method, it should neither produce extra pixels nor miss pixels; thus, it can reduce the crosstalk by 10%-15%. Therefore, it is expected that pixelwise-based method will increase the allowable viewpoint speed to avoid the crosstalk. It should also handle viewpoint movement for in-depth direction and be less crosstalk than the simple method.

2.3 System Configuration

Our system consists of a high-speed projector-camera system controlled by a computer. Fig. 4 shows the developed system. In our system, we used a projector with 1024 × 768 pixels at 1000 fps and a camera with 720 × 520 pixels at 500 fps. We also used Xeon E5-2687W as

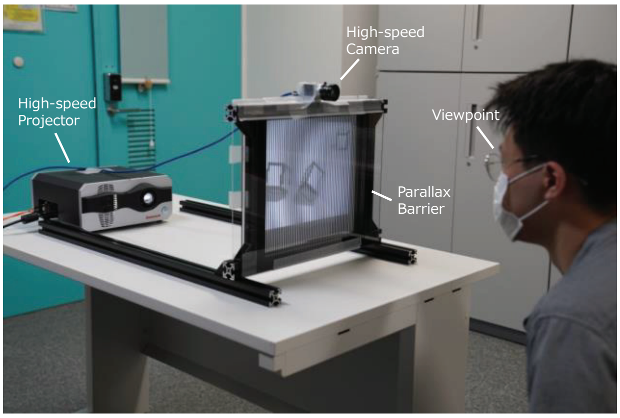

Fig. 4 Experimental environment

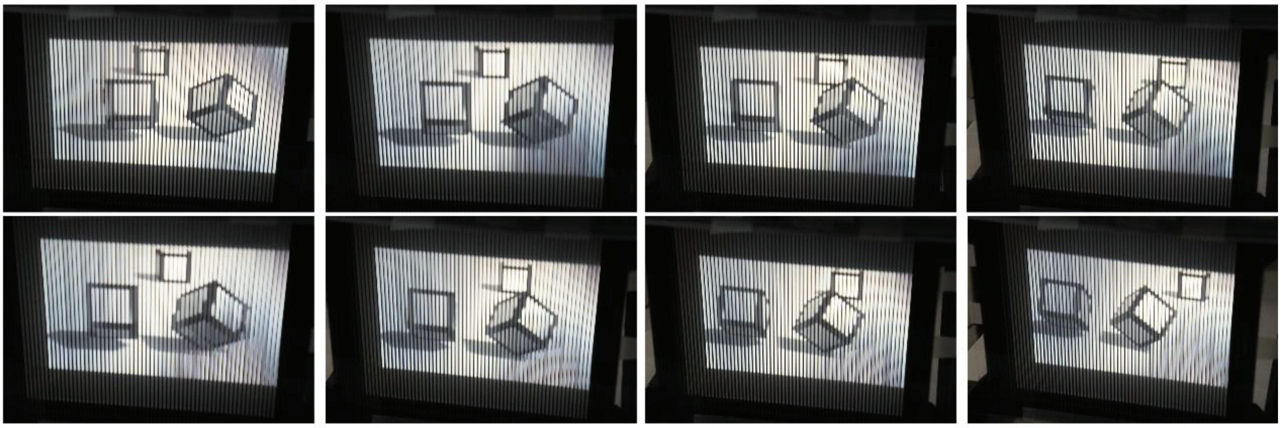

Fig. 6 Experimental result: Upper part comprises left-eye images and lower part comprises right-eye images

the CPU and QuadroREG M5000 GPU. The measured latency was 7–8 ms including 2 ms viewpoint tracking latency, 2 ms projection latency and 3–4 ms image generation latency. The parallax barrier was manufactured using acrylic print. To efficiently accomplish viewpoint-tracking with low latency, the marker was attached to the eye position. In the future, we intend to use high-speed facial landmark detection to replace the marker tracking method [17]. The distance between the human subject and the screen was 800 mm. The high-speed projector projects the image onto the rear screen from the opposite side. The projection size was 300 mm×225 mm.

The functioning of the system can be described as follows: First, the camera obtains the eye position by using high-speed viewpoint-tracking. Next, the coordinates of the eye position are transformed from the camera coordinate system to the world coordinate system; this enables real-time estimation of the relative position of the eyes with respect to the parallax barrier required to create two pixel-wise images, one for the left eye and the other for the right eye. Finally, we mix these two binocular images into one image and finally display it on the rear screen using the high-speed projector.

3 EXPERIMENTS

3.1 Simulations

Fig. 5 shows the simulation results to the crosstalk of the proposed method based on the system described in the Section 2.3 with the conventional system based on 60fps viewpoint tracking, 120fps display refresh rate and simple image warping method. The upper part comprises proposed method and the lower part comprises the conventional system. From the left, each column represents the observed images at the viewpoint movement speed of 1.0 m/s, 1.5 m/s and 2.0 m/s. Consequently, for the conventional method, when the viewpoint movement speed was approximately 1 m/s, the crosstalk was already faintly visible and the crosstalk was approximately 5%. When the moving speed increased to 1.5 m/s, the crosstalk was 15% and very clearly visible. The binocular stereo was also seriously affected.

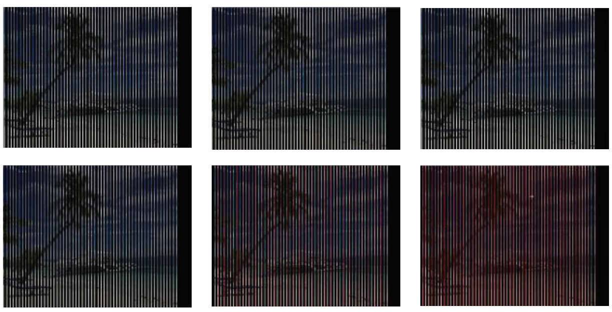

Fig. 5 Simulation results

Further increase of the viewpoint moving speed to 2 m/s revealed the crosstalk that occurred in more than half of the entire image, with a complete collapse of the stereo vision. In contrast, in our proposed method, we did not observe any crosstalk for viewpoint movement speeds of 1 m/s, 1.5 m/s, and 2 m/s. The crosstalk was always 0%.

3.2 Experiments Using the Developed System

Fig. 6 shows the results using the developed system. We created the stereoscopic image in which the viewer could see three virtual cubes standing on the platform. The two front cubes were placed side by side at a certain distance in the horizontal direction. Another cube was located directly behind the right front cube. In Fig. 6, the viewpoint movement speed was about 2.0 m/s. The time interval between two adjacent images in horizontal direction was about 20ms. The viewer was moving to the right and the four columns represented the viewer's different places.

The cube in the back was always further to the right in the right-eye image than in the left-eye image. In addition, the left side of the front cube of left-eye image was always larger than the part in the right-eye image. We didn't see any combination of left-eye and right-eye image. Also, there wasn't any doubled or ghosting image appeared in our experiment. Therefore, the stereo vision was achieved without any crosstalk although the viewpoint moved very fast.

4 CONCLUSIONS

We proposed a parallax barrier stereoscopic display based on high-speed viewpoint-tracking and high-speed projection; a pixel-wise-based image warping method to improve the allowable maximum speed of viewpoint movement was also employed. The proposed system can reduce the crosstalk to 0% even when the viewer moving speed reaches approximately 2 m/s. The proposed solution can significantly improve system performance by providing dynamic, immersive experiences such as projection-type virtual reality displays, high-speed sports motion-sensing games, and similar applications.

In the future, display resolution, which is also a significant drawback in the case of conventional systems, must be thoroughly investigated. We also think that it is important to develop a large-scale display for the applications mentioned above. The findings of the present study are expected to improve the performance of glasses-free stereoscopic displays.

REFERENCES

[1] K. Mashitani, G. Hamagishi, M. Higashino, T. Ando, and S. Takemoto, "Step barrier system multi-view glassless 3-D display," SPIE, Stereoscopic Displays and Virtual Reality Systems XI, pp. 265-272 (2004).

[2] J. Geng, "Three-dimensional display technologies," OSA,Advances in Optics and Photonics V, pp. 456-535 (2013).

[3] Woods, A. J, "Crosstalk in stereoscopic displays: a review," Journal of Electronic Imaging, 21(4), 040902 (2012).

[4] Seuntiens, P. J. H., Meesters, L. M. J. and IJsselsteijn, W. A., "Perceptual attributes of crosstalk in 3D images," Displays, vol. 26, no. 4-5, pp. 177-183 (2005).

[5] Xing. L., Ebrahimi, T., and Perkis. A, "Subjective evaluation of stereoscopic crosstalk perception," In Visual Communications and Image Processing, Vol. 7744, p. 77441V. International Society for Optics and Photonics (2010).

[6] Regan, M. J., Miller, G. S., Rubin, S. M., and Kogelnik, C, "A real-time low-latency hardware light-field renderer," In Proceedings of the 26th annual conference on Computer graphics and interactive techniques, pp. 287-290 (1999).

[7] Greuter, Stefan and David J. Roberts, "Controlling viewpoint from markerless head tracking in an immersive ball game using a commodity depth-based camera," Journal of Simulation, 9(1), pp. 54-63 (2015).

[8] Woodgate, G. J., Ezra, D., Harrold, J., Holliman, N. S., Jones, G. R., and Moseley, R. R, "Autostereoscopic 3D display systems with observer tracking," Signal Processing Image Communication, pp. 131-145 (1998).

[9] Kim, S. K., Yoon, K. H., Yoon, S. K., and Ju, H. "Parallax barrier engineering for image quality improvement in an stereoscopic 3D display," Optics express, 23(10), pp. 13230-13244 (2015).

[10] Peterka, Thomas, and Daniel Sandin, "Dynamic parallax barrier autosteroscopic display system and method," U.S. Patent No. 8,248,462 (2012).

[11] Pund, Marvin L, "Stereoscopic display." U.S. Patent No. 4,649,425, (1987).

[12] Lv, G. J., Zhao, B. C., Wu, F., Zhao, W. X., Yang, Y. Z., and Wang, Q. H. "Stereoscopic 3D display with high brightness and low crosstalk," Applied optics, 56(10), pp. 2792-2795 (2017).

[13] Matsumoto, T., Kusafuka, K., Hamagishi, G., and Takahashi, H, "Glassless 3D Head Up Display using Parallax Barrier with Eye Tracking Image Processing," In SID Symposium Digest of Technical Papers Vol. 49, No. 1, pp. 1511-1514 (2018).

[14] Minami, Y., Hamagishi, G., Yoshimoto, K., and Takahashi, H, "Portrait and landscape mode convertible stereoscopic display using parallax barrier," Electronic Imaging, pp. 106-112 (2017).

[15] Q. H. Wang, D. D. Pan, D. H. Li, X. F. Li, and R. L. Zhao, "Stereoscopic image crosstalk factor for auto-stereoscopic display based on parallax barrier," J. Optoelectron. Laser 21, pp. 1058–1061 (2010).

[16] Y.Watanabe, T. Kato and M. Ishikawa. "Extended Dot Cluster Marker for High-speed 3D Tracking in Dynamic Projection Mapping," IEEE International Symposium on Mixed and Augmented Reality, pp. 52-61 (2017).

[17] Takashi Nomoto, Ryo Koishihara, and Yoshihiro Watanabe, "Realistic Dynamic Projection Mapping Using Real-Time Ray Tracing," ACM SIGGRAPH 2020, Emerging Technologies, (2020).