One-Dimensional Viewpoint Generation for Approximated Super Multi-View Head-Mounted Display

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Keywords: Head-mounted display, Approximated super multi-view display, Vergence-accommodation conflict, VR/AR

ABSTRACT

We previously proposed the approximated super multi-view head-mounted display to mitigate the vergence-accommodation conflict. The accommodation-invariant region was produced by the two-dimensional synchronous shifts of the parallax images and the viewpoints. This study explores the possibility of using one-dimensional shifts and shows the effects for the accommodation-invariant feature.

1 Introduction

Head-mounted displays (HMDs) are important interface devices for virtual reality (VR) and augmented reality (AR). Recently, their resolution and viewing angle have been improved. However, the vergence-accommodation conflict (VAC) is a significant issue in conventional HMDs because it causes visual fatigue [1] which prevents the usage for long time and young people. Several HMD techniques have been developed to solve the VAC problem, such as, the light field technique [2], the varifocal technique [3], and the accommodation-invariant technique [4]. We have also proposed the HMD based on the super multi-view (SMV) technique [5] and the HMD based on the approximated SMV technique [6].

The approximated SMV technique mitigates the VAC by generating the accommodation-invariant (AI) region. Because blur of 3D images displayed in the AI region is virtually invariant, eyes could move their focus to the depth position where perceived by the vergence. The AI region is generated by shifting the parallax images two-dimensionally in synchronization with the viewpoint generation. The approximated SMV is a low-cost solution because a high-speed display is not required to show different parallax images and a mechanical system was used for the two-dimensional shifts of the parallax images in our previous system.

In this study, we examine the possibility of using one-dimensional synchronous shifts for the viewpoint generation of the approximated SMV HMD. The use of the one-dimensional shifts can significantly simplify the mechanical system used for the movements of the parallax images.

2 Approximated SMV technique

First, the approximated SMV technique is briefly explained. Figure 1 illustrates the approximated SMV technique. The parallax image is shifted differently corresponding to the positions of the viewpoints such that the plural blur distributions are crossed at the center of the depth range (CDR). With this technique, the blur width for each viewpoint is not the smallest when the eyes focus at the CDR. When the eyes focus at a position other than the CDR, the plural blur distributions are separated. Figure 2 illustrates the blur formation of the approximated SMV technique. When eyes focus on the screen, the blur width for each viewpoint is minimum, and the blur distributions are separated. As the focus position approaches the CDR, the blur width increases and the separation decreases. When the eye focus is on the CDR, the blur still increases and the separation becomes zero. When the eye focus moves farther from the CDR, the blur further increases and the separation begins to increase. It was revealed that AI region is generated around the position of the CDR. [6]

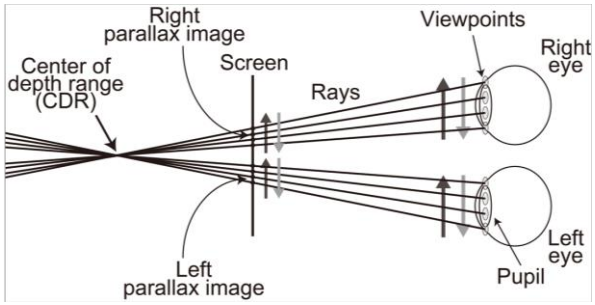

Fig. 1 Approximated SMV HMD technique

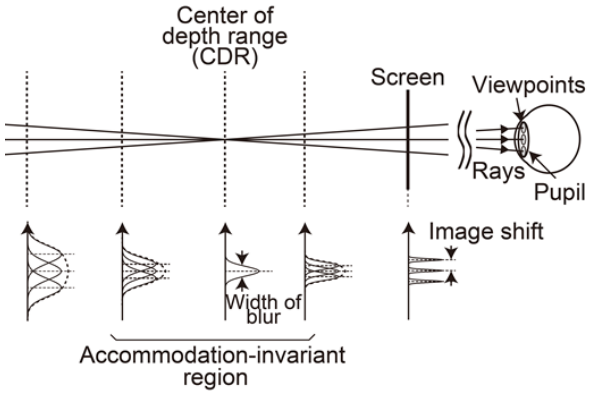

Fig. 2 Blur formation of the approximated SMV technique.

3 Theory

In this study, the viewpoints and the parallax images are synchronously shifted one-dimensionally. Figure 3 illustrates the generations of the viewpoints examined in this study. In Fig. 3(a), the viewpoints are generated in the horizontal direction. Each viewpoint has a vertically enlarged light distribution to increase the eye box in the vertical direction. In Fig. 3(b), the viewpoints are generated in the vertical direction and each viewpoint has a horizontally enlarged light distribution.

For the horizontal viewpoint generation, the AI feature will be obtained in the horizontal direction and the image blur occurs in the vertical direction similar to the conventional two-view HMDs. For the vertical viewpoint generation, the AI feature will be obtained in the vertical direction and the image blur similar to the two-view HMD will occur in the horizontal direction. In this study, the combined effects of the AI feature in one direction and the image blur in the perpendicular direction will be examined experimentally.

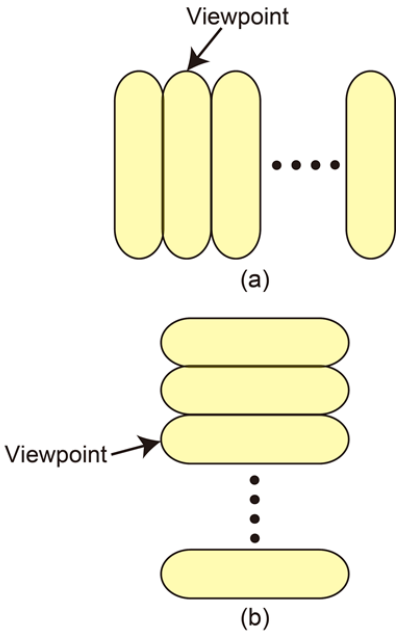

Fig. 3 One-dimensional formations of viewpoints in (a) horizontal direction, and (b) vertical direction

4 Experiments

The approximated SMV HMD system [6] was used to evaluate effects of the proposed technique. Figure 4 shows the photograph of the experimental system. We used linear-type stepping motor to shift the parallax images by vibrating the LCD panel. LED array is imaged by Lens 1 and Lens 2 to generate viewpoints. An Arduino microcontroller was used to synchronize the two LED arrays and the stepping motor. Previously, the system generated four viewpoints horizontally and three viewpoints vertically by using the time multiplexing technique. In this study, the vertically and horizontally enlarged viewpoints were generated by making four LEDs aligned in the vertical and horizontal directions emit light at the same time. The interval between the enlarged viewpoints was 2.0 mm and the number of viewpoints was four for both the horizontal and vertical viewpoint generations.

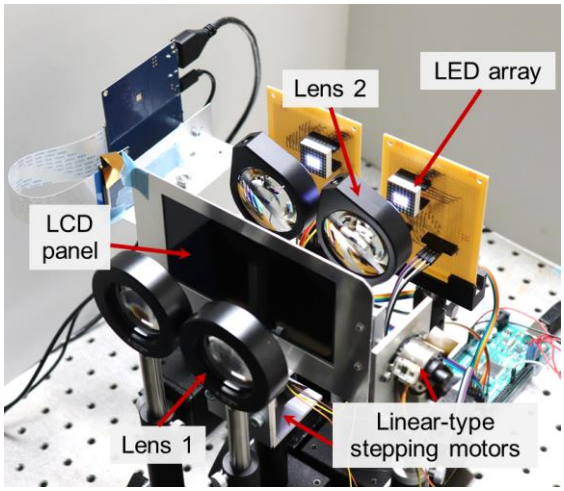

Fig. 4 Experimental system

The AI feature of the proposed technique was evaluated by capturing the retinal images at different focus positions. A video camera was used to capture the retinal images. The lens with an entrance pupil diameter of 5 mm (average human pupil diameter) and a focal length of 16 mm (close to human eye focal length) was used. The position of the virtual image was at 600 mm and the position of the CDR was at 800 mm. The focus of the video camera was set at length of 600, 700, 800, 900, 1,000, and 1,100 mm from the viewpoints.

Figure 5 shows the captured retinal images for the horizontal and vertical viewpoint generations. For comparisons, the retinal images for the conventional two-view display and the two-dimensional viewpoint generation were also captured. For the conventional two-view display, the sharpest retinal image was obtained at 600 mm and the blur increases when the length increases. For the two-dimensional viewpoint generation, the blurs of the retinal images were almost equivalent when the camera focus was changed from 700 to 1,100 mm. For the horizontal and vertical viewpoint generations, the vertical and horizontal blurs are larger than the two-dimensional viewpoint generation, respectively. The blurs of the retinal images were almost equivalent when the camera focus was changed from 700 to 1,000 mm. The blur was noticeable when the camera focused at 1,100 mm.

5 Summary

This study presented the evaluation of the AI feature of approximated SMV HMD when the viewpoints and the

parallax images were shifted one-dimensionally. The AI region was also generated for the one-dimensional shifts. However, the range of the AI region for the one-dimensional shifts was a little narrower than that generated by the two-dimensional shifts.

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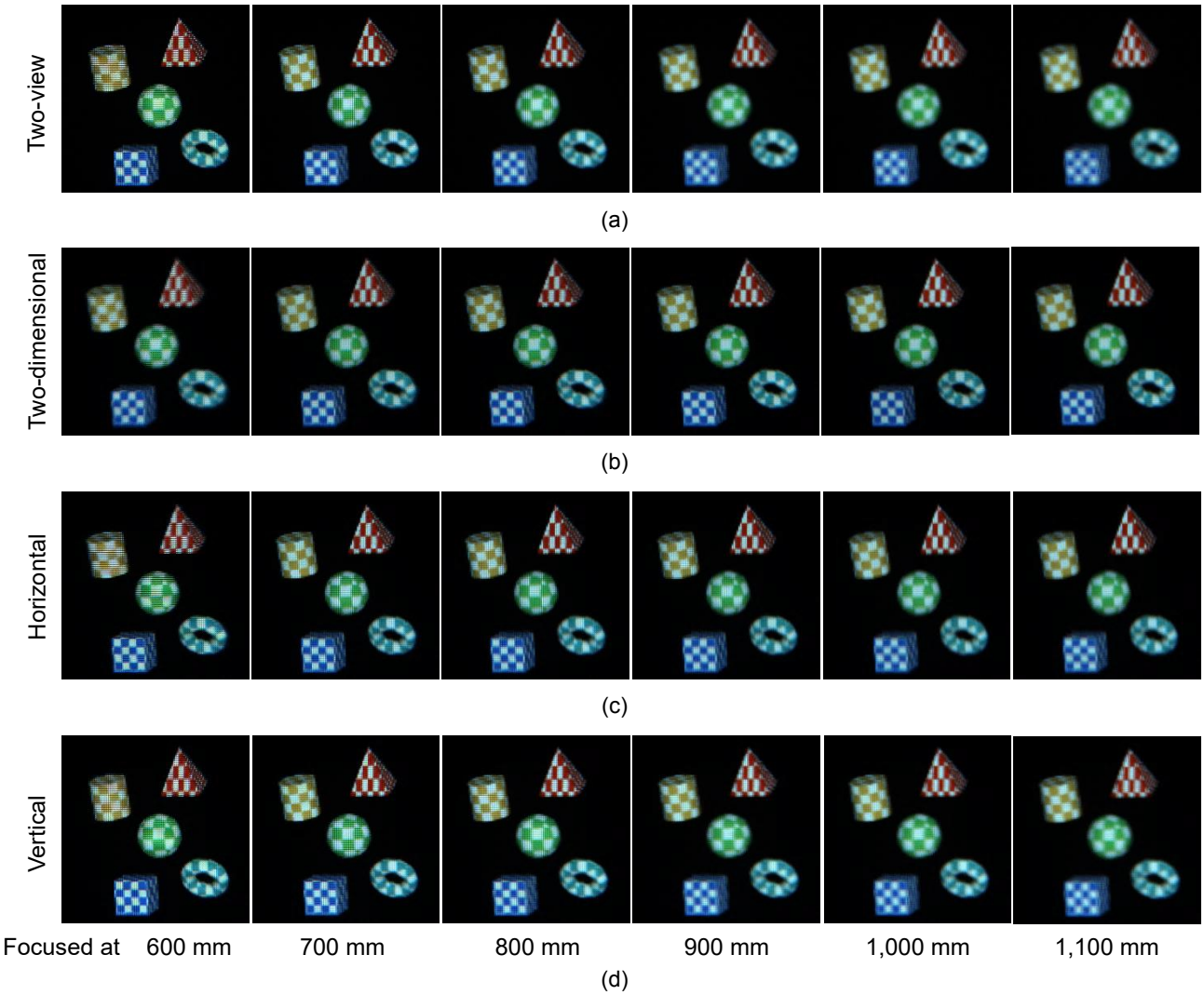

Fig. 5 Captured retinal images: (a) conventional two-view display, (b) two-dimensional viewpoint generation, (c) horizontal viewpoint generation, and (d) vertical viewpoint generation.