Resolution Evaluation of a Simplified Super Multi-View Head-Mounted Display

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ABSTRACT

We have proposed the simplification technique of the super multi-view head-mounted display to reduce the system and computation costs. This study provided a resolution evaluation of the prototype system. The resolution was higher than 14.3 pixels/degree when the eyes' focus was at 380–530 mm and 700–1,200 mm.

1 INTRODUCTION

The vergence–accommodation conflict (VAC) is a significant issue in head-mounted displays (HMDs) because it is a source of visual fatigue and discomfort [1]. Several HMD techniques have been developed [2–6] to address this problem, such as light field technique [2], holographic technique [3], multi-focal-plane technique [4], varifocal technique [5], and accommodation-invariant technique [6]. Previously, we revealed that the VAC can be mitigated using an HMD that has been developed based on a super multi-view (SMV) technique [7]; however, such an SMV HMD generates multiple viewpoints two-dimensionally with an interval smaller than the human pupil diameter and should display different parallax images to the corresponding viewpoints. We have recently proposed an SMV HMD simplification technique to reduce the system and computation costs and have verified its effectiveness [8]. However, in this simplified technique, an image blur occurs because of image shift. Therefore, the evaluation of the image resolution is important. In this study, we evaluated the resolution of the prototype system of the simplified SMV HMD.

2 SIMPLIFID SMV HMD TECHNIQUE

Before explaining the experiments of the resolution evaluation, the SMV HMD simplification technique is briefly explained.

Figures 1(a) and 1(b) illustrate the three-dimensional (3D) image generations for the conventional SMV HMD and the proposed simplified SMV HMD, respectively. In the SMV HMD, as shown in Fig. 1(a), the difference between the parallax images is very small because of the limited number of viewpoints and their small pitch (less than 5 mm). Thus, as depicted in Fig. 1(b), an identical parallax image is spatially shifted by pitch Δs corresponding to the positions of the viewpoints for approximating multiple parallax images for each eye. The

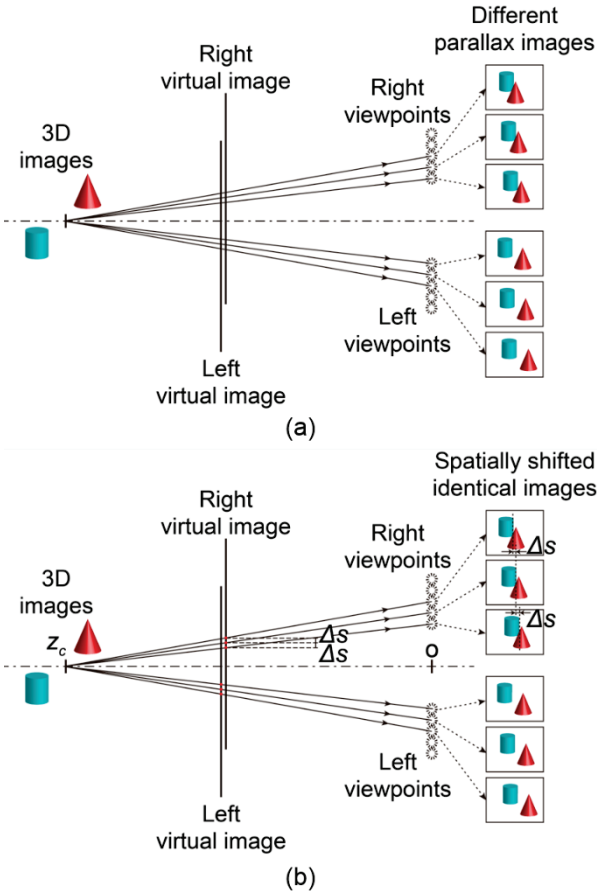

Fig. 1 Three-dimensional image generation schemes for (a) the conventional SMV HMD and (b) the proposed simplified SMV HMD

center of the depth range of the 3D images (z_c) can be varied by changing the shift pitch of the virtual images, Δs.

3 EXPERIMENTS AND RESULTS

Figure 2 shows an experimental system for the simplified SMV HMD, comprising a liquid-crystal display (LCD) panel, a pair of LED arrays, a pair of imaging optics, and two linear-type stepping motors. The LCD panel with a resolution of 2,560 × 1,440 pixels, a screen size of 6.0 in., and a framerate of 50 Hz displayed the left and right parallax images. The left and right virtual

images were produced at 600 mm from the viewpoints, and their field of view was 48.5° × 48.5°. Two linear-type stepping motors having a stepping pitch of 33 μm vibrated the LCD panel to shift the parallax images two-dimensionally with horizontal and vertical vibration frequencies of 60 and 40 Hz, respectively. The LED arrays were used to produce the two-dimensionally aligned viewpoints for each eye using the time multiplexing manner. For each eye, the number of generated viewpoints was 4 × 3 with an interval of 2.0 mm. The LCD panel was vibrated in synchronization with the viewpoint generation. Figure 3 shows the photograph of the experimental system.

We evaluated the resolution of the simplified SMV HMD system. The line patterns were displayed, and a video camera having an entrance pupil diameter of 5 mm (average human pupil diameter) was used to capture the retinal images. First, we placed the center of the depth range at z_c = 800 mm by setting Δs = +0.5 mm; the corresponding shift pitch of the LCD panel was +33 μm. Figure 4 shows the captured retinal images. The line patterns located at the left lowest position and having the highest spatial frequency of 2 pixels/cycle (14.3 pixels/degree) were resolved when the focus of the camera was moved from 700 to 1,200 mm. Then, the center of the depth range was moved to z_c = 480 mm by setting Δs = –0.5 mm, where the corresponding shift pitch of the LCD panel was –33 μm. The captured retinal images are also shown in Fig. 4. The line patterns were resolved when the camera focus was moved from 380 to 530 mm. All retinal images shown in Fig. 4 had approximately equivalent blur. Thus, the simplified SMV HMD technique enlarged the depth-of-field (DOF) of eyes.

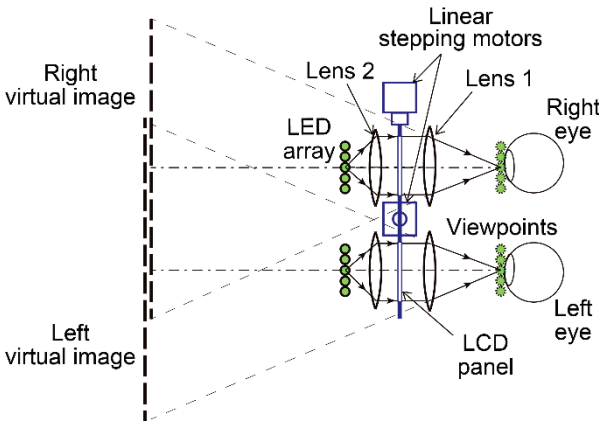

Fig. 2 Schematic of the experimental system for the simplified SMV HMD

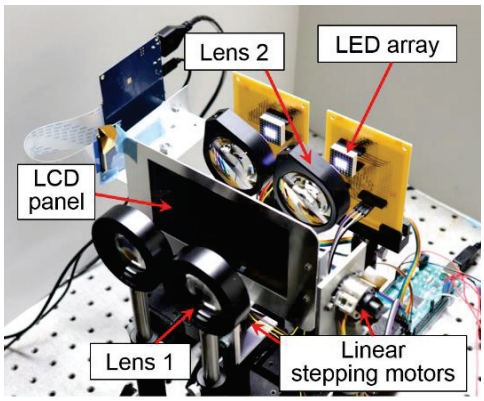

Fig. 3 Photograph of the experimental system

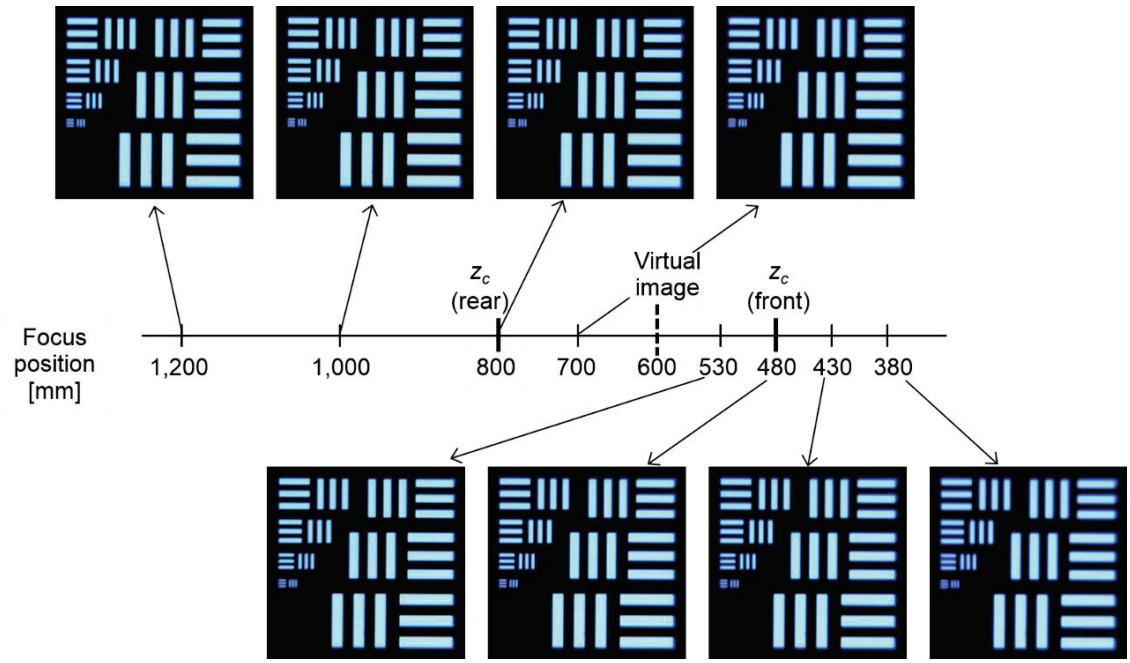

Fig. 4 Results of resolution evaluation for the retinal images

4 DISCUSSION

The resolution evaluation shown in Fig. 4 proved that line patterns having a spatial frequency of 14.3 pixels/degree were resolved in depth ranges of 380–530 and 700–1,200 mm. Therefore, the simplified SMV HMD can display high-resolution 3D images in wide depth ranges.

Furthermore, the simplified SMV technique can extend the DOF of eyes and produce an accommodation-invariant feature. A recent study [6] demonstrated that a display exhibiting the accommodation-invariant feature can mitigate the VAC because the eyes can focus at the depth position of the 3D images perceived by the vergence.

Previously proposed techniques [2-7] including the SMV HMD [7] and accommodation-invariant HMD [6] require a complicated optical system, comprising high framerate SLMs, adaptive optics, and heavy image processing. Our simplified SMV HMD can be realized at low cost in a manner that two LED arrays and two small-stroke actuators (as small as approximately 100 μm) should be added to the conventional HMDs. With a requirement of only two parallax images, the simplified SMV technique has good compatibility with the conventional HMD system to ensure the utilization of the conventional two-view software and content.

5 CONCLUSION

This study presented the evaluation of image resolution produced by the SMV HMD simplification technique. The experimental system of the simplified SMV HMD was built for the resolution evaluation. The resolution was higher than 14.3 pixels/degree when the focus of eyes was at 380–530 mm and 700–1,200 mm.

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