Occlusion-capable Head-mounted Display

Kwangsoo Kim[a], Daerak Heo[b] and Joonku Hahn[c]
School of Electronics Engineering, Kyungpook National University, 80 Daehak-ro, Buk-gu, Daegu, 41566, South Korea

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Abstract: Head-mounted display (HMD) is regarded as one of the most popular device for providing three-dimensional (3D) contents in virtual reality (VR) or augmented reality (AR). Technologies on HMD have been deeply studied because it has a potential to make the people enjoy 3D contents. In this paper, we propose the application for digital micro-mirror device (DMD) as both the filter and the combiner. DMD has a benefit that it generates many images in short time. The real background image and the image generated by the organic light-emitting diode (OLED) are watched through the DMD, and these two images are combined as one image to generate AR.

1 INTRODUCTION

Head-mounted display (HMD) is one of the most prospective systems to display 3D contents (Inoguchi et al., 1995, Ando et al., 1998, Cakmakci et al., 2004, Rolland et al., 2005, Hong et al., 2011, and Arens-Arad et al., 2016). Since HMD is the best device for representing VR and AR, many research groups have developed these technologies (Earnshaw, 1993, Drascic et al., 1996, Ando et al., 1999, Zhou et al., 2008). Occlusion capability and accommodation effect are very important factors in enhancing the reality of 3D contents in HMD. In consideration of accommodation effect, the holographic technique is ideal to provide 3D contents within diffraction limit (Moon et al., 2014 and Gao et al., 2017). However, the narrow viewing window owing to the space-bandwidth of the spatial light modulator (SLM) is a practical problem (Lohmann et al., 1996). In addition, it brings about the sacrifice of the quality of 3D contents resulting from annoying speckle noise. The occlusion capability is necessary to block the appearance of some background part where the 3D contents appear (Kiyokawa et al., 2004 and Wilson et al., 2017). In occlusion-capable HMDs, two components are required, one is an SLM for selective pass of the environmental scene and the other is a combiner to overlay the selectively filtered environmental scene and the virtual contents. Some multi-layered displays meet the purpose of occlusion capability (Lim et al., 2017). Triple-layered LC can function as displaying near and far contents and selectively filtering one of them (Kim et al., 2017).

In this paper, we designed a novel HMD using a DMD as both filter and combiner. In IMID 2018, we already presented its concept (Kim et al., 2018). The DMD has a benefit that it can generate many images in a short time (Cossairt et al., 2004, Kim et al., 2016, and Lim et al., 2017). In addition, the DMD combines the background image and 3D contents reproduced on the OLED, allowing observers to watch the image with low distortion.

2 OPTICAL DESIGN OF OCCLUSION-CAPABLE HEAD MOUNTED DISPLAY

This system consists of two parts, OLED part and background part. Figure 1 shows the optical design of the system. In Fig. 1(a), the optical path of the whole system is shown. The real scene is seen through the HMD as a background and the 3D images is displayed by the OLED. These two images are combined by the DMD selectively by choosing the state of the DMD

[a] https://orcid.org/0000-0002-9786-6921
[b] https://orcid.org/0000-0002-0446-4991
[c] https://orcid.org/0000-0002-5038-7253

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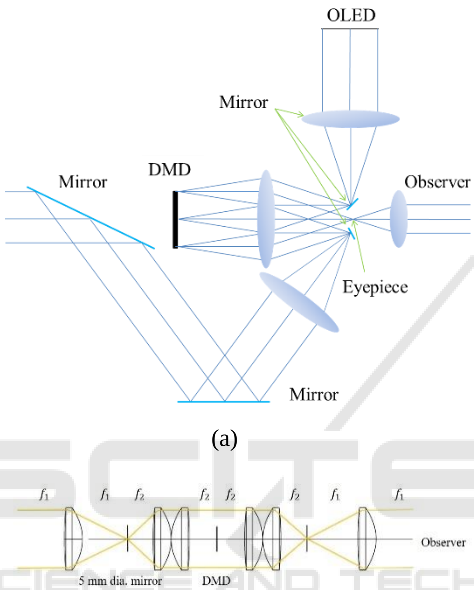
between on sate and off state. Therefore, the observer watches the combined image through the DMD. Figure 1(b) shows 4f system including the DMD. The images from the outside and the image from the OLED are projected on the DMD through the first 4f system, and each image are combined and relayed to the observer by the second 4f system.

When we design the system, we use small size optical elements in order to build a compact HMD. The OLED is useful since backlight is not required for displaying 3D contents.



(a)

(b)

Figure 1: Occlusion-capable head-mounted display; (a) system layout, (b) 4*f* system including the DMD.

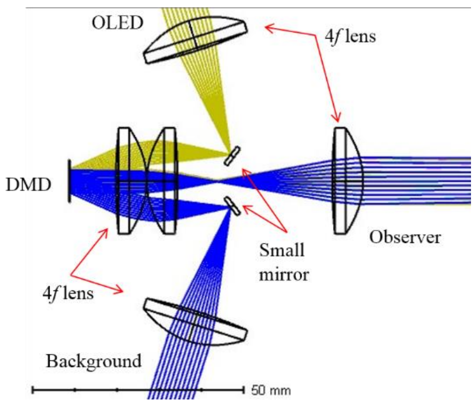


Figure 2: Optical layout using Zemax.

Figure 2 shows the optical layout. This was designed with a Zemax. The distance from the lens to the observer that is the size of the main optical system of the HMD is about $100mm \times 100mm$. Since the optical system is designed in a limited space, we use an aspheric lens with large F/#. In addition, it is difficult to design a small lens with a large refraction angle at a short distance, so that two aspheric lenses are placed in serial to shorten the focal length.

3 EXPERIMENT

This system uses both the OLED and the DMD. Table 1 and 2 show the specification of them respectively. The OLED has an active area with 38.1 $mm \times$ 30.5 mm and its resolution is $1{,}280 \times 1{,}024$ with the pixel pitch 29.7 μm. 3D contents generated by the OLED are projected on the DMD. As the DMD, V7001 model made by Vialux corporation is used. It has an active area with 14.0 $mm \times$ 10.5 mm and the resolution is $1{,}024 \times 768$ with the pitch 13.7 μm. In 6-bit gray level mode, the switching rate of the micromirror is 1,091 Hz. We made a program code by Matlab to control the DMD.

This setup is constructed to prove the feasibility of our idea. So, we set up our system on the optical breadboard and it is not proper for the observer to wearing this system. For the purpose that our compact system is made compact as a wearable system, there remains several issues such as minimizing the control board of the DMD and the OLED.

Table 1: The specification of OLED.

OLED	SXGA – 1012SD
Video input type	HDMI
OLED resolution	SXGA (1280×1024)
Refresh rate	30 ~ 85 Hz
Active area	38.1 $mm \times$ 30.5 mm

Table 2: The specification of DMD.

DMD	Vialux V7001
DLP chipset	Discovery 4100
DMD resolution	XGA (1024×768)
Micro-mirror pitch	13.7 μm
Active mirror array area	14.0 $mm \times$ 10.5 mm
Array switching rate 1bit B/W	22,727 Hz
Array switching rate 6bit Gray	1, 091 Hz
Array switching rate 8bit Gray	290 Hz

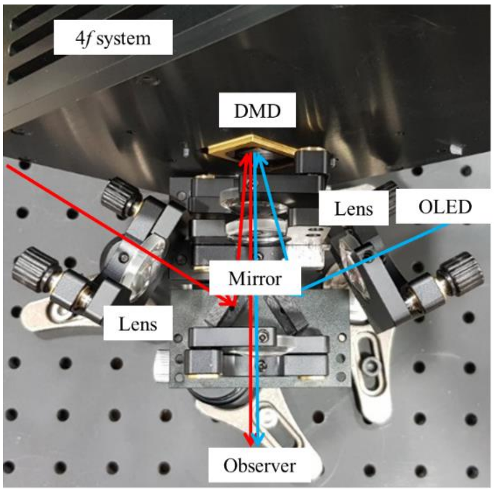


Figure 3: System setup of occlusion-capable head-mounted display.

4 CONCLUSIONS

In this paper, we proposed a novel HMD with a DMD and an OLED where the DMD functions as both filter and combiner. With this system, the observer watches both the environmental scene and the virtual contents. The virtual contents are displayed by the OLED and they are combined with the environmental scene at the DMD. With our setup, we succeed in proving the feasibility of our idea. For the next step, we have a plan to make the system compact suitable for the user to wear it.

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