Contact Lens Display Based on Holography

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ABSTRACT

Holographic display technique is used to generate images far from the display device embedded in a contact lens to enable an eye focus on the images. The see-through function is also provided using the phase-only SLM and the laser backlight. The proposed image formation and see-through functions were experimentally verified.

1 INTRODUCTION

A contact lens display is an ultimate display used for augmented reality because users do not need to wear headsets or glasses. The developments of techniques in many engineering fields are required to realize practical contact lens displays. This study focuses on the development of the optical technique to implement the contact lens displays.

Several techniques have been developed to integrate electronic devices into a contact lens. Lingley et al. [1] showed embedding of the LED-array into a contact lens and demonstrated its wireless activation. Smet et al. [2] demonstrated the integration of the liquid crystal display into a contact lens.

This study proposes the image formation technique using holography, which is required to realize contact lens displays. The experimental verification of the proposed technique is shown.

2 PROPOSED SYSTEM

The issue of the contact lens displays in the image formation aspect is shown in Fig. 1(a). When the display device is embedded in a contact lens, a crystalline lens of an eye cannot focus on the display screen because the display screen is too near to focus. This study proposes the use of the holographic technique to solve this problem. As shown in Fig. 1(b), a hologram pattern is displayed on the display device in a contact lens. Using the wavefront reconstruction of holography, three-dimensional (3D) images can be generated apart from the display device. The display device generates wavefront emitted from images located far from the eyes. Therefore, eyes can focus on the holographic images.

The structure of the holographic contact lens display proposed in this study is depicted in Fig. 2. It consists of a phase-only spatial light modulator (SLM), a laser backlight, and a polarizer. The proposed system can produce images at distant positions where eyes can focus and also

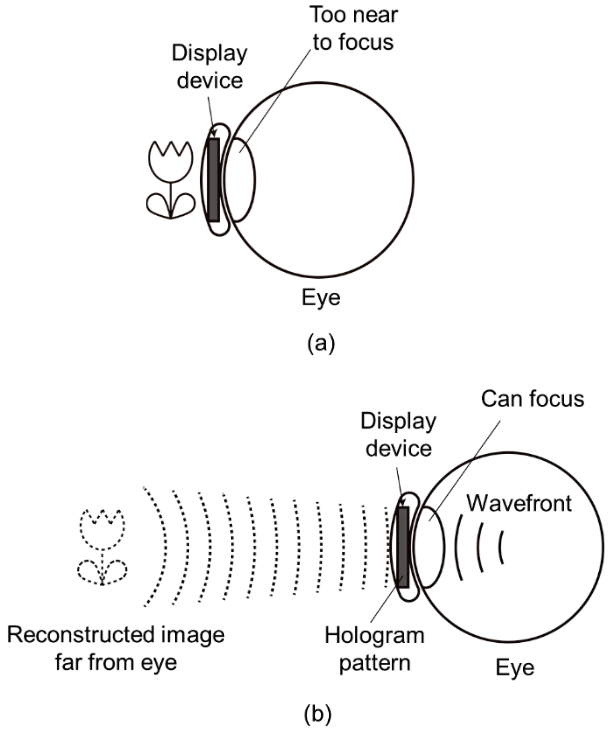

Fig. 1 Image formation for contact lens display: (a) problem using conventional displays, and (b) solution using holographic technique

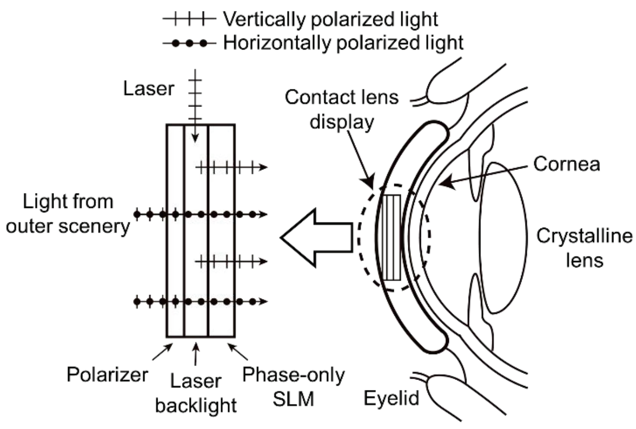

Fig. 2 Structure of holographic contact lens display

provide the see-through function that enables eyes to see outer scenery. The laser backlight emits vertically polarized laser light to illuminate the phase-only SLM. The phase-only SLM modulates the phase of the vertically polarized light and do not modulate the phase of the horizontally polarized light. The vertically polarized light is modulated to produce wavefront for the image generation. The polarizer transmits the horizontally polarized light from outer scenery, which is not modulated by the SLM. Thus, the see-through function is obtained.

3 EXPERIMENT

The image formation of the proposed technique was verified by the benchtop experiments.

The phase-only SLMs employ the parallel-aligned nematic liquid crystal for modulating linearly polarized light. Unfortunately, most of commercial phase-only SLMs are reflection-type SLMs and the transmission-type was not available. Thus, we used a transmission-type twisted nematic liquid crystal SLM for the phase modulation because it can modulate the phase of circular polarized light [3].

The experimental system is illustrated in Fig. 3. A polarizing beam splitter (PBS) was used instead of the laser backlight and the polarizer. The quarter-wave plate (QWP) was used to transform the vertically polarized laser light into right-handed circularly polarized light whose phase is modulated by the SLM. The light from the outer scenery is transformed into left-handed circularly polarized light whose phase is not modulated by the SLM.

As the SLM, LC2012 (HOLOEYE Photonics AG) was used. A laser diode with a wavelength of 445 nm was used. The measured phase modulation characteristics is shown in Fig. 4. Because the maximum phase modulation was approximately 1.5π, the number of phase levels used to represent hologram patterns was set to four. The phase distributions of the phase-only holograms displayed on the SLM were calculated using the Gerchberg-Saxton algorithm [4].

Figure 5 shows the experimental result. Both the reconstructed image and the real object (soccer ball) could be observed through the screen of the SLM. The reconstructed image was produced at the distance of 500 mm from the SLM and the object was placed at the same depth position. Repeated reconstructed images were observed because the pixel pitch of the SLM was large (36.0 µm). The transmittance of light from outer scenery of the experimental system was 24.9 %.

4 SUMMARY

The holographic contact lens display which can generate images at distances where eyes can focus and provide the see-through function was proposed. The image formation at far distances and the see-through function of the proposed technique was experimentally verified.

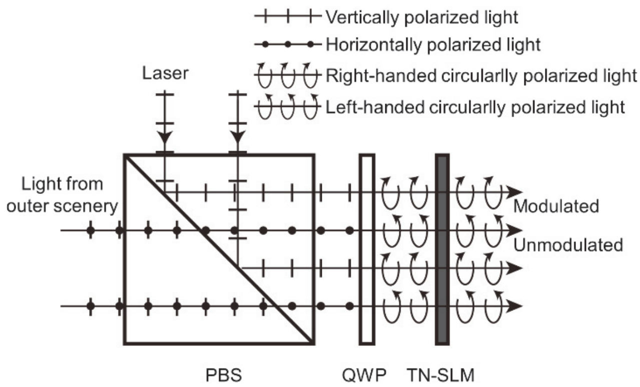

Fig. 3 Experimental system

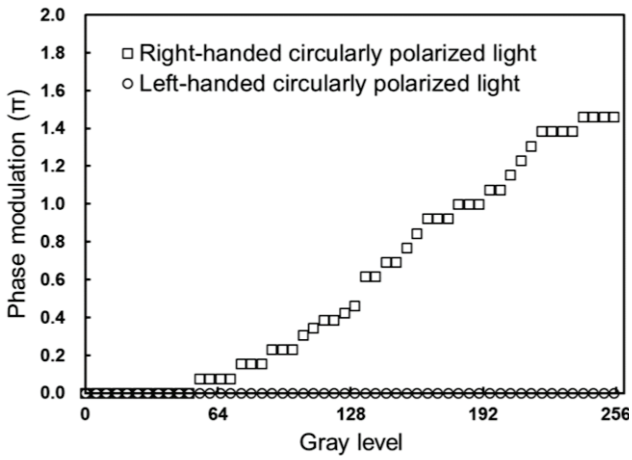

Fig. 4 Measured phase modulation characteristic of the TN-SLM

Fig. 5 Experimental result

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