High Field-of-View Near-Eye Display Using Total Internal Reflection Prism and Holographic Printing Technique

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ABSTRACT

By using holographic printing technique, a high field-of-view (FOV) holographic eyepiece for near-eye display can be implemented. However, due to the high FOV, it is hard to separate the reference beam from the signal beam. In this paper, we used total internal reflection prism to solve the problem and a holographic near-eye display for augmented reality is implemented.

1 INTRODUCTION

Recently, with the development in display devices and communication speeds, interest in augmented reality (AR) near-eye display (NED) is increasing. In AR NED, a transparent eyepiece optic called AR combiner, which combines AR images and real scene together, is one of the key components. The most well-known AR combiner is half-mirror, but due to the disadvantages of reduced external light intensity and its large volume, diffraction based optics, such as diffractive optical element (DOE) and holographic optical element (HOE), are attracting attention. DOE, which is commercially used by Microsoft's HoloLens [1], can be precisely fabricated by surface etching or other fine processes. However, it is expensive to manufacture and has the disadvantage of unwanted diffraction orders. Recently, HOEs have received attention because of their fine angular and wavelength selectivity and multiplexing ability [2]. However, the difficulty of applying digital manufacturing process is a big obstacle to the commercialization of HOEs. The disadvantage of HOEs can be overcome by using holographic printing techniques as shown in Fig. 1 [3]. In holographic printing process, high resolution computer generated holograms (CGH) are displayed on spatial light modulator (SLM) and recorded in sequence on holographic material such as photopolymer. Since it records CGH, we can manufacture HOE with high field-of-view (FOV) for AR NED as purpose.

In previous studies of AR NED with HOE, AR images are directly projected on the eyepiece HOE [4, 5]. Since they have relatively low FOV, the direct projection is possible. However, in the case of high FOV eyepiece HOE, due to the disturbance of user' head or the reference beam as shown in Fig. 2, it is hard to use direct projection within the distance of eye relief. To overcome the problem, some additional optics such as waveguide should be required. An easy solution is implementing total internal reflection (TIR) prism, which is designed for commercial video projectors. By implementing TIR prism, the reference beam of HOE can be projected without any disturbance and it has relative freedom in incidence angle compared to waveguide optics.

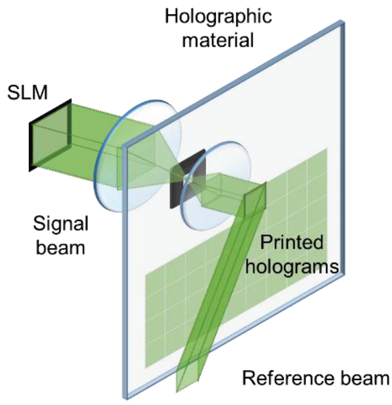


Fig. 1. Concept diagram of holographic printing
The signal beam modulated by SLM is printed sequentially on the holographic material.

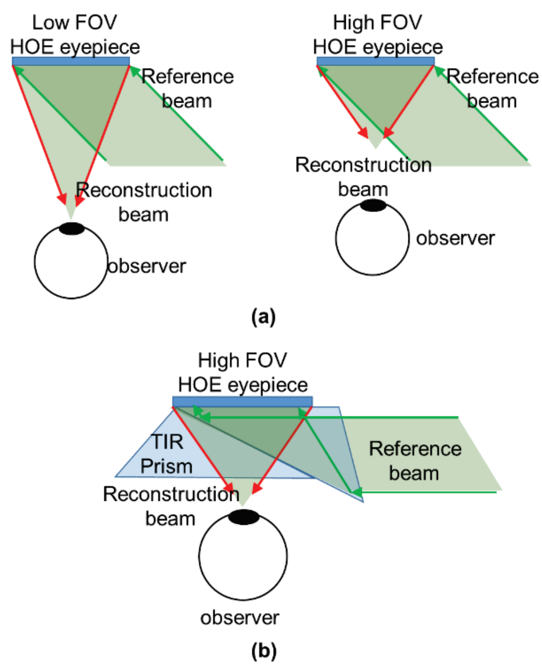


Fig. 2. Concept of proposed near-eye display
(a) The problem of high FOV HOE eyepiece and (b) concept of NED using TIR prism.

In this paper we manufactured a high FOV (50 degrees) digitally designed HOE by using holographic printer and proposed AR NED concept using a TIR prism to project the reference beam efficiently.

2 EXPERIMENT

The experiments were divided into two stages. In the first part, high FOV HOE lens was manufactured by a holographic printer, and in the second part, holographic NED setup is implemented with TIR prism and manufactured HOE.

2.1 Manufacturing HOE with holographic printer

Figure 3 presents the schematic diagram of the holographic printer. The experimental setup can be divided into the reference path and the signal path. The power ratio between the reference beam and the signal beam is controlled by a polarized beam splitter (PBS). The signal path is constructed by using 4K resolution amplitude SLM and the final signal wavefront is generated by sideband filtering and anamorphic Fourier transform technique [6]. The specifications of the HOE are described in detail on Table 1. The designed FOV of the HOE is 50 degrees and we used high numerical aperture aspherical lens enough to present bandwidth of signal beam. As shown in Fig. 4, the HOE is transparent for the background scene so that it is suitable for AR combiner of AR NED.

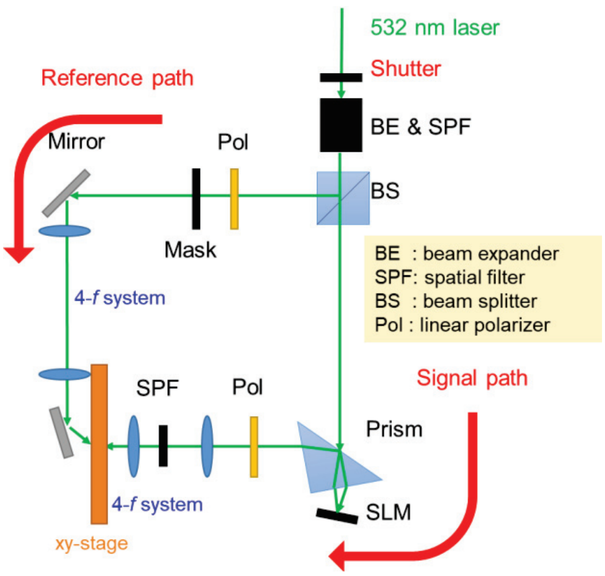
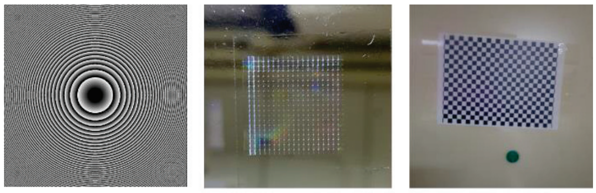


Fig. 3. Schematic diagram of holographic printer
The signal beam and reference beam are aligned at the *xy*-stage. The *xy*-stage, electrical shutter and SLM are synchronized and controlled by serial communication.

Table 1. Specifications of manufactured HOE

Resolution of total hologram	38000 x 38000 pixels
Resolution of a hogel	1900 x 1900 pixels
Number of hogels	20 x 20
Size of a hogel	1 mm x 1 mm
Focal length	30 mm
Field-of-view	50 degrees
Total printing time	~ 40 minutes



(a) (b) (c)

Fig. 4. Manufactured HOE
(a) Designed CGH pattern of HOE lens, (b) manufactured HOE with holographic printer, and (c) background checkerboard pattern which is seen through the HOE.

2.2 Near-eye holographic display

A near-eye AR holographic display setup was implemented using the high FOV HOE fabricated in the section above. The optical system of holographic display is shared as used in the signal path of the holographic printer. The generated hologram was incident on the HOE using a TIR prism as shown in Fig. 5. In this way, the TIR prism allows the input hologram to enter the HOE eyepiece without being limited to short eye relief and high FOV. Since we took apart the TIR prism from a commercial video projector, there is no need for complicated optical design and manufacture process.

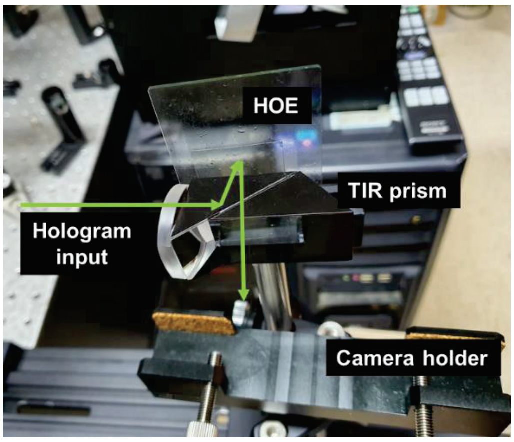
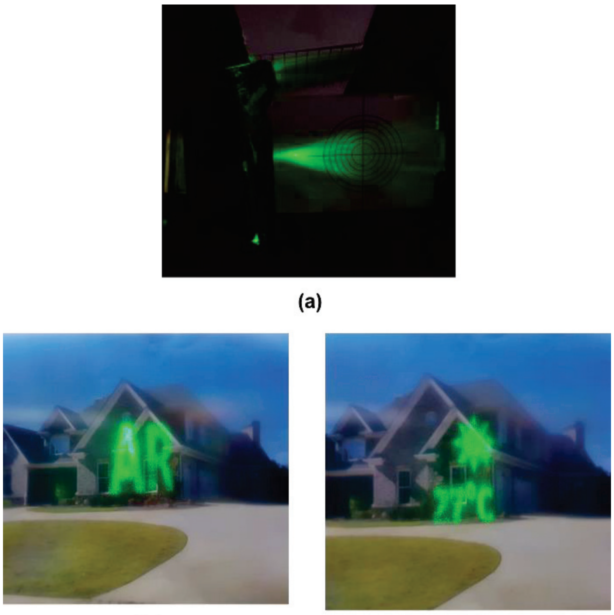


Fig. 5. Implemented near-eye holographic display
A bench top near-eye AR holographic display setup was implemented.

3 RESULTS

In this section, we verified that the HOE fabricated in Section 2 functions as an AR combiner eyepiece lens with a high FOV and the implemented NED can show the real scene and holographic images simultaneously.



(a)

(b) (c)

Fig. 6. Experimental results

(a) The reconstructed beam of HOE which shows its FOV. The holographic images overlay on the real scene (a picture of a house) (b) the word 'AR' and (c) weather information.

By projecting plane wave to the HOE through TIR prism, the wavefront of the recorded lens profile is reconstructed. As shown in Fig. 6(a), the beam is converged to a focal point and diverged with 50 degrees. We also project holographic images to the HOE through TIR prism and capture the holographic images and real scene simultaneously with a camera. The camera is located at 30 mm in front of HOE, which is the designed eye relief of the AR NED system. The results are presented in Figs. 6(a) and 6(b). The word 'AR' and the image of weather information are overlapped clearly on the real photo scene.

4 CONCLUSIONS

In this paper, we presented high FOV AR NED system with TIR prism and HOE, which is manufactured by holographic printing technique. With the holographic printing technique, the eyepiece HOE can have high FOV and be manufactured as customized design. With TIR prism, the AR NED display system can be implemented in compact scheme. The results verify that the HOE and AR NED display are implemented as the proposal. However, there are still some noises in the printed HOE such as diffusive terms and the AR images should be displayed more clearly. To record clear HOE, it should be recorded surrounded by materials of the similar refractive index. For the further research, we will focus on solving this problem.

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