Beaming Display Using Thin Holographic Waveguides for Wider Head Orientation Angle Range

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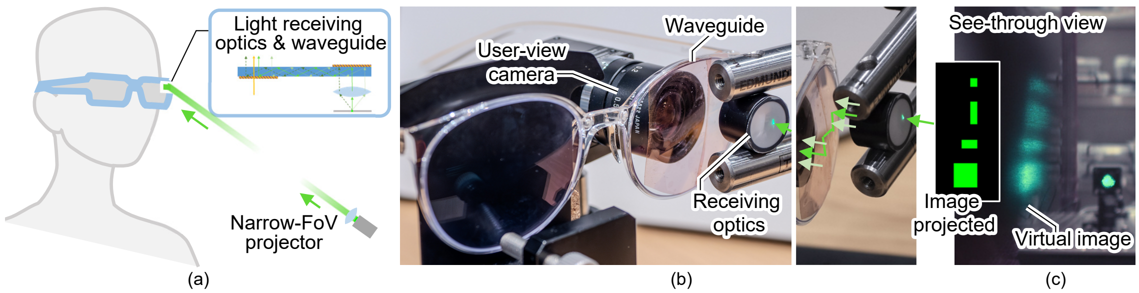

Figure 1: Our BD setup with waveguide-based passive light-receiving glasses and narrow FoV projector. (a) Conceptual illustration of our BD with thin light-receiving glasses, (b) Our eyeglass-type prototype of passive light-receiving glasses with schematic waveguide path visualization on the right photo, and (c) a see-through view from the user-perspective camera behind the prototype.

Abstract

Augmented Reality (AR) glasses face fundamental challenges related to technical trade-offs. Emerging Beaming Displays (BDs) offer a compelling solution by separating the active and passive components. However, existing BD-based AR glasses have yet to achieve a thin and lightweight design with wide incident projection angles. This work proposes an eyepiece for BDs, including a holographic waveguide with tailored in- and out-coupling gratings. The proposed design aims to achieve a millimeter-thin form factor with a wide tolerance for incident angles, thus overcoming the limitations of existing designs. We have constructed proof-of-concept passive AR glasses prototypes, all approximately 2mm thick, including one in the form of conventional eyeglasses, and demonstrated an acceptable lateral angle of incidence of up to 90 degrees.

Index Terms: Beaming display, Augmented reality, Near-eye display, waveguide, HOEs.

1 Introduction

Augmented Reality (AR) glasses face fundamental challenges related to technical trade-offs such as computing, image brightness, size, battery, and weight [5]. These trade-offs hinder the realization of the practical AR displays envisioned [7].

The Beaming Display (BD) approach divides AR displays into a steering projector and light-receiving glasses (Fig. 1(a)) [4, 1]. The steering projector(s), distributed in the environment, tracks the light-receiving glasses and directs its beam to project the image directly onto them. The glasses have passive (buttery-free) optics, which relay the images to the user's eyes. This approach could help future AR glasses deliver less obtrusive AR experiences.

However, current BD approaches still face many challenges. In particular, existing light-receiving glass designs have struggled to achieve a thin, lightweight design [4] while providing mobility, *i.e.*, a wider head orientation range that the users can receive images.

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Although recent work [1] has successfully reduced the thickness by integrating a holographic optical elements (HOEs) lens, their design requires precise alignment between the projector and the glasses. Even a few degrees of misalignment of the angle of incidence (AoI) can significantly degrade image visibility and limit user's mobility.

This work addresses this challenge by exploring BD's light-receiving passive optics. Specifically, we prototype a tailored waveguide with HOE couplers to realize thin passive optical glasses for BDs with a wider head-orientation range. Our main contributions include:

- We propose a passive light-receiving glasses eyepiece design for BDs with waveguides using HOEs for a wider head-orientation range, enabling 2mm-thin waveguides with an acceptable AoI range of 90° across the lateral axis.
- We evaluate a prototype with a narrow field-of-view (FoV) projector following discussions to further explore this research area.

2 Implementations

This section provides an overview of our system's optical design and prototype implementation, including a steering projector for remote image projection and light-receiving glasses utilizing a waveguide with in-/out-couplers.

Optical Design The system has two main components: a narrow FoV projector and light-receiving glasses. The glasses feature a waveguide with HOEs serving as in-couplers and out-couplers. The screen optics, equipped with a diffuser, receive a micro image from the projector and direct the light through lens optics to the waveguide. The waveguide, a transparent substrate, guides the light to the user's eye via total internal reflection (TIR). A standard laser projector, modified with projection lenses, is used to project a small image, matching the designed wavelength of the couplers.

Light-Receiving Glasses The fabrication process involves creating HOE couplers using an analog hologram approach with a photopolymer film. The recording setup includes a right-angle prism and a flat glass plate, where the recording and reference beams are incident on the film, creating an analog hologram. The recorded HOEs are attached to the glass plate, serving as in-couplers and out-couplers in the waveguide. The light-receiving optics consist of a diffuser and lens optics to guide the projected light to the in-coupler as collimated light.

Narrow-FoV Projector A narrow-FoV projector is essential to project a small image onto the receiving glass from a distance. We selected a laser projector for its wavelength selectivity to avoid chromatic aberration. An off-the-shelf laser projector was modified with projection lenses to narrow the FoV, enabling image projection at distances. While the current design is bulky, future iterations aim to reduce the form factor. Dynamic tracking and steering of the projector were not implemented in this proof-of-concept setup.

3 EVALUATION

We evaluate our glasses' optical performance, the see-through image quality, and the AOI, i.e., the head orientation range.

Waveguide Performance The total light usage of the HOE, i.e. the ratio between the input beam and an output beam from the outcoupler was about 0.51%. We also evaluated whether waveguides with the HOEs guide incident light as designed. We built three prototypes with different substrates: a glass plate, a curved plastic eyeglass lens base before cutting (0D lens, t=2mm, dia.=80mm), and eyeglasses (0D plastic lens, t=2mm). They have similar thicknesses of about 2mm, but their lens materials and shapes are different. Since our HOEs are on photopolymer films, we attached the HOEs to each substrate.

User-view Image We tested our light-receiving prototypes by projecting images. To capture the see-through view, we used a user perspective camera, Ximea MC023CG-SY-UB (1936×1216 pixels, 1/1.2" diagonal) with a lens, Tamron M118FM08 (f=8mm, F/1.4). We took the three light-receiving glasses prototypes and combined our Fresnel lens receiving optics, which gives the smallest form factor among our current receiving-optics implementations.

We observe that all three prototypes can reproduce the image projected on the screen. However, the horizontal FoV is extremely limited, and only a central strip of the projected image is visible. Since the vertical FoV is maintained, we assume that the horizontal FoV issue is caused by the mismatch of the redirection angle of the current HOE's design and the waveguide's thickness.

Projection AoI for Head Orientation Figure 2 summarizes our evaluation of the AoI capability. We used our flat glass substrate-based prototype and projected an image onto it while orienting the glasses setup in lateral/vertical incident angles. In Fig. 2, the image is visible between -30° and 60° in lateral angles, indicating a range of approx. 90° for acceptable lateral AoI. Although we focused on the lateral AoI, in Fig. 2(b), the image is also visible in an acceptable vertical angle range. Notably, the visibility at large lateral angles was sensitive to the change in vertical angles, suggesting that a more uniform diffuser is an option for improvement.

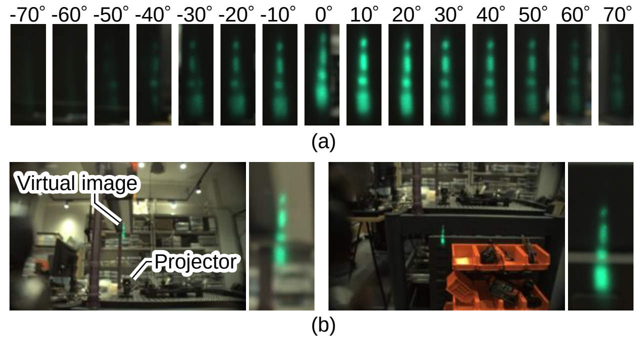

Figure 2: Qualitative image evaluation against the head orientation angles. (a) When changing horizontal incident angles, *i.e.*, when the receiving glasses rotated horizontally, (b) and when tilted vertically.

4 DISCUSSION

The current waveguides with our custom HOEs have a narrow horizontal FoV, likely due to the mismatch between the designed HOE's reflection angle and the thickness of the waveguide. Optimizing the HOE is crucial and can be adapted to our research applications [2]. Additionally, reducing the distance from the display panel to the user's eye is a trend in VR displays. Using a Fresnel lens is a common approach, while other methods employ pancake optics designs with reflective elements. We use a volume HOE in our design, which is less polarization-dependent and compatible with a wider range of projectors. Recent designs with opposing layouts for holographic near-eye displays can also be adapted to our approach [6].

The tracking part of BDs is another essential aspect in practice. Our design's wide incident-angle tolerance allows for the integration of existing tracking approaches. For example, a low-latency dynamic-feedback approach with an IR marker [3] can be seamlessly applied since the HOE couplers do not interfere with light outside the designed wavelength.

Typical waveguides use flat substrates, which may limit design factors and be incompatible with ordinary prescription eyeglasses. In our eyeglasses-type prototype, HOEs can work on curved surfaces. Employing curved or free-form waveguides and optimizing the HOEs accordingly would be an exciting research area to adapt to our applications.Our current prototype uses the green channel of the projector since our custom HOE was fabricated for 532nm (green) light. Existing approaches for full-color HOE include multiple layered HOEs and a single HOE with broad bandwidth.

Lastly, the diffuser determines the image quality of the projected images. While we used an off-the-shelf diffuser film, material science explores more advanced diffusers with uniform scattering properties using micro/nanoparticles.

5 CONCLUSION

In this study, we utilized waveguides with holographic optical elements (HOEs) to develop thin passive optical glasses for a BD approach, addressing trade-offs in AR displays. Our design of light-receiving optics and reflective HOEs achieved a thin form factor with a wider head-orientation range, overcoming the limitations of existing designs. We built three proof-of-concept glass prototypes with passive optics, accompanied by a narrow FoV projector capable of projecting small images onto them. Our results demonstrate that our design provides a range of 90° acceptable lateral AoI.

ACKNOWLEDGMENTS

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