See-Through Near-Eye Displays for Visual Impairment

Lei Zhou, Chao Ping Chen*, Yishi Wu, Keyu Wang, Zhonglin Zhang

Smart Display Lab, Department of Electronic Engineering, Shanghai Jiao Tong University, Shanghai 200240, China
Email: ccp@sjtu.edu.cn

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ABSTRACT

We propose a see-through near-eye display, which is dedicated to the users who are visually impaired. Our design is characterized by a pair of corrective lenses coated with holographic volume gratings. Its key optical performance include FOV of 14°, MTF above 0.4 at 5 cycles/mm, and distortion less than 5%.

1. INTRODUCTION

See-through near-eye display is the key component of the augmented reality (AR) [1]. One of the typical applications of see-through near-eye displays is known as the smart glasses. However, the current smart glasses are not quite suitable for people having visual impairment—such as myopia and presbyopia—as they have to wear extra glasses or contact lens for vision correction. To address this issue, we propose a compact design of see-through near-eye display, which features a pair of corrective lenses coated with holographic volume gratings or holograms. With this design, no extra glasses or contact lens are needed. Based on numerical simulations, its field of view (FOV), modulation transfer function (MTF), and distortion have been evaluated.

2. PROPOSED SOLUTION

Fig. 1 outlines the schematic drawing of the proposed see-through near-eye display. It mainly consists of dual pico projectors and a pair of corrective lenses. The pico projector comprises a micro-display and a 4-element projection lens [2]. The corrective lenses are used for compensating the refractive errors of the eyes. They can come in a variety of shapes and designs, depending on the actual visual acuity of the wearers. By way of example, divergent lenses with negative power for 300-degree myopia are adopted. The holographic volume grating is coated on the inner surface of the corrective lens to reflect the light toward the eyes. Alternatively, it can be also coated on the outer surface of the corrective lens. Since the volume grating is highly selective on both wavelengths and angles, multiplexing of different gratings is quite necessary. For the same reason, the effect of the volume grating on the real scene can be neglected.

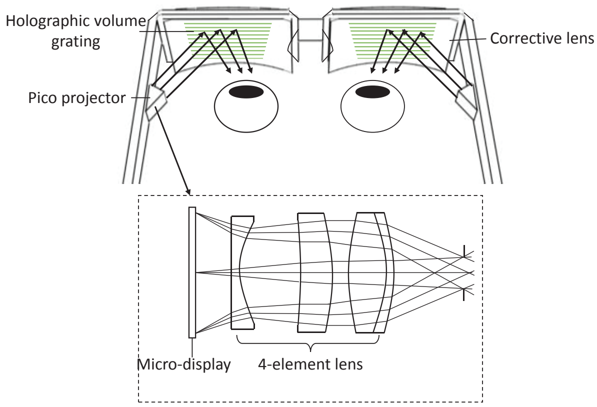


Fig. 1 Schematic drawing of the proposed see-through near-eye display

3. RESULTS AND DISCUSSIONS

Optical simulation is implemented with the assist of the software Code V (Synopsys). All parameters used are summarized in Table 1.

Table 1 Simulation parameters

System data	Entrance pupil diameter: 2 mm			Object height: 15 mm		
	Wavelength: 550 nm			Temperature: 20°C		
Lens data	Surface	Surface type	Y radius	Thickness	n of glass	Refract mode
	Object	Sphere	Infinity	4.9000		Refract
	1	Sphere	Infinity	1.0000	1.62	Refract
	2	Sphere	10.7242	7.4608		Refract
	3	Sphere	-69.3967	3.9859	1.62	Refract
	4	Sphere	-30.1314	2.0533		Refract
	5	Sphere	32.8373	4.5000	1.62	Refract
	6	Sphere	-18.4608	1.0000	1.70	Refract
	7	Sphere	-21.7107	15.0000		Refract
	Stop	Sphere	Infinity	25.0000		Refract
	9	Sphere	-197.2000	333.7263		Diffract
	Image	Sphere	Infinity	-0.0848		Refract
Properties of surface 9	Type: volume grating			Thickness: 15 μm		
	Refractive index modulation: 0.06			Base index: 1.48		
	Construction wavelength: 550 nm			Period: 1441.2 nm		

3.1 Diffraction Efficiency

Holographic volume grating—also known as volume hologram—plays a critical role in our solution, as it would largely affect FOV and overall light utilization. Following

Fourier modal method, its diffraction efficiency (DE) is calculated with respect to the wavelengths and incident angles, as shown in Fig. 2 and Fig. 3, respectively. As can be seen, the wavelength bandwidth for DE>10% is 24 nm, whereas the angular bandwidth for DE>10% is 14 degrees.

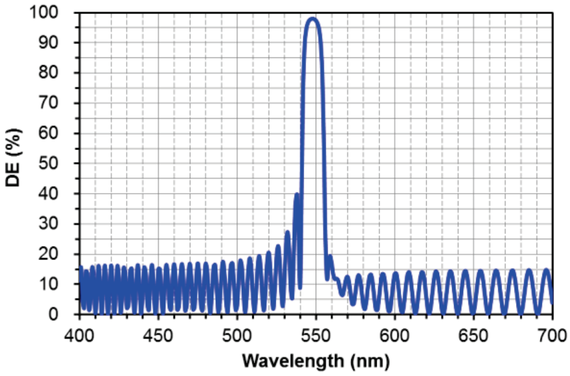


Fig. 2 Calculated DE with respect to wavelengths

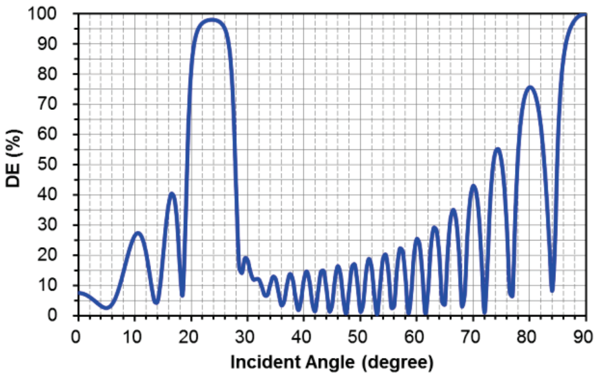


Fig. 3 Calculated DE with respect to incident angles

3.2 MTF & Distortion

By computing Fourier transform of the line spread function, the diffraction MTFs at the central and marginal FOVs are plotted in Fig. 4, where MTFs for all FOVs are above 0.4 at 5 cycles/mm. Besides, the distortion, defined as the displacement of image height or ray location, is less than 5%.

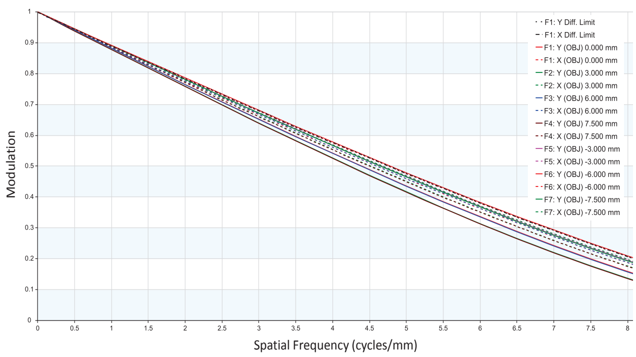


Fig. 4 Calculated MTF

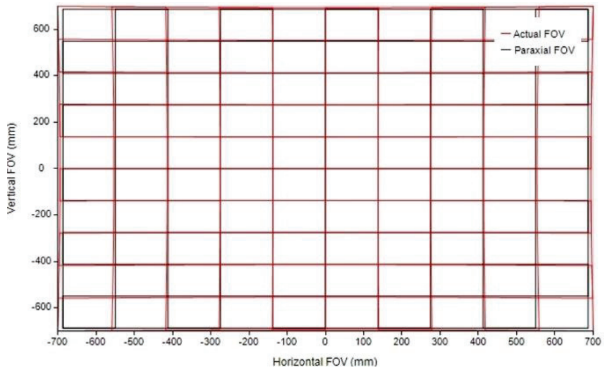
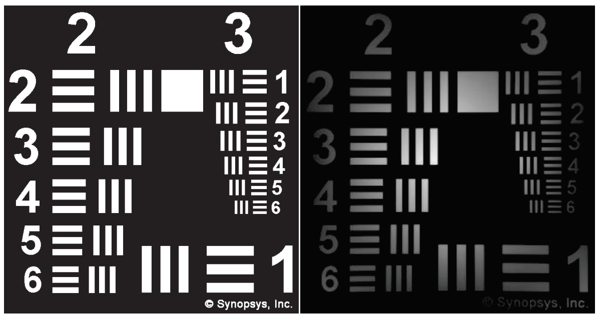


Fig. 5 Calculated distortion grid

3.3 Simulated Imaging

To view the imaging quality, the imaging simulation that takes into account the effects of distortion, aberration blurring, diffraction blurring, and relative illumination is performed, as shown in Fig. 6. By comparing the original and simulated images, it can be seen that the distortion and blurring are small, whereas the brightness is reduced, which agrees with the above results.



(a) (b)

Fig. 6 (a) Original image & (b) simulated image

4. SUMMARY

A compact design of see-through near-eye display, featuring a pair of corrective lenses coated with holographic volume gratings, has been proposed. Based on the simulation, its optical performance including FOV, MTF, and distortion has been studied. By eliminating the need for extra glasses or contact lens, this type of see-through near-eye display could be particularly appealing to the users who are visually impaired.

REFERENCES

[1] W. Barfield: *Fundamentals of Wearable Computers and Augmented Reality* (CRC Press, 2016)

[2] M. S. Brennesholtz and E. H. Stupp: *Projection Displays 2nd Edition*, (Wiley, 2008)