

Holographic Mixed Reality Ultra-High-Definition Traffic Signs to Increase Safety and Inclusivity in Transportation

Jana Skirnewskaja,^{1,*} Yunuen Montelongo² Timothy D. Wilkinson¹

¹ *Electrical Engineering Division, Department of Engineering, University of Cambridge, 9 JJ Thomson Avenue, Cambridge, CB3 0FA, UK*

² *Department of Engineering Science, University of Oxford, Parks Road, Oxford OX1 3PJ, UK*
E-mail: js2459@cam.ac.uk

Abstract. Current 2D windshield head-up displays can lead to driver distractions due to a shift of gaze from the road towards a small area of the windshield. Customizable mixed reality real-time head-up displays can increase safety in transportation due to the holographic road obstacles being aligned with the road scene. Based on accelerated parallel processing algorithms, a 4K spatial light modulator, virtual Gabor lenses and a He-Ne laser, 3D holographic road signs appear within 1.15 seconds in the driver's gaze on the road.

Keywords: Mixed Reality, Liquid Crystal on Silicon, 3D Computer-Generated Holography, Head-Up Displays, Automotive Applications.

1 Introduction

Safer transportation requires evolving standards. Taking everyone into account when developing technology is crucial to inclusivity and transparency. Holographic Head-Up Displays (HUDs) provide a basis for the transportation sector to build on inclusive design strategies. However, current proposals of holographic HUDs lack a pull-parallax effect, the number of pixels needed to recreate a duplicate holographic augmented reality (AR) object of the original object and the speed to reach real-time projections [1]. Holography provides an opportunity for safer and more secure transportation by generating depth cues in the replay field results perceivable for the driver. In consequence, augmented reality in-eye head-up displays (HUDs) implement realistic 3D object and add them into the driver's gaze without any distractions. This natural visualization technique of physical 3D objects is an attractive tool in the automotive sector. Hence, this study focuses on accelerating the generation of ultra-high-definition (UHD) holographic road-signs for real-time use during the driving experience. Various existing approaches tackle the challenge of speed for generating computer-generated holograms from real-object data such as the polygon-based method, the depth plane technique, and the point cloud approach [2-4]. To generate real-time high-resolution 3D floating replay field results, a layered holographic method based on phase retrieval and virtual lenses was utilized [5, 6]. A modified and accelerated Gerchberg-Saxton algorithm was generated to project holograms through a Liquid Crystal on Silicon (LCoS) display panel of an UHD Spatial Light Modulator (SLM). Ghost images in augmented reality mode as replay field results were generated at variable focal distances of up to 60 cm. This was achieved through computational techniques by reducing optical lenses in the setup and

introducing virtual Gabor lenses. The customizable 3D holographic projection algorithm allows for the integration of people with various conditions into the transportations sector.

2 Methods

2.1. Materials

An UHD SLM (3840×2160 px, EXULUS-4K1 from Thorlabs), a HeNe laser (random polarization, $\lambda=632.8$ nm, 5 mW), an aspheric lens ($f=3.30$ mm, $NA=0.47$), plano-convex lenses ($f=50, 75$ and 150 mm, $\varnothing 1"$, N-BK7, ARC: 350-700 nm), a linear polarizer ($\varnothing 1"$, N-BK7, 38% transmission), a polymer zero-order half-wave plate ($\varnothing 1"$, 633 nm), and a non-polarizing beamsplitter (50:50 split, 30 mm) were utilized in the study. The UHD SLM was manufactured by Jasper Display Corporation and was found to have an operating wavelength of 400-850 nm after calibrations studies with full factor of >90%, a panel active area of 15.6 mm×9.2 mm, pixel pitch of 3.74 μm , phase/retardance range of 2π at 633 nm, and a frame rate of 30 Hz. The replay field images were taken with a digital camera and equipment from Sony ($\alpha 7S$ III E-mount, full frame sensor (35.6 mm×23.8 mm), 24. MP) and a camera lens (FE 16-35 mm, F2.8 GM).

2.2 Computer-Generated Hologram generation and calibration.

All CGHs were created by utilizing SolidWorks 2022 (SP3.0, Dassault Systèmes) CAD modeling, and importing 3D models into MATLAB (R2021a, MathWorks). The CGH data was transmitted to the UHD SLM via HDMI for replay field projection data. The processing time to generate the CGH via the MATLAB

* Corresponding author: js2459@cam.ac.uk

code on a Lenovo ThinkPad laptop (i9-9880H, 2.30 GHz, 64 GB RAM) with a NVIDIA GeForce GTX 1650 Max-Q 4GB GDDR5 graphics card required an average of 1.15 s. Figure 1 presents the calibration of the developed optical system to determine the recorded resolution of the UHD replay field results.

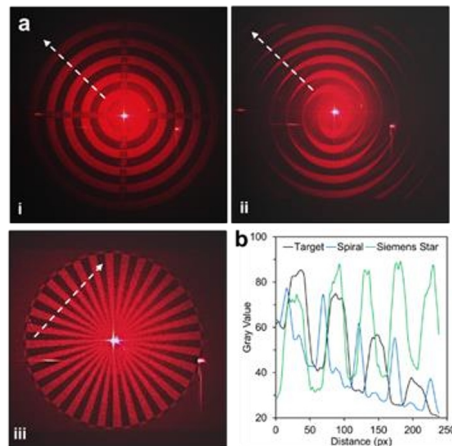


Fig. 1. Calibration of the UHD holographic replay field results. a) Resolution and brightness test charts. b) Recorded resolution and brightness results of the UHD holographic optical system.

3 Results

The benefit of utilising multi-phase modulation with the UHD SLM is the absence of conjugate orders and the residual zero-order surface reflection was removed with the improvement of the algorithm. Another focus of this work was the improvement of perspective and defocus blur. The field of view was determined to be equal to the size of the beamsplitter. However, a panoramic view of several objects aligned with real-life objects was achieved in this study. The fast processing time for the application of real-time customizable head-up displays was paramount in this work. Additionally, the 4k resolution and accuracy of the replay field results as augmented reality objects was achieved as presented in Figure 2.



Fig. 2. Augmented reality UHD holographic replay field results. a) Phone application and speaker signs. b) Infotainment system signs. c) Car charging sign. d) Hotel sign. e) Speedometer sign. f) Wi-Fi connection sign. g) Construction sign. h-i) Traffic signs. j) Speed sign in km/h.

4 Conclusion

This work has demonstrated the basic principles of customizable real-time holographic augmented reality traffic signs for the application in inclusive head-up displays. This process could be optimized computationally with analyzing additional accelerating methods. The accuracy of the replay field images could be further enhanced with layering techniques and multiple viewpoint rendering techniques.

The authors acknowledge the Engineering and Physical Sciences Research Council (EPSRC) for research funding (EP/S022139/1), the Worshipful Company of Scientific Instrument Makers and the Foundation of German Business. The authors declare no competing financial interests.

References

1. Kunieda, O. and K. Matsushima, *High-quality full-parallax full-color three-dimensional image reconstructed by stacking large-scale computer-generated volume holograms*. Applied Optics, 2019. **58**(34): p. G104-G111.
2. Matsushima, K. and S. Nakahara, *Extremely high-definition full-parallax computer-generated hologram created by the polygon-based method*. Appl Opt, 2009. **48**(34): p. H54-63.
3. Arai, D., et al., *An accelerated hologram calculation using the wavefront recording plane method and wavelet transform*. Optics Communications, 2017. **393**: p. 107-112.
4. Skirnewskaja, J. and T.D. Wilkinson, *Automotive Holographic Head-Up Displays*. Advanced materials, 2022. **34**(19): p. 2110463.
5. Skirnewskaja, J., Y. Montelongo, and T.D. Wilkinson. *3D computer-generated holograms for augmented reality applications in medical education*. in *Applications of Digital Image Processing XLIV*. 2021. SPIE.
6. Wang, Z., et al., *Enhanced resolution of holographic stereograms by moving or diffusing a virtual pinhole array*. Optics Express, 2020. **28**(15): p. 22755-22766.