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Synthetic holographic display for three — Dimensional optical see —Through augmented reality using a zero-order nulled grating

Yanfeng Su [a,b], Zhijian Cai [a,b,*], Quan Liu [a,b], Peiliang Guo [a,b], Yifan Lu [a,b], Lingyan Shi [a,b]

[a] *College of Physics, Optoelectronics and Energy & Collaborative Innovation Center of Suzhou Nano Science and Technology, Soochow University, 1st Shizi Street, Suzhou 215006, China*
[b] *Key Lab of Advanced Optical Manufacturing Technologies of Jiangsu Province & Key Lab of Modern Optical Technologies of Education Ministry of China, Soochow University, 1st Shizi Street, Suzhou 215006, China*

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ABSTRACT

In this paper, a synthetic holographic display system for three-dimensional (3D) optical see-through augmented reality (AR) is proposed and implemented. The system is composed of a synthetic hologram reconstruction module and an optical see-through display module. The synthetic hologram reconstruction module utilizes a spatial light modulator (SLM) to present the virtual 3D image in the form of left and right stereo images, and the parallax angle between two stereo images can be enlarged by the zero-order nulled grating to meet the split angle requirement of normal stereoscopic vision. The virtual reconstructed scene and the real physical world will fuse together through the optical see-through display module. The zero-order nulled grating is specifically designed and fabricated, and its diffraction efficiency is measured. Furthermore, an experimental verification system for the proposed AR 3D display is presented. The experimental results prove that the proposed system can support virtual 3D display without crosstalk, and it is able to generate the realistic augmentation successfully.

1. Introduction

Augmented reality (AR) display, which allows overlaying or superimposing of virtual two-dimensional (2D) or three-dimensional (3D) digital information upon the real physical world in real time, greatly enhances the viewer' s perception of and interaction with reality [1–6]. It has already been applied in a lot of applications, such as medical treatment [7,8], military [9], cultural protection [10] and entertainment [11].

Head-mounted display (HMD) is one of the most prevailing expressions for AR display technology, and its typical products include Google glass [12] and Lumus AR products [13]. Although Google glass and Lumus AR products have demonstrated impressive AR displays with high quality, they cannot display virtual images in 3D, but only superimpose virtual 2D images on real 3D scene, which greatly limits their applications. Recently, several studies have been reported about AR display systems supporting virtual 3D images [14–16]. Hoon et al. proposed an integral floating AR system for virtual 3D display by using a

* Corresponding author at: Soochow Unversity, 1st Shizi Street, Suzhou, China.
E-mail address: caizhijian@suda.edu.cn (Z. Cai).

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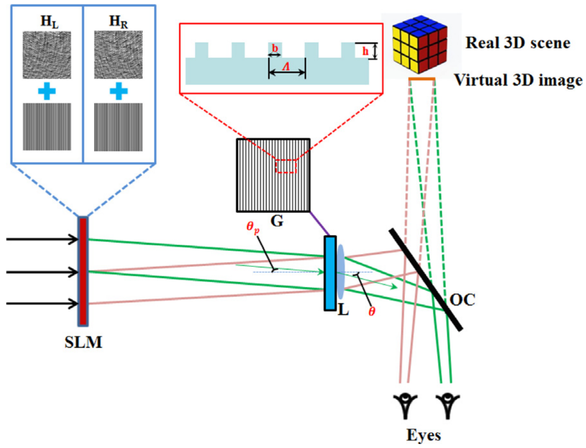

Fig. 1. Schematic diagram of the proposed optical see-through synthetic holographic 3D display system, where G represents grating, L is the ocular lens, and OC represents optical combiner.

convex half mirror [14]. Later, Li et al. from the same group proposed the projection-type integral imaging AR display system by using a lens-array holographic optical element (HOE) as the image combiner [15]. However, the fabrication processes of image combiners in these systems need complicated procedures and very high precision, which will lead to soaring cost. In addition, Takasi et al. proposed a super multi-view (SMV) scheme for AR system supporting virtual 3D display [16]. But this system put forward excessively high resolution requirement to the imaging device to satisfy the SMV condition.

Compared with these 3D display methods, holographic display [17], especially electronic holography [18,19], is regarded as an ideal virtual 3D display technology for AR [20], because it can reconstruct the wave-front of the light field including both amplitude and phase information. In spite of its great potential, electronic holography has many limitations, mainly due to the inadequate space bandwidth product (SBP) [11,21], which is caused by the overlarge pixel pitch and insufficient pixel number of the spatial light modulator (SLM). Synthetic holography, as a holographic stereography, is a practical realization approach for AR 3D display because only auto-stereoscopic 3D images need to be provided for observer. However, the parallax angle between the left and right stereo images provided by the SLM is not enough to meet the split angle requirement of normal stereoscopic vision. Therefore, Choi et al. proposed a projection lens module to solve this problem [22,23], but such a projection lens with high quality always needs more strict machining precision and higher price.

In this paper, we propose a synthetic holographic 3D display system for optical see-through AR, where virtual 3D image is reconstructed by the synthetic computer-generated hologram (CGH) encoded on the SLM. Moreover, a parallax angle enlarging method is proposed by using a zero-order nulled grating, with which the two stereo images will be re-directed to different viewing zones so that the parallax angle can be enlarged. With special grating design, the zero-order diffraction is eliminated, so that the virtual 3D display will be free of crosstalk. Furthermore, this system can also achieve realistic augmentation because the reconstructed virtual 3D image will blend into the real 3D scene through the optical see-through display module. Compared with the projection lens module in Ref [22,23], the zero-order nulled grating is more compact, easier to fabricate, and of lower cost. In the next sections, the theoretical principle and system configuration will be described in detail, and the verification experiment results will be presented and analyzed.

2. Theoretical principle and system configuration

2.1. System configuration of the proposed AR 3D display

Fig. 1 is the schematic diagram of the proposed optical see-through synthetic holographic 3D display system. It is composed of two modules: the synthetic hologram reconstruction module and the optical see-through display module. The synthetic hologram reconstruction module, including a SLM and a grating, is used for generating virtual stereoscopic 3D image. Here, a SLM is adopted for loading synthetic holograms (H_L,H_R) of the left and right stereo images, and these two stereo images will be reconstructed in different directions, with the directional information expressed by the digital gratings encoded on the SLM. However, the parallax angle between the left and right stereo images is still not enough to meet the split angle requirement of normal stereoscopic vision. So, a grating with special design is set in the reconstruction plane. The left and right stereo images are re-directed to two different viewing zones by the designed grating, and these two stereo images will enter into the corresponding eyes of the observer after passing through the optical see-through display module. In such a way, a virtual 3D image will be formed. An ocular lens and an optical combiner (such as a beam splitter or a half mirror) are employed as the optical see-through module, and the observer will see the combination of virtual 3D image and real 3D scene through the optical combiner.