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An approach for holographic projection with higher image quality and fast convergence rate

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Holographic display is regarded as one of the most promising technologies to realize real three dimensional (3D) display in the near future. However, it is limited to low quality reconstruction and time consuming. In this paper, we present an effective design method of computer generated hologram (CGH), special constraints are introduced to control the signal to noise ratio (SNR) of the holographic image with high speed and accuracy, and high resolution of the holographic image to reduce speckles and granularsensation. Finally, simulation experiments are carried out to verify the performance of the proposed method. This work also can provide a feasible algorithm tool for holographic near-eye display in the field of augmented reality (AR) and virtual reality (VR).

1. Introduction

The Iterative Fourier Transform Algorithm (IFTA) and its modified forms are the most popular algorithm used for generating holograms in holographic display and projection, as well as technologies where phase retrieval is required [1–3]. However, this type of algorithm often suffers from stagnation of convergence after a few iterations, which leads to reconstructed images with low accuracy, high speckle noise and large time cost. The degradation of reconstructed quality will seriously affect the observation effect especially in display applications such as head up display (HUD) and head mounted display (HMD) [4,5]. Consequently, the quality of holographic display is still far from achieving the standard of traditional display with high resolution, SNR and dynamic broadcast.

In the past decades, various algorithms have been proposed to improve the quality of reconstructed holographic images. The time-integral speckle averaging method is common means used to restrain speckles by sequentially loading sub-holograms with different initial phase on the spatial light modulator (SLM) [6,7]. A moving diffuser is also employed to destroy the coherence of the incident laser for speckle reduction [8]. Qi et al. presented a complex modulation based on double-phase method, where the complex amplitude of the holographic plane is encoded into the superposition of two pure phase sub-holograms with an advantage of short time cost, but the use of checkerboard will lead to the loss of resolution, as well as bring with artifacts, and the diffraction efficiency is low [9,10]. Tsang et al. proposed the bi-direction error diffusion method and localized error diffusion and redistribution method, which the complex Fresnel hologram is converted into a

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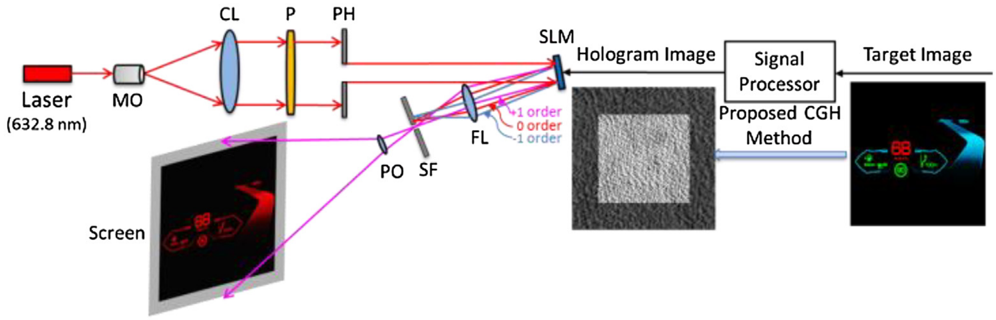

Fig. 1. Schematic diagram of the optical system for holographic projection with the proposed method. MO is a microscope objective, CL is a collimating lens, P is a polarizer, PH is a pin hole, FL is a Fourier lens, SF is a spatial filter, and PO is projection objective.

phase only hologram. The magnitude of each pixel is forced to be a constant value, while preserving the exact phase, then the resulting error is diffused to the neighboring pixels. The algorithm exceeding the capability of generating quality phase-only holograms in video rate, but the reconstructed image size can't exceed the size of hologram, the speckles are still serious, and the diffraction efficiency is low [11,12]. Pang et al. further improved the error diffusion method, where the target image is first added with a special quadratic phase and then padded with zeros. The reconstructed image is clear and bright, but degraded with artifacts, and the diffraction efficiency is low [13]. Qu et al. proposed a small sampling interval method, for which the resolution of reconstructed image is 2 times of the previous reconstructed image that is not limited by the size of the spatial light modulator (SLM), and the speckles are well suppressed at the same time. However, it is easy to suffer from stagnation of the convergence and fall into a local minimum during the iteration, which leads to large time cost. Meanwhile, the amplitude of around padding points on the SLM can't reach zeros finally, hence good optimization results are difficult to be obtained [14,15].

In this paper, we further propose and investigate an effective design method of computer generated hologram (CGH) with high quality, high diffraction efficiency and short time cost. Small sampling interval $\Delta\xi = \frac{\lambda f}{2L}$ instead of $\Delta\xi = \frac{\lambda f}{L}$ with high resolution $2M \times 2N$ is set up on the reconstructed plane by using $M \times N$ sampling points padding with extra $3M \times N$ zero amplitude on the holographic plane to reduce speckles and granularsensation. During the iteration, a special varying weighting factor is added to speed up constraining the amplitude distribution in the signal window. Considering the stagnation situation, another kind of constraint is applied to jump out the local minimum, which ensured the reconstruction with high accuracy, SNR, and less processing time. In the next section, we first provide a brief review of the small sampling interval method, and then described the proposed algorithm in detail. The simulation and experimental results of the proposed algorithm are demonstrated in Section 3, where multiplane 3D hologram and colorful hologram are also simulated to verify the performance of the proposed algorithm. In Section 4, we discussed the method can also be applied to leverage the image reconstruction performance for other types advanced holographic displays including denoising hologram, multiplane hologram, and colorful hologram. Finally, the content of this work is summarized in Section 5.

2. System and principle

The schematic diagram of the optical system is shown in Fig. 1. A Gaussian distributed plane wave emitted from a He-Ne laser with 632.8 nm wavelength. The hologram is generated by a signal processor with the proposed CGH method, and loaded on the phase only SLM. After the light modulated by the SLM and a Fourier lens, a spatial filter is off-axially set to $\frac{\lambda f}{2\Delta x}$ on the back focal plane of the Fourier lens to ensure that only the first order diffraction can pass through it. Finally, a projection objective lens was employed to magnify the reconstructed image for a better viewing.

The complex amplitude distribution on the back focus of Fourier lens can be derived via the fast discrete Fourier transform operation of the hologram loaded on the SLM, with a blazed grating phase profile superimposed for off-axial separation of the first order from the zeroth order. The hologram loaded on the SLM can be written as below,

$$\begin{aligned} G(\xi,\eta) &= F\{F(x,y)\} = F\{E_{in}(x,y)\exp[i\varphi_{in} + i\frac{2\pi(x\sin\alpha + y\sin\beta)}{\lambda}]\} \\ &= T(\xi,\eta)\sum_m\sum_n t(x,y)\exp[-i2\pi(m\Delta x\xi + n\Delta y\eta)] \end{aligned} \tag{1}$$

where $F\{\}$ denotes the Fast Fourier transform operation, E_{in} denotes the input amplitude, φ_{in} denotes the input computational hologram, λ is the wavelength, α, β denotes the blazed angles in the x, y direction, respectively, and m, n are the coordinates of sampling number in the horizontal and vertical directions, respectively. $T(\xi,\eta)$ is an envelope that limits the signal bandwidth and can be expressed by

$$T(\xi,\eta) = \triangle x\triangle y \sin c(\triangle x\xi)\sin c(\triangle y\eta) \tag{2}$$