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A holographic zoom system without undesirable light

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ABSTRACT

In this paper, we propose a holographic zoom system without the undesirable light caused by zero-order diffraction beam and high-order reconstructed images. By loading a divergent spherical wave, the focus planes of the reconstructed image and the zero-order diffraction beam induced by the liquid crystal on silicon (LCoS) can be separated. By controlling the focal lengths of the liquid lens used in the system and the encoded divergent spherical wave on the LCoS, we can change the magnification of the reconstructed image very quickly, while the system does not have undesirable light and the output plane of the system keeps stationary.

1. Introduction

Recently, holographic display based on a spatial light modulator (SLM) has attracted much attention in order to meet the requirements of dynamic real-time display [1–3]. As a SLM, liquid crystal on silicon (LCoS) is used due to its remarkable advantages including high integration, large opening ratio, high resolution, small size and fast response. Some space-division and time-division methods to adjust the magnification of the reconstructed images of the holographic display have been proposed [4,5]. Lensless zoomable holographic projection has also been proposed by using scaled Fresnel diffraction [6]. In addition, the active optical components such as liquid lens and liquid crystal lens also have been widely used in zoom systems [7–10]. However, because of the pixelated structure of the LCoS [11,12], the visual impression of reconstructed image is disturbed by the undesirable light caused by zero-order diffraction beams and multi-order reconstructed images. Some methods have been proposed to eliminate the undesirable light, such as using loading phase wave to the phase distribution of the hologram [13–15] and 4*f* system [16–18]. But the systems using these methods are complex and it is hard to realize holographic zoom without undesirable light. In this paper, we propose a holographic zoom system without the undesirable. By controlling the focal lengths of the liquid lens used in the system and the encoded divergent spherical wave on the LCoS, we can change the magnification of the reconstructed image very quickly, while the system does not have undesirable light and the output plane of the system keeps stationary.

2. Structure and operating principle

The proposed system consists of a laser, a beam expander, a collimating lens, a LCoS, a solid lens, a filter, a liquid lens and a receiving screen, as shown in Fig. 1. The laser, the beam expander and the collimating lens are used to generate a

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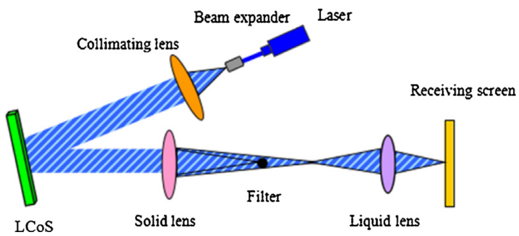

Fig. 1. Principle of the proposed system.

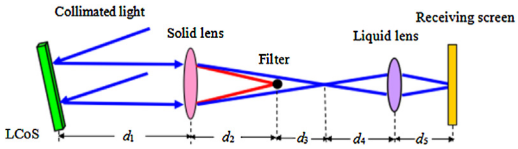

Fig. 2. Analysis of the proposed system.

collimated light. The solid lens is placed behind the LCoS and the filter locates at the focal plane of the solid lens. The liquid lens locates between the filter and the receiving screen.

The analysis of the proposed system is shown in Fig. 2. d_1 is the distance between the LCoS and solid lens, d_2 is the distance between the solid lens and the filter and also the focal length of the solid lens, d_3 is the distance between the zero-order diffraction beams and the multi-order reconstructed images caused by pixelated structure of the LCoS, the liquid lens locates behind the filter at d_3+d_4, and the distance between liquid lens and receiving screen is d_5. In order to separate the focus planes of the reconstructed image and the zero-order diffraction beams, a divergent spherical wave is loaded on the phase distribution of the hologram, and its phase can be expressed as follows:

$$\phi_s = -\frac{k}{2r}(x^2+y^2), \tag{1}$$

where $k=2\pi/\lambda$, λ is the wavelength of the collimated light, and r is the radius of the divergent spherical wave. As the divergent spherical wave acts on active area of the LCoS, the focus position of zero-order light remains unchanged in the back focal plane of the solid lens, while the focus positions of the multi-order reconstructed images move backward. So we set a filter at the focal plane behind the solid lens to eliminate zero-order light. According to the diffraction theory, the complex amplitude distribution U_r behind the LCoS at r is [16]

$$U_r(x,y) = \frac{e^{ikr}}{i\lambda r}\exp[\frac{i\pi}{r\lambda}(x^2+y^2)]\int\int_{-\infty}^{\infty}[U(u,v)]\exp[\frac{-2i\pi}{r\lambda}(xu+yv)]dudv, \tag{2}$$

where $U(u,v)$ is the complex amplitude distribution on the hologram, u, v are the horizontal and vertical coordinates on the hologram, respectively, and the size of the reconstructed image behind the LCoS at r can be expressed as [17]

$$h = \frac{r\lambda}{p}, \tag{3}$$

where p is the pixel pitch of the LCoS. According to the lens' imaging equation, the distance between the focus positions of the zero-order diffraction lights and multi-order reconstructed images satisfies the following equation:

$$\frac{1}{d_1+r}+\frac{1}{d_2+d_3}=\frac{1}{d_2}. \tag{4}$$

The lateral magnification of the solid lens is $M_1=-(d_2+d_3)/(d_1+r)=-d_2/(d_1+r\text{-}d_2)$. Behind the liquid lens, we can see the reconstructed image on the receiving screen. d_5 can be expressed as follows:

$$\frac{1}{d_4}+\frac{1}{d_5}=\frac{1}{f}, \tag{5}$$

where f is the focal length of the liquid lens. The lateral magnification of the liquid lens is $M_2=-d_5/d_4=-(d_5\text{-}f)/f$. From Eqs. (2)–(5), we can get the following equation:

(6) $d_2+d_3+d_4=\frac{fd_5}{d_5-f}+\frac{d_2(d_1+r)}{d_1+r-d_2}$,

and the size of the reconstructed image on the screen is given by the following equation:

$$H=|h\bullet M_1\bullet M_2|=|\frac{r\lambda d_2(d_5-f)}{pf(d_1+r-d_2)}| \tag{7}$$