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Development of Hologram Acquisition system for Holographic Media Service

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Keywords: Holography, Holographic camera, Self-interference.

ABSTRACT

The hologram media service, including the direct acquisition, real-time processing, transfer, and displaying system, needs to be developed intensively as a futuristic immersive broadcasting system. Among them, the direct acquisition of natural light scene hologram is presented in this abstract.

1 INTRODUCTION

About a decade ago, the interest of the public and the investment of the market on three-dimensional (3D) displays and contents are grown, but now it has been quiet again. There are various practical problems as the reason for the decrease of interest, but one of the reasons is that stereoscopic technology provides incomplete 3D depth-cues which results in eye fatigue. In contrast, the holographic display provides the ultimate sense of depth, without the requirement of wearing any equipment. Therefore, it is a natural way to think that the development of holographic media service is a valuable step to prepare the futuristic immersive broadcasting system.

The holographic media service consists of the following parts. The holographic camera should capture the real-world scene as the current photographic camera does. Digital contents are created by the various computer design tools to present the virtual world scene or the augmented scene. Likewise, the creation of computer-generated holography and the transformation of a holographic dataset is required to manipulate the real or virtual world hologram. As the digital data compression and transmission techniques exist, the holographic data compression algorithms and broadband transmission systems are worth to be developed. Lastly, the holographic display is demanded to present the transmitted realistic holographic scene toward the viewer.

Among the essential parts of the holographic media service chain, the real-time acquisition technique of the natural holographic scene is discussed in this abstract. The application of the holographic recording system is quite limited so far. Because the coherent light source is mostly required to capture the macroscopic objects. And due to the two-channel interferometric structure, the holographic recording system should be mounted on the bench-top system with damping legs. A decade ago, the holographic recording systems which can record the incoherent light scene are proposed [1,2]. In these systems, the incoming beam from the unit point source is separated and modulated either by the Michelson-interferometer or the phase-only spatial light modulator, then creates an interference pattern on the image sensor by the self-interference effect. But the feasibility of those systems in various applications is limited due to the difficulty of realizing the compact design and the real-time acquisition.

Recently, the real-time video holographic recording system is proposed, which is referred to as a geometric-phase self-interference incoherent digital holography, or shortly in GP-SIDH [3]. In this system, the geometric phase (GP) lens is utilized as the wavefront modulation device. And the bias and twin image problem are eliminated by the parallel phase-shifting method with the polarized image sensor, which realizes the real-time recording of the complex hologram data [4]. The system can be implemented into a small form-factor with a low-cost optics, which seems a good candidate system of the futuristic holographic camera as a part of holographic media service.

In this paper, the recent prototype of a geometric phase based holographic recording system, as a full color incoherent holographic camera is introduced.

2 PRINCIPLE

Figure 1(a) presents the schematic illustration of the proposed system. The system consists of a conventional convex lens that collects the light from the objects, a linear polarizer, GP lens, and the color polarized image sensor. The structure of the color polarized image sensor is illustrated in Fig. 1(b), each of which is red, green, and blue color filter array, micro-polarizer array, and the photo-diode array. Here, the micro-polarizer array is composed of wire-grid polarizers with the rotation angle of 0, 45, 90, 135 degrees, in a two-by-two tiled structure.

The GP lens is a kind of meta-surface lens where the dielectric antenna layer is defined by the twisted nematic liquid crystals, instead of metallic nanorods.

The optical characteristics of this lens are very intriguing because the lens serves either as a convex or concave lens according to the input circular polarization structure. Specifically, if the lens has an original focal length of f for the input wavelength of λ with right-hand circular polarization state, then the lens has a focal length of $-f$ when it comes to the left-handed circular polarization input.

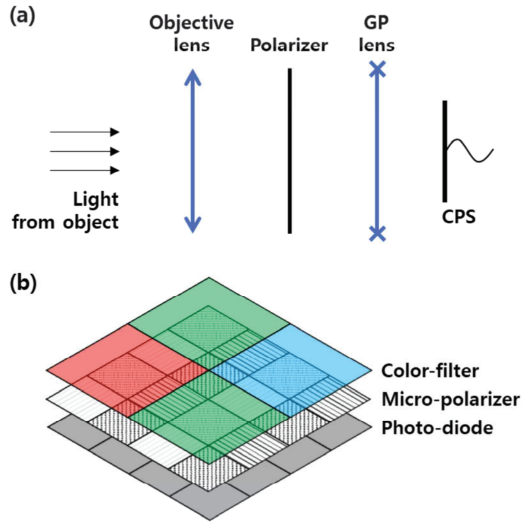

Fig. 1 (a) schematic illustration of the proposed system, (b) the structure of the color polarized image sensor (CPS).

The aforementioned polarization selective lens functionality can be applied to the common-path wavefront splitter and the modulator inside the self-interference incoherent digital holography. Because the linearly polarized light can be expressed as the sum of the two correlated waves each of which has an orthogonal circular polarization state, the GP lens serves both as a convex and concave lens. In other words, the input object wave can be modulated into the two correlated twins with different curvature radii, so that the Fresnel hologram can be obtained at the sensor plain after passing through the other linear polarizer.

The bias and twin image of the on-axis holography is a fundamental problem due to the nature of the interference. To eliminate such undesired information, and extract the complex hologram data, the phase-shifting method is utilized. In the proposed system, the phase-shifting method is easily dissolved by adopting the parallel phase-shifting method with the polarized image sensor [5]. If the orientation axis of the local area of the GP lens has an angle of Ω from the base plane, x-z plain for instance, and the relative angle between the GP lens and polarizer is θ, then the resultant intensity due to the interference at the sensor plane is proportional to,

$$2 + 2\cos(4\Omega - 2\theta)\ . \qquad (1)$$

Equation 1 implies that the rotation of the linear polarizer, relative to the GP lens, gives rise to an additional phase-shifting angle. And the amount of shifting angle is twice the rotation angle of the polarizer. Therefore, to utilize this scheme into the widely known four-step phase-shifting method, which requires the four 90 degrees of phase-shifted interferograms, the polarized image sensor is a simple solution since this device has a micro-polarizer array where the polarizer is attached on each photo-diode with 45 degrees to one another. The implementation of the polarized image sensor, instead of the rotating polarizer, provides another great benefit to the system, which is the video recording capability.

3 FULL-COLOR IMAGE RECONSTRUCTION

As long as the GP lens is a type of diffractive lens with a fixed diffraction grating along the radius axis, the focal length of the lens varies depends on the wavelength of the input light. If the lens has a focal length of f for the input wavelength of λ, then the focal length f'
is deduced from the relation of $f\lambda/\lambda'$ for different input wavelength λ'.

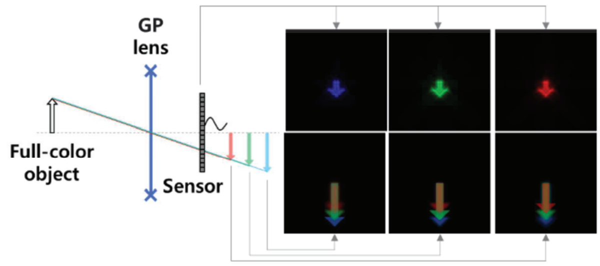

Fig. 2 Schematic diagram of the full-color holographic imaging versus general imaging.

In the case of full-color imaging with the wavelength-dependent GP lens, the captured image might suffer from a several color aberration effect, because each color channel images are focused on different focal plains, and the size of the image varies according to the focal distances. Therefore, a similar problem seems to happen in the full-color holographic recording and reconstruction process as well. However, such concern is easily resolved when it comes to the holographic recording.

As long as the purpose of the holographic recording is to intercept and capture the object wavefield in the middle of the imaging system and the corresponding imagery of the object scene, all of the chief rays of different color channels reach on the same pixel position of the image sensor. Therefore, when it comes to the general angular spectrum method for the reconstruction, the object size remains the same along with the different colors, so that the perfect full-color registration is achieved. The only thing to consider is to calculate the reconstruction distances of each color channel due to the different wavelength input. When the green channel image with the central wavelength of λ_g has a reconstruction distance of z_g, then the reconstruction distance of other wavelength λ has the following relation,

$$z = z_g \lambda_g / \lambda. \quad (2)$$

4 EXPERIMENTAL SYSTEM AND RESULT

Figure 3 shows the experimental setup of the proposed system. As mentioned above, the system consists of the general convex lens as an objective lens, linear polarizer, GP lens, and the color polarized image sensor. The relay lens is implemented to obtain a more vivid interference fringe pattern. The objective lens has a focal length of 150 mm. Since the amount of phase shifting is only dependent on the relative rotation angle of the polarizer, GP lens, and the polarizers on the image sensor, the transmission axis of the linear polarizer is set to an arbitrary angle. The GP lens has a focal length of 100 mm for 550 nm wavelength of light input (#34-466, Edmund Optics, USA). Nikon f1.2 50 mm lens is utilized as a relay lens. Then the color polarized image sensor is located (HT-12000-S, Emergent vision technologies, Canada). The pixel number of the sensor is 4096 and 3000 in the horizontal and vertical direction, respectively. The pixel size is 3.45 μm. Because the parallel phase-shifting method is applied to obtain a complex hologram, the pixel number of the extracted hologram is 2048 by 1500, and the effective pixel size is doubled. The color filtering occurs only at the color filter on the image sensor.

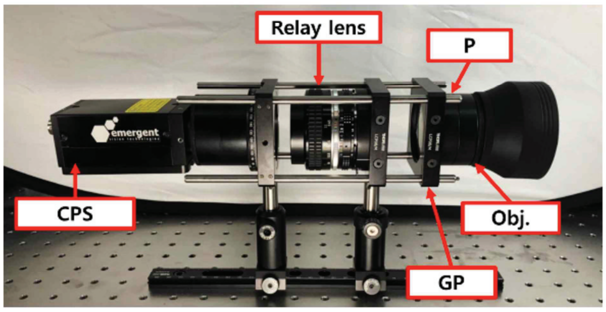

Fig. 3 Experimental setup. Obj.: objective lens, P: polarizer, GP: GP lens, CPS: color polarized image sensor.

For the sake of demonstration of the system, the hand holding an object is captured and presented in Fig. 4. The light source is a broadcasting purpose white LED lighting. 20 images are captured within 1 second, while holding the hand in the air, in front of the system, then averaged to reduce the noise of the hologram. Four phase-shifted color interferograms are extracted from the single raw image, then recombined to complex hologram without the bias and twin image noise. Then the angular spectrum method is applied to reconstruct the hologram for each color channel. Thanks to the single-shot recording capability, the appearance of the fingers is expressed well even though the slight movement of the unsupported hand. The focus variation of the image is well observed in Fig. 4(b).

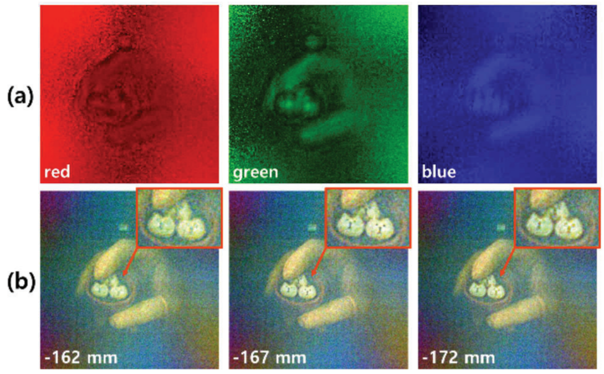

Fig. 4 Full-color hologram sample demonstrated by the proposed system. (a) the red, green, and blue channel phase-angle hologram, (b) full-color reconstruction results. The digits below each figure show the reconstruction distances.

5 CONCLUSION

The full-color single-shot hologram recording system is introduced and the demonstration sample result is presented. This system is highly portable and capable of video recording. The components required in the system are simple and cost-effective. The system seems a good candidate for the futuristic holographic camera as a part of the holographic media service chain, in this respect.

ACKNOWLEDGEMENTS

This work was supported by Institute of Information & communications Technology Planning & Evaluation (IITP) grant funded by the Korea government(MSIT) (No. 2019-0-00001, Development of Holo-TV Core Technologies for Hologram Media Services)

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