Optical Reconstruction of 3D Information Acquired by Incoherent Digital Holography

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ABSTRACT

Holograms acquired by incoherent digital holography (IDH) contain information on the depth direction. We acquired objects placed at different depths by IDH, generated a hologram for display by using the acquired hologram for calculation, and reconstructed the hologram. As a result, we could display images of objects three-dimensionally.

1 Introduction

Incoherent digital holography (IDH) can acquire three-dimensional (3D) information of an object under incoherent light such as light-emitting diode (LED) light and sunlight [1,2]. Although incoherent light has low coherence, a hologram can be generated on the basis of the self-interference of light from an object (object light), which is produced by separating the object light into two optical paths, making a slight optical-path difference for one path, and then combining them. A two-dimensional image focused at an arbitrary depth can be reconstructed by back-propagation calculation from holograms acquired by IDH. In addition, displaying 3D images using horizontal parallax was reported [3]. With this method, holograms of an object were acquired from multiple angles in the horizontal direction by IDH, and a 3D image was displayed using a holographic stereogram. However, it is possible to display a 3D image from a hologram taken at a single location because a hologram acquired by IDH contains information on the depth direction.

In this study, we display a 3D image using a hologram generated on the basis of 3D information obtained from holograms acquired by IDH. In addition, the non-linearity of IDH can be compensated. First, we get a hologram via IDH. Next, on the basis of the 3D information obtained from the acquired hologram, the object and the depth distance of the object are identified [4]. Then, a hologram for display is generated by calculating the propagation of light from the object using the depth distance. Finally, this hologram is displayed on a spatial light modulator (SLM) and optically reconstructed.

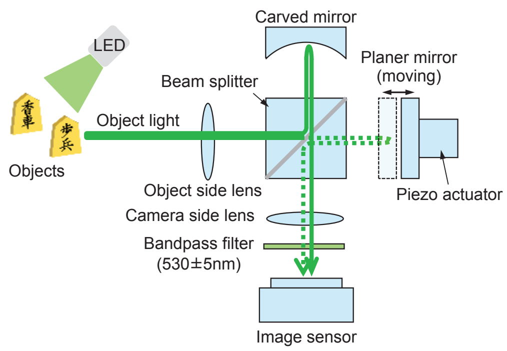


Fig. 1 Optical setup of IDH for acquiring hologram

2 Experiment

2.1 Hologram acquired via IDH

Figure 1 shows the optical setup for acquiring an object via IDH. The object is illuminated with an LED light, and its reflected light (object light) passes through the object side lens and is divided into two optical paths by a beam splitter (BS). One is reflected by the planar mirror and the other by the curved mirror with slight focusing. Both the reflected lights enter the BS again and interfere. The interfered light passing through the camera side lens and the bandpass filter is captured using an image sensor as interference fringes. In this optical setup, we used two-inch optical elements. Furthermore, a phase-shifting method is used to obtain a complex amplitude distribution of the hologram. We placed the planar mirror on a piezo actuator, which can control the phase of interference fringes with $\pi/2 \times n$ (n = 0,1,2,3) each. By shifting the phase of light sequentially, holograms with four different phases can be obtained. From these four holograms, the complex amplitude distribution of the hologram can be calculated.

2.2 Generation of hologram for display

A hologram for display is generated from the hologram acquired by IDH described in the previous

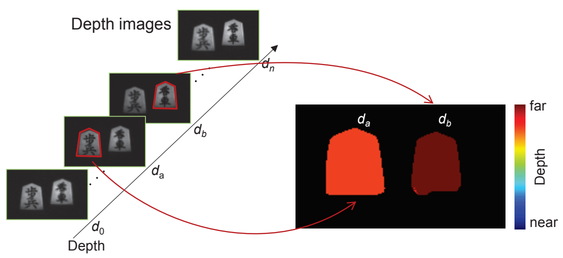


Fig. 2 Obtaining depth map of objects from depth images

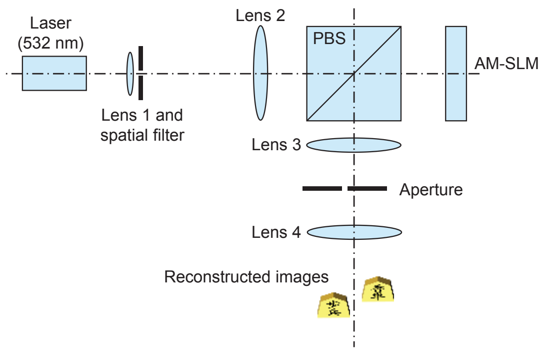
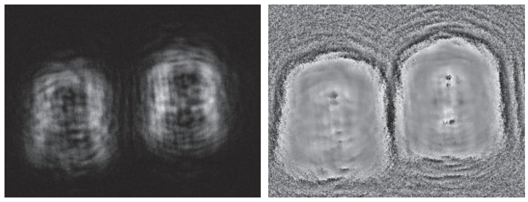
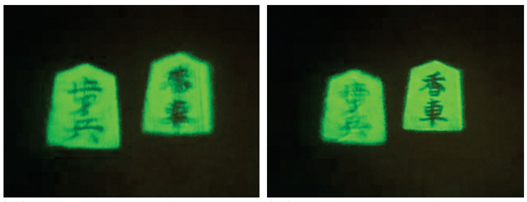


Fig. 3 Optical setup for reconstruction



(a) amplitude (b) phase

Fig. 4 Complex amplitude distribution of hologram of objects acquired by IDH



(a) Focused on "Fu" (b) Focused on "Kyosha"

Fig. 5 Reconstructed images

section. First, by calculating the back propagation of light using the Fresnel propagation from the hologram acquired by IDH, arbitrary depth images as shown on the left side of Fig. 2 are reconstructed. Next, the objects in the reconstructed images are identified. The depth of the object becomes the distance information *d* when the depth image with the focused object is reconstructed, as shown on the right of Fig. 2. Then, on the basis of each object and its depth distance, the light from each object (object light) propagates to the hologram plane. A hologram for display is generated by superimposing the propagated object light and the reference light of the plane wave on the hologram plane.

2.3 Reconstruction of hologram

Figure 3 shows the optical setup that reconstructs 3D images from generated holograms for display in the previous section. The laser beam is magnified by lenses 1 and 2 and incident on the amplitude modulation SLM (AM-SLM). The generated hologram is displayed on the AM-SLM. The laser beam reflected by the AM-SLM is focused by lens 3. An aperture is set on the focal plane to block light other than the primary light carrying the object information. The primary light passes through the aperture and lens 4, and a reconstructed 3D image is obtained.

3 Result

Two shogi pieces, "Fu" placed at the left side front and "Kyosha" at the right side back, were used as objects. They were placed at different depths whose gap was 100 mm, illuminated by green LED light, and holograms were acquired by IDH. Figure 4 shows the complex amplitude distribution of a hologram obtained by the phase-shifting method. By using this hologram, a hologram for display was generated. Figure 5 shows the reconstructed image when the hologram for display was displayed on the AM-SLM in Fig. 3 and reconstructed. The wavelength of the laser was 532 nm. Figure 5 (a) is an image of "Fu," and Fig. 5 (b) is an image of "Kyosha" in focus. When one piece was focused on, the other piece was out of focus, and these pieces placed at different positions in the depth direction could be displayed three-dimensionally. We confirmed that a 3D image could be reconstructed using a hologram generated on the basis of 3D information acquired by IDH.

4 Conclusion

We acquired a hologram of objects by IDH, generated holograms for display, and reconstructed images of objects. Objects placed at different positions in the depth direction were illuminated with LED light, and holograms were acquired by IDH. Next, on the basis of 3D information obtained from acquired holograms, the objects and the depth distance of the objects were identified, and a hologram for display was generated by calculating the propagation of object light and reference light. When the generated holograms were displayed on an AM-SLM, we could reconstruct images of the objects three-dimensionally. We confirmed that 3D images could be reconstructed by using holograms generated on the basis of 3D information acquired by IDH. This technology is useful for acquiring and displaying 3D information using holography.

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