Faithful Wavefront Synthesis for Holography Using Light Field and Depth Information

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ABSTRACT

A novel image capturing technique for holography is proposed, which utilizes both the light field and depth cameras. The depth and light field information are used to determine the shapes of zone plates and their amplitude modulation, respectively. The proposed technique can generate faithful wavefronts which produce sharp 3D images.

1 Introduction

Holographic displays can reconstruct wavefront which generates sharp three-dimensional (3D) images in space [1]. However, the holographic technique to capture 3D images is not practical because dark-room and anti-vibration environments are required. This study proposes the technique which enables to synthesize faithful wavefront using both light field and depth cameras.

Several techniques have been proposed to transform light field information into wavefront [2-4]. However, they can generate incomplete wavefront because they reconstruct rays using the holographic technique. The light field information includes the intensities and the directions of rays. The light field displays cannot produce sharp 3D images in space, because rays diverge in space and the superposition of rays do not reduce the beam width of rays. Thus, the wavefront synthesized by the conventional techniques inherits the demerit of the light field displays. Therefore, the conventional techniques spoil the important advantage of the holographic displays.

This study proposes the technique which enables to synthesize faithful wavefront that produces sharp 3D images in space using the light field information captured by the light field camera and the depth information captured by the depth camera. Because the light field cameras and the depth cameras are commercially available, the proposed technique provides a practical way to realize the holographic camera.

2 Theory

The technique proposed in this study is based on the wavefront synthesis technique using the amplitude modulation of zone plates which we have previously proposed [5]. In this previous technique, the 3D objects are modeled as an aggregate of object points and zone plates generating the object points are superimposed to synthesize holograms. The amplitude distributions of the zone plates are modulated based on the Phong shading so that the reconstructed images are shaded.

This study proposed the wavefront generation technique which utilizes the depth information captured by the depth camera to determine the 3D positions of the object points. The light field information captured by the light field camera is utilized to modulate the amplitude distribution of the zone plates generating the object points. As shown in Fig. 1, the technique proposed in this study uses both the depth and light field information to produce the faithful wavefront which can generate sharp 3D images in space. The conventional techniques use only the light field information to produce the wavefront which cannot fundamentally generate sharp 3D images.

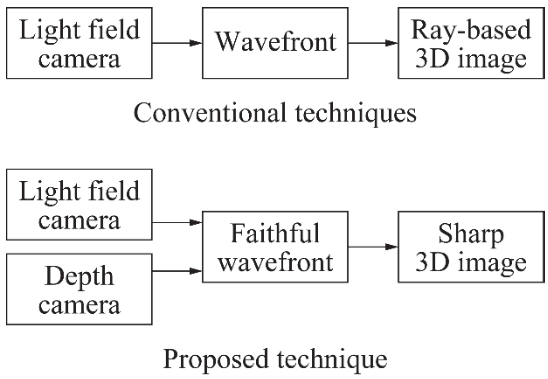


Fig. 1 Wavefront synthesis by conventional and proposed techniques.

Fig. 2 illustrates the image capturing setup used in this study. The camera array used for the light field camera is located on the (u, v) plane. The screen where the cameras are focused is located on the (s, t) plane, which is the screen of the holographic display. The optical axis lies along the z-direction. The position of the depth camera is arbitrarily determined while the measured 3D positions are defined relative to the coordinate system.

The principle of the wavefront synthesis proposed in this study is depicted in Fig. 3. The 3D positions of the object points (x_o, y_o, z_o) are determined from the depth information from the depth camera. Then, the shape of the zone plate is defined for each object point, i.e., the center, the radius, and the period. Next, rays emitted from all points on the zone plate are considered and the positions of the rays intersecting on the camera plane (u, v) are calculated. For each ray, the nearest and the second nearest cameras from the intersection are determined to calculate the intensity of the ray by interpolating the pixel values at the ray emitting point in the images captured by the two cameras. The squared root of the obtained intensity is used as the amplitude at the ray emitting point of the zone plate. Consequently, the amplitude modulations of the zone plates are determined using the light field information from the light field camera.

The amplitude modulation of the zone plate can be easily calculated using the Epipolar geometry [6]. The rays in the light slab between (s, t) and (u, v) planes are represented in the (s, t, u, v) space [7]. Fig. 4 shows the (s, t, u) space for the ease of illustration. The cross section plane corresponding to the 3D position (x_o, y_o, z_o) of the object plane is considered. The distribution on the cross section plane provides the amplitude distribution of the zone plate for the object point.

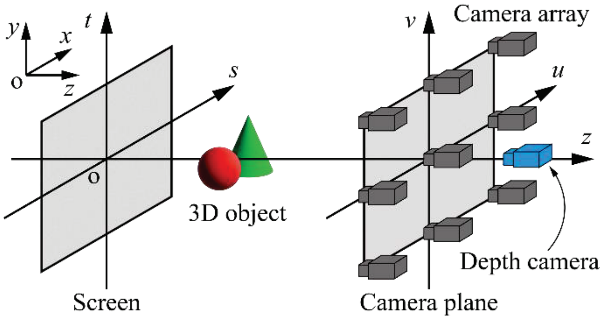


Fig. 2 Image capturing setup.

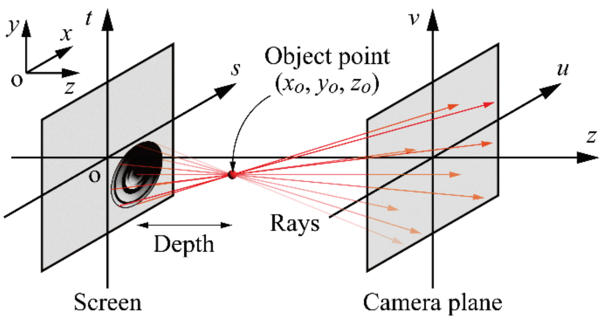


Fig. 3 Wavefront synthesis technique proposed in this study.

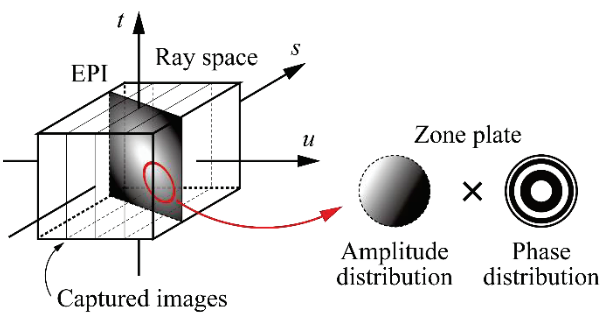


Fig. 4 Calculation of amplitude modulation of zone plate using Epipolar geometry.

3 Experimental Results

The proposed light field wavefront conversion technique was verified experimentally.

The 3DCG software (Blender) was used to obtain the depth image captured by the depth camera and multi-view images captured by the camera array. The resolution of the depth image was 320 × 180 and that of the multi-view images was 640 × 360. The camera array consisted of 16 × 9 cameras. Thus, the number of object points was 320 × 180 and the light field information contains 640 × 360 × 16 × 9 rays.

The SLM used for the experiments was HOLOEYE GAEA-2 (HOLOEYE Photonics). The resolution was 3,840 × 2,160 and the pixel pitch was 3.74 μm. The light source was He-Ne laser with a wavelength 632.8 nm. The 4*f* imaging system was used to eliminate the conjugate image and zero-order diffraction light [8]. The size of screen was 14.4 mm × 8.08 mm, and the viewing angle was 9.7° × 4.8°.

The reconstructed images produced by the holograms generated by the proposed technique is shown in Fig. 5. The radial pattern and the checker pattern were located at the distances of 3 mm and 16 mm from the screen, respectively. In the upper and lower photos, the camera was focused on the radial and checker patterns, respectively. From this figure, the generation of sharp 3D image by the proposed technique was confirmed.

Fig. 6 shows reconstructed images of a metal sphere and a glass sphere in a cuboid having a checker board floor. The left metal sphere reflected the floor, while the right glass sphere refracted the floor. The focus of the camera was changed in the depth direction.

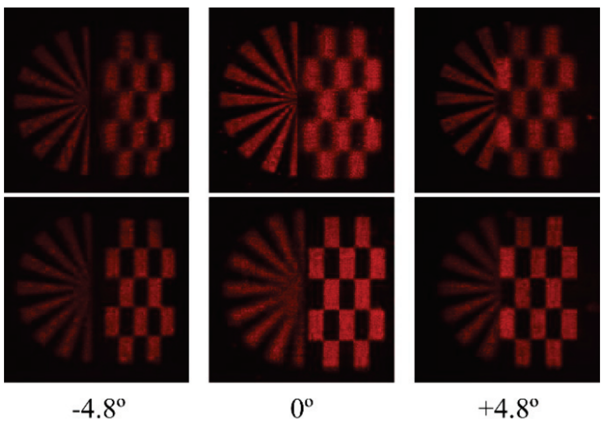
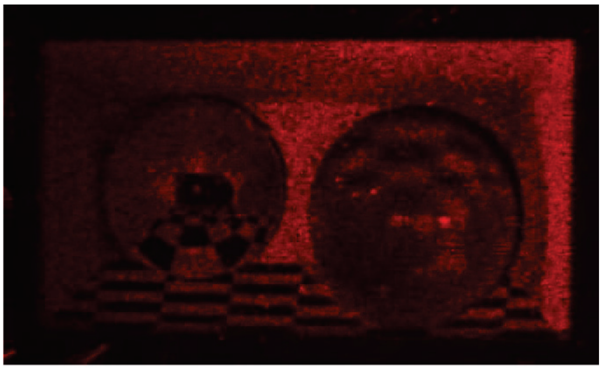
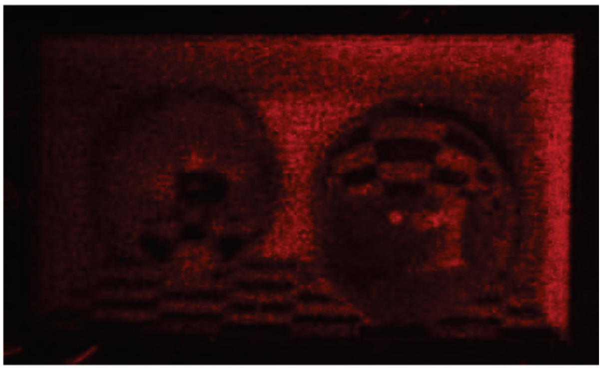


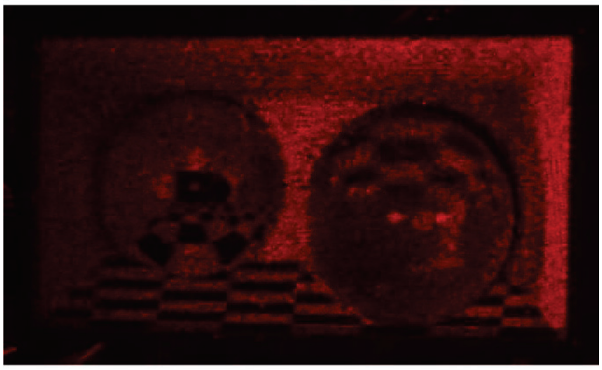
Fig. 5 Reconstructed images: focus and horizontal position of camera was changed.



(a)



(b)



(c)

Fig. 6 Reconstructed images of metal and glass spheres: camera focus was (a) on the metal sphere, (b) on the glass sphere, and (c) at the middle of the two spheres.

4 Conclusions

The technique to synthesize the faithful wavefront using the light field and depth cameras was proposed. The effectiveness of the proposed technique was experimentally verified.

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