Application of wavefront printer -from static 3D visualization to projection-type holographic display-

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Abstract: Wavefront printer can record arbitrary designed wavefront not only for static 3D visualization but also for holographic screen to be used on projection-type holographic display. Some applications related to the wavefront printer are introduced.

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1. Introduction

For hologram recording of digital three-dimensional (3D) data, wavefront printer has been proposed by several research groups [1-4]. In contrast to a holographic stereogram (HS) printer that is based on the recording/reconstruction of dense light-rays, wavefront printer records the wavefront with full-control of both amplitude and phase distributions reproduced by computer generated holograms (CGH). Therefore the expected application of wavefront printer is not only 3D data visualization but also the fabrication of holographic optical element (HOE) implemented with a digitally designed arbitrary optical function. In this paper the basic principle of wavefront printer is introduced and then the some applications; recording of real/virtual 3D data for visualization, fabrication of HOE as a holographic screen used on projection-type holographic 3D display are reported.

2. Principle of wavefront printer

In pre-processing of wavefront printing, an arbitrary wavefront to be recorded is transformed to a CGH and then it is divided into a set of sub-CGH if the pixel number of spatial light modulator (SLM), which is used in wavefront printer, is not enough to display an original CGH.

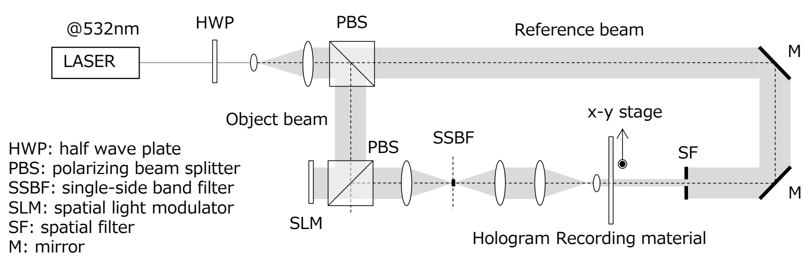

Fig.1 Optical setup

Fig.1 shows the optical system of our wavefront printer. In A collimated light at 532 nm of wavelength is split by polarization beam splitter (PBS) and then, two beams will form an object beam and a reference beam to record a sub-hologram as a reflection-type volume hologram. Sub-CGH is displayed on SLM and the reproduced wavefront passing through the reduction optical system is sequentially recorded as a sub-hologram at the given region in tilling manner to form an entire hologram by using a motorized X-Y stage. Cobestro Bayfol®HX-102 photopolymer film is used as a hologram recording material. After the recording of all sub-holograms, holographic recording material is then processed by the bleaching so as to own high transmission at visible light wavelength.

3. Recording 3D data of real/virtual objects

To confirm the potential of wavefront printer for 3D data visualization, 3D data of both real and virtual objects were recorded. CGHs of the real object: the miniature stature of "Buddha", and the virtual object: 3DCG (3D computer graphics) data "Venus", were calculated based on the holographic stereogram (HS) based approach from 544 × 544 of perspective images at 512 × 512 pixels rendered by CG rendering software. In the case of "Buddha", 47 of multi-view images were taken from random positions by the camera and then the pictures were combined to generate 3D CG data on the software "123D catch" [5] to render a set of perspective images. The hologram size was set 10 × 10 cm and the total pixel number of CGHs were 278,528 × 278,528 pixels. All of CGH calculation processes from a set of perspective images were executed on the supercomputer TSUBAME2.5 provided by GSIC center in Tokyo Institute of Technology [6]. CGHs were then divided into 155 × 155 of sub-hologram data at 3,600 × 1,800 pixel considered with overlapping recording condition [4].

Fig.2 shows the original 3D data "Venus", "Buddha" and the results of optical reconstruction. Both 3D contents were successfully recorded into the holograms. Since the recorded holograms have the wavelength selectivity as a principle of reflection-type volume hologram, the white illumination light source could be used for the optical reconstruction.

Fig.2 Application of 3D data visualization

4. Fabrication of holographic screen for projection-type holographic 3D display

DDHOE (digitally designed holographic optical element), which is an HOE fabricated by using the wavefront printing technique, has several advantages compared with the general diffractive optical element/HOEs, for example, the freedom of implemented optical functions, the ease of fabricating large HOEs, good transparency due to its wavelength selectivity. In this section, the application example of DDHOE fabricated to be used as a holographic screen on projection-type holographic 3D display is introduced. Generally holographic 3D displays have the inherent trade-off between two parameters: the display size and the visual angle to view the entire display area, due to the severe limitation of the spatial-temporal resolution of current SLM for holographic 3D display use. From the viewpoint of the practical use, however, freely design of both parameters is important to allow wide application fields such as digital signage, in-car head-up displays, smart-glasses and head-mounted displays. To overcome the trade-off between the display size and the visual angle, the projection-type holographic 3D display in which the DDHOE of holographic screen is used as a see-through screen of holographic projection technique. In this approach, the digital holographic projector magnifies the holographic image on the DDHOE screen. This holographic image is then reflected to the target observation point by the implemented optical function of DDHOE screen. From the center of projection at $(0, 0, z_P)$ to the target observation point at (x_O, y_O, z_O), the phase distribution implemented on the DDHOE screen is defined as

$$\phi(x,y) = -\frac{k}{2d}\left(x^2+y^2\right)+\frac{k}{2z_P}\left(\xi^2+\eta^2-2\xi x-2\eta y\right) \quad (1)$$

where the origin of XYZ coordinate was set at the center of DDHOE screen, $d = z_O z_P/(z_O + z_P)$, ξ and η are

$$\xi = -\frac{z_P}{z_O}x_O, \quad \eta = -\frac{z_P}{z_O}y_O. \quad (2)$$

In this time, the center of projection and the target observation point were set at (0 mm, 0 mm, 1,000 mm) and (0 mm, 59 mm, 200 mm), respectively. Fig. 3 shows the visualization of the optical function of the fabricated DDHOE screen. In the artificial fog, the spherical wave, which is supposed to the holographic projection light, propagated from (0 mm, 0 mm, 1,000 mm) to the DDHOE screen, then the incident light was reflected to be focused at the target observation point [see Fig.3 (a)].

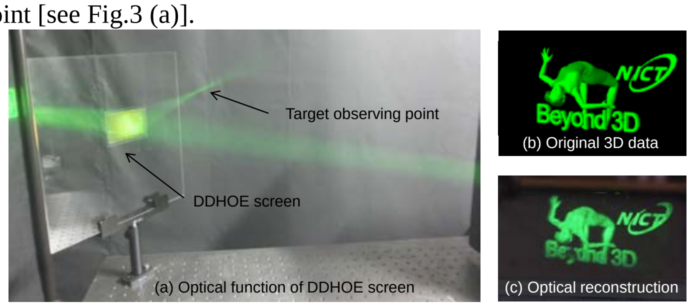

Fig.3 Optical function of DDHOE screen and the optical reconstruction of projection-type holographic 3D display

Fig.3 (b) shows the original 3D data to be displayed in the experiment. The CGH data of this content was calculated based on HS approach. The holographic projector had 8K (7,680 × 4,320 pixels) SLM at 4.8 μm of pixel period. The optically reconstructed wavefront of the CGH was then projected on the DDHOE screen by the projection lens at 1,500 mm of the focal length. The magnification ratio was set 2.0 and so the display size became 75.4 × 41.4 mm^2. Fig.3 (c) shows the result of optical reconstruction. It is clear that the holographic image was successfully observed at the target observation point via the see-through holographic screen of DDHOE.

5. Conclusion

An overview of wavefront printing technique and its some applications: 3D data visualization and fabrication of digitally designed HOE to be used on the projection-type holographic 3D display, were introduced. In the future work, the full-color wavefront printer and speed up of recording process will be handled.

6. Acknowledgement

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6. References

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