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Denisyuk-type Wavefront Printer Developed for Printing Large-Scale Display CGVH

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ABSTRACT

The latest status of development is presented in a novel type of wavefront printer called the Denisyuk-type wavefront printer. The introduced 4K high-definition SLM and improved optics facilitates fabrication of large-scale full-parallax CGVHs with a wide viewing angle.

1 Introduction

Computer-generated hologram (CGH) is a hologram created by generating interference fringe of virtual object using a computer. The calculated fringe pattern is printed with a very fine printing equipment, such as e-beam or laser lithography systems. However, the holograms obtained by the ordinary printing systems are so-called 'thin holograms' because the ordinary printing systems print two-dimensional fringe pattern. As a result, the printed CGHs exhibit chromatic aberration when illuminating with white light. On the other hand, the fringe of volume holograms, sometimes called 'thick' hologram, has a three-dimensional structure and thus gives wavelength selectivity. Accordingly, volume holograms can avoid the issues of thin holograms and reconstruct 3D images with a white light illumination.

In a conventional manner, fabrication of computer-generated volume holograms (CGVH) requires two steps: creation of a master hologram using lithography, and transfer of the holographic image onto the recording material such as photopolymer [1]. A Wavefront printer is the equipment that makes it possible to perform these processes in a single step [2-5]. In the conventional wavefront printers, light emitted from a coherent light source is commonly split into two arms using a beam splitter: beams for a write field recorded in the recording material and reference field. The beam for the write field is commonly split again in order to use an LCOS spatial light modulator (SLM) for producing the write field, i.e., wavefront. As a result, intensity of the write field decreases to one-eighths of the output of the light source, in general. This reduction leads to longer exposure time and increases vulnerability to vibrations.

A Denisyuk-type wavefront printer is proposed to overcome the problem of reduction of the write field [6, 7]. This type of wavefront printer not only avoids reduction of the write field but also reduce the number of optical components used in the system. Therefore, the printer features more simple, compact and resistant to vibrations during printing.

In this paper, we present the latest status of the development of the Denisyuk-type wavefront printer, where a 4K SLM is introduced to increase the size and viewing angle of full-parallax high-definition (FPHD) CGVHs. In fact, we demonstrate an FPHD-CGVH whose size is 12.3 cm × 9.0 cm. The viewing angle is 33° in both horizontal and vertical directions. Not only a presentation on the wavefront printer but also actual

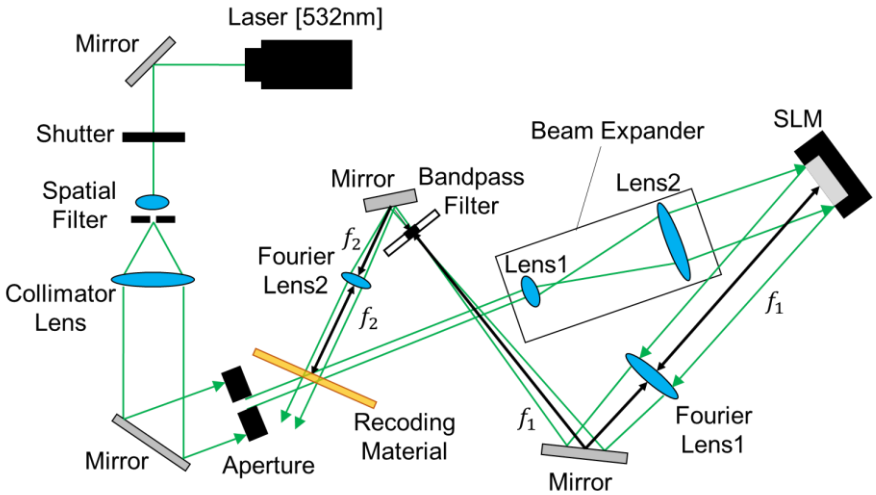

Fig. 1 Optical setup of the Denisyuk-type wavefront printer.

Table 1 Specifications of SLM.

Model	JD7714 (Jasper Display)
Number of pixels	4,094 × 2,400
Pixel pitches [μm]	3.74 × 3.74
Display size [mm^2]	15.31 × 8.97

Table 2 Parameters of the printed CGVH.

Design wavelength [nm]	532
Number of tiles	32 × 40
Total number of samples of write field	131,008 × 96,000
Sampling interval of write field [μm]	0.935 × 0.935
Size [mm^2]	122.5 × 89.7
Viewing angle [deg]	33.1 × 33.1
Settling time [s]	3
Exposure time [s]	0.25
Photopolymer	Bayfol®HX200

printed CGVHs will be presented in the poster or exhibition room.

2 Denisyuk-type wavefront printer

2.1 Principle

Denisyuk hologram is a hologram, where subjects are illuminated by light transmitted through the recording material. The hologram fringe is generated by optical interference between the object field reflected by the subjects and the light entering the recording material. As a result, the optical system is very simple because of no beam splitting. Since the generated fringe has a 3D structure, the recorded hologram is a volume hologram.

2.2 Optical setup

Figure 1 and Table 1 show the optical setup of the Denisyuk-type wavefront printer where a 4K SLM introduced in this work. In the optical system, the output of the laser light source is converted into a collimated beam using the spatial filter and collimator lens. The collimated beam is then shaped into a rectangular beam using a variable rectangular aperture. The rectangular beam passes through a photopolymer sheet used for the recording material and illuminates 4K LCOS SLM after transmitting the beam expander. The write field generated by the 4K SLM irradiates the photopolymer almost perpendicularly to the surface after passing through a 4-f optical system with the bandpass filter. In this optical setup, since f_1 = 400 mm and f_2 = 100 mm, the effective sampling interval of the write field is reduced to 0.935 μm.

2.3 Tiling small CGVHs

The space-bandwidth product of the write field produced by the SLM is very small. Therefore, the tiling technique is commonly used in wavefront printers to increase the size of holograms. As shown in Fig. 2, a large-scale wavefield of the write field is first calculated and then divided into small sub-fields (tiles) that can be generated by the SLM. The sub-fields are printed sequentially as moving the photopolymer using an automatic stage. This allows us to reconstruct the whole large-scale wavefield.

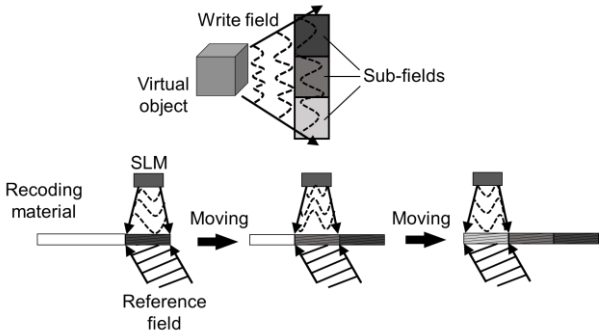

Fig. 2 Printing by tiling.

3 Printing large-scale CGVH

The 3D scene of the printed CGH is shown in Fig. 3. A checkerboard wallpaper is placed behind the surface model of the Venus statue. The full-parallax wavefield of the 3D scene is calculated with the polygon-based method and the silhouette method for occlusion processing [8].

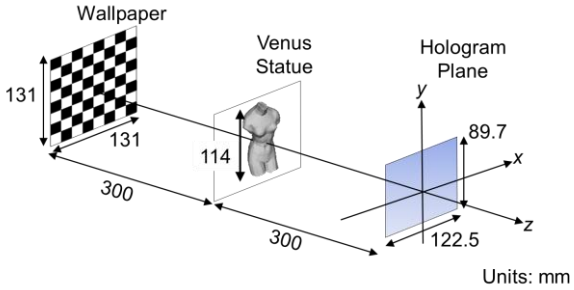

Fig. 3 The 3D scene of the printed CGVH.

The parameters of the printed CGVH are presented in Table 2. The total number of samplings of the write field is more than 12.5 billion. The size of the printed CGVH is approximately 123 mm × 90 mm. This is achieved by combination of 32 × 40 tiles. The sampling interval of the write field is reduced to one-fourth of the SLM pixel pitches by the 4-f setup in Fig. 1. To avoid vibration caused by moving the photopolymer by the stage, a settling time between printing sub-tiles is set to 3 seconds. The total printing time of the CGVH was approximately 2.5 hours.

4 Optical reconstruction of printed CGVH

The photographs of optical reconstruction of the printed FPHD-CGVH are shown in Fig. 4, where a pigtail white LED is used for the illumination light source. We can confirm apparent occlusion when moving the

viewpoints because of the large size and wide viewing angle of the printed CGVH.

5 Conclusion

We reported the latest Denisyuk-type wavefront printer, where 4K high-definition SLM is installed and the improved optics achieves fabrication of 12.5 G-sampled large-scale CGVHs with a viewing angle more than 30°.

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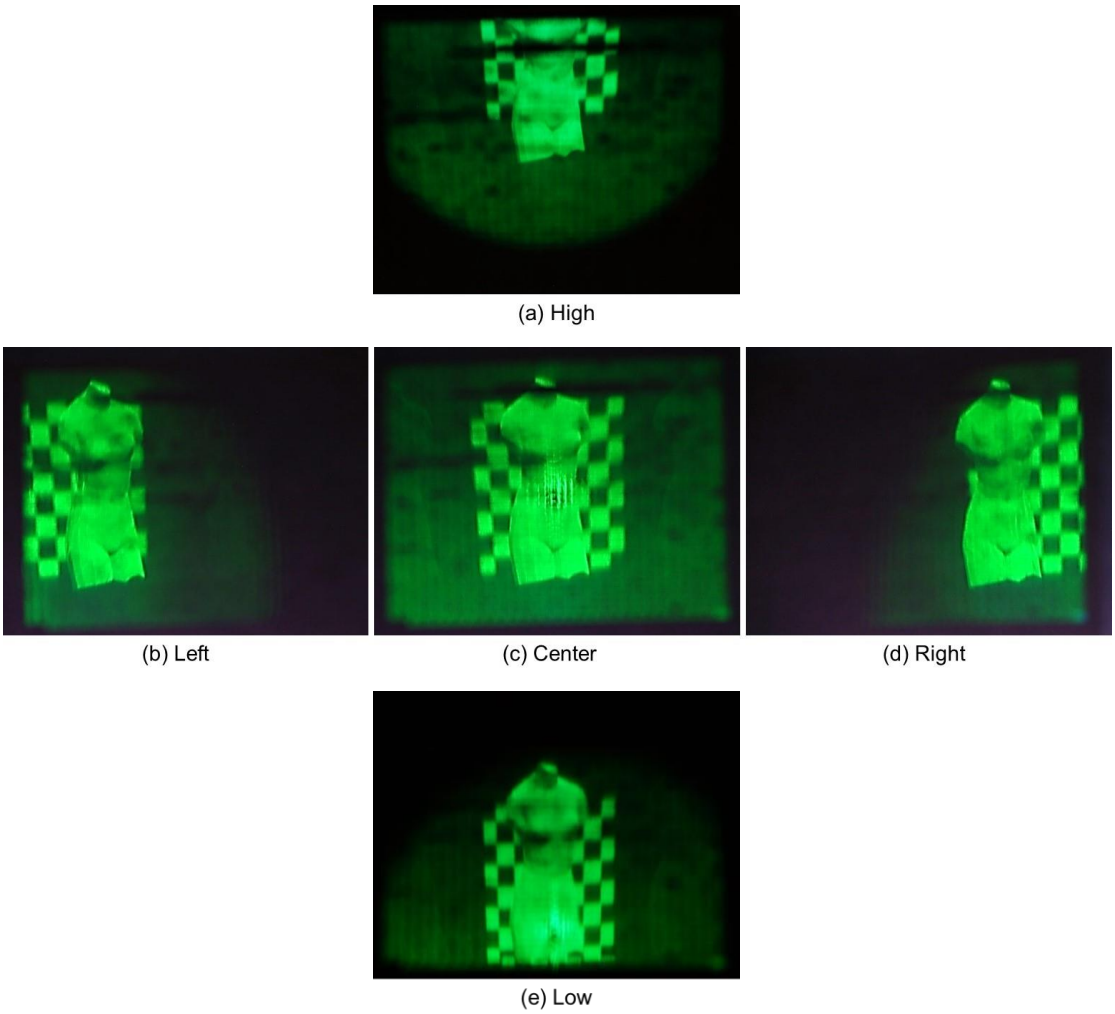

Fig. 4 Optical reconstruction of the printed FPHD-CGVH. The pictures are taken from different viewpoints.