Real-time Aerial 3D Display Using Holographic Projector

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ABSTRACT

We report aerial 3D display using holographic projector and retroreflector. Holographic projector projects the focused 3D image on 3D screen. The transmitted diffuse light generates a 3D real image in air using retroreflector. Finally, we realized real-time aerial 3D display of the 3D movie comprising 28,520 points at 30 fps.

1 Introduction

With the spread of COVID-19 infections, aerial displays that can project real images in the air have been attracting attention. Aerial displays using retroreflective transmissive optical elements [1][2] or retroreflector (Aerial Image by Retro-reflection: AIRR) has been reported [3]. Furthermore, aerial display of three-dimensional (3D) images using a light field display for AIRR [4] and aerial display of 3D images using a conventional projector to map two-dimensional images projected by a conventional projector onto a 3D screen and the reflected light from the screen for AIRR have also been reported [5].

On the other hand, a projection of a 3D image by a holographic projector has been proposed [6]. A holographic projector is a technology that projects images by computer-generated holograms (CGH). A single holographic projector can project a focused 3D image onto multiple arbitrarily shaped 3D screens placed at arbitrary locations. However, a computer-generated hologram (CGH) calculation is enormous. In our previous work, high-speed CGH computations using GPU have been reported [7-9]. However, our previous CGH calculation method [7] no longer fully exploits the performance of an Ampere architecture GPU [10]. To achieve CGH calculations that fully exploit the performance of an Ampere GPU, the number of trigonometric calculations must be reduced. We proposed the simple and fast CGH calculation algorithm to reduce the number of the trigonometric function calculations [11].

In this research, we proposed a real-time aerial 3D display using holographic projector and retroreflector.

2 Method

In the proposed holographic 3D display, we used a simple algorithm to calculate an in-line phase-type CGH from the 3D object of the point cloud model.

Fig.1 shows the coordinate system of a phase-type CGH. A 3D object is consisted of N_p points. In this study, we use the following equation to calculate the phase of light wave on phase-type CGH.

$$\theta(x_\alpha, y_\alpha) = \tan^{-1}\frac{\sum_{j=1}^{N_p} A_j \sin\phi_j}{\sum_{j=1}^{N_p} A_j \cos\phi_j}, \tag{1}$$

2.1 Phase-type CGH calculation

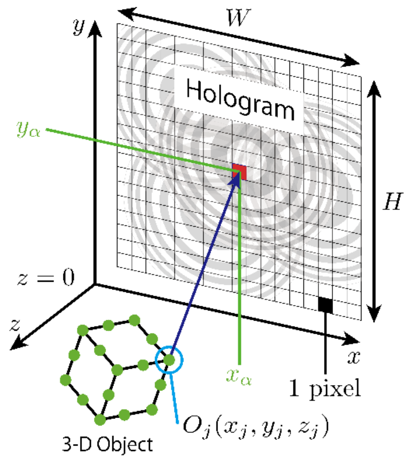

Fig. 1 Coordinate system of CGH

$$\phi_j = \frac{\pi}{\lambda z_j}\left\{(x_\alpha - x_j)^2 + (y_\alpha - y_j)^2\right\}, \tag{2}$$

where θ (x_a, y_a) is the phase of light wave on the pixel position (x_a, y_a) of a phase-type CGH. (x_j, y_j, z_j) and A_j indicate the coordinate and intensity of the j-th object point on the 3D object, respectively. λ is the wavelength of the reconstructing light.

2.2 GPU computation [11]

The following equations are obtained from trigonometric addition formulas.

$$\theta(x_\alpha, y_\alpha) = \tan^{-1}\frac{\sum_{j=1}^{N_p} A_j \sin(X+Y)}{\sum_{j=1}^{N_p} A_j \cos(X+Y)}, \tag{3}$$

$$\theta(x_\alpha, y_\alpha) = \tan^{-1}\frac{\sum_{j=1}^{N_p} A_j\,(\cos X \sin Y + \sin X \cos Y)}{\sum_{j=1}^{N_p} A_j\,(\cos X \cos Y - \sin X \sin Y)}, \tag{4}$$

where Z, X, Y are define as follows:

$$Z = \frac{\pi}{\lambda z_j}, X = Z(x_\alpha - x_j)^2, Y = Z(y_\alpha - y_j)^2.$$

Figure 2 shows the outline of our GPU computation to reduce the number of trigonometric function calculations in Equation (3). In Figure 2, phase-type CGH computation is performed as follows:

Step 1) sin X and cos X in the x direction are calculated, respectively.
Step 2) sin Y and cos Y in the y direction are calculated, respectively.
Step 3) The phase θ (x_a, y_a) on the pixel position (x_a, y_a) of phase-type CGH is obtained from the calculated values at Step 1 and 2.

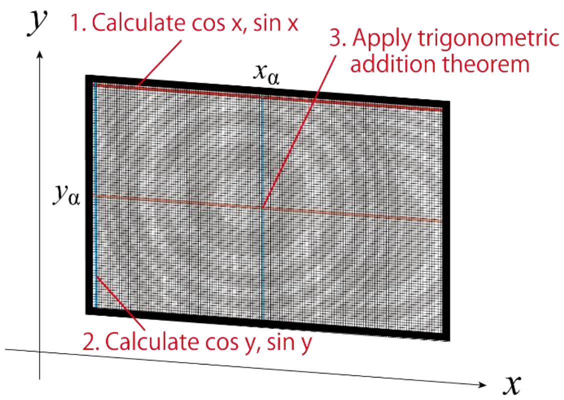

Fig. 2 Outline of our GPU computation

2.3 Holographic projector

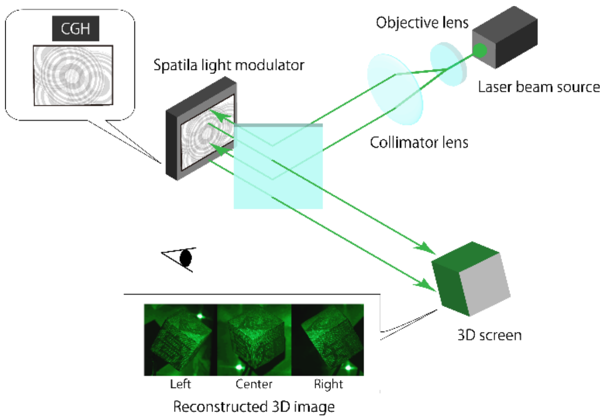

Fig. 3 Outline of holographic 3D image projection

Figure 3 shows holographic projection mapping using a holographic projector. A laser beam is used as the reconstructing light. Collimated light is produced by the objective lens and collimator lens. The collimated light reflects off a half-mirror and is irradiated onto a reflective spatial light modulator (SLM). The diffracted light reflected from the SLM is then irradiated onto a 3D screen to reproduce a 3D image.

A holographic projector can freely change the distance, size, shape, etc. of the reproduced 3D image by recalculating CGH, without using lenses. A single Holographic projector can project focused images on multiple screens at different distances and angles. Furthermore, as shown in Figure 3, it is possible to project 3D images onto a 3D screen.

2.4 Holographic aerial 3D display

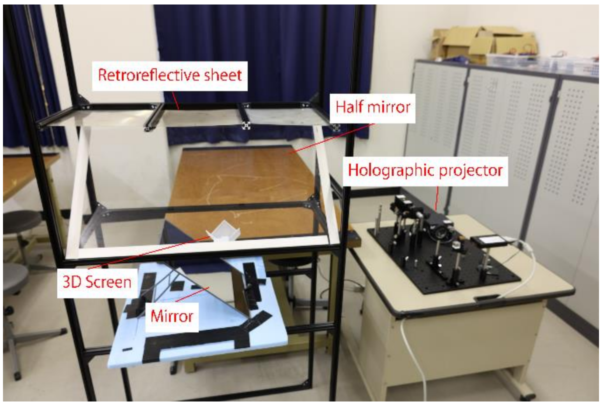

Fig. 4 Holographic aerial 3D display system

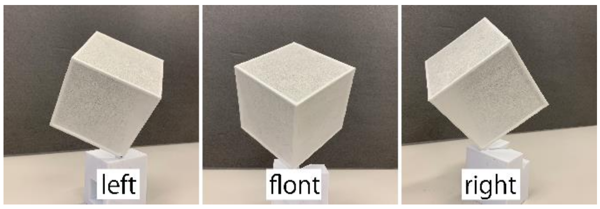

Fig. 5 3D screen

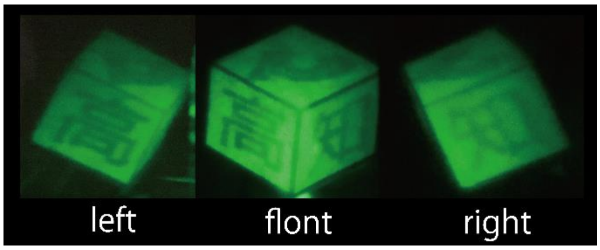

Fig. 6 Reconstructed aerial 3D image

Figure 4 shows our aerial 3D display system using a holographic projector. The light from the holographic projector is reflected by a mirror and projected onto a 3D screen shown in Figure 5. The light from the 3D image projected on the 3D screen is transmitted and diffused, passes through the half-mirror, and enters the retroreflective sheet. The light retroreflected by the retroreflective sheet is reflected by a half-mirror to form the same 3D real image in the air as that projected on the 3D screen. This aerial 3D image is projected plane-symmetrically from the 3D screen with the half-mirror as the axis, and is a 3D real image, which can be seen from various angles with the naked eye (Figure 6).

3 Results and discussion

We used a PC with a graphics card (MSI GeForce

Table 1 Specifications of PC

CPU	Intel Core i5 8400 (Base clock: 2.8 GHz)
Main memory	DDR4-2666 16GB
OS	Linux (Ubuntu 20.04.4 LTS)
Software	NVIDIA CUDA 11.6 SDK, OpenGL
GPU	NVIDIA GeForce RTX 3080

Table 2 Performance evaluation (CPU vs GPU)

Object	Calculation time[ms]		Speed-up
Points	CPU	GPU	CPU / GPU
10,240	2680.5	10.6	253
20,480	5187.9	21.3	244
30,720	7950.9	33.1	240
40,960	9622.2	45.7	211
51,200	12,561.5	55.7	226
102,400	24,155.6	110.8	218

RTX 3080 VENTUS 3X 10G OC) and HOLOEYE PLUTO-VIS as a SLM. The phase-type CGH is 1920x1024 pixels. Table 1 shows the specifications of PC. In the phase-type CGH calculation, Table 2 shows the speed-up of our GPU computation relative to CPU computation. In the CPU computation, we used Intel C++ Compiler Classic (icc) as C compiler and "-O3 -xCORE-AVX2" as compile options. The Open MP was also used for parallel computation. The phase-type CGH calculation using CPU was performed by six threads. Table 2 indicate that our GPU computation are more than 200 times faster than CPU computation. The 3D model comprising up to 30,000 points can be reconstructed in real time at 30 fps.

Figure 7 shows Snapshots of the reconstructed aerial 3D movie. The original 3D movie comprises up to 28,520 points. We realized a real-time aerial 3D display of the 3D movie at 30 fps.

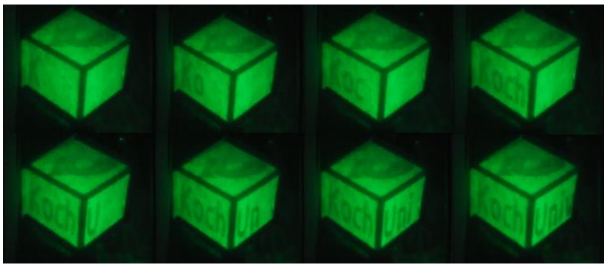

Fig. 7 Snapshots of the reconstructed aerial 3D movie

4 Conclusions

We reported an aerial 3D video display using holographic projector and retroreflective sheet. Consequently, we realized a real-time aerial 3D video display of the 3D model comprising 28,520 points at 30 fps.

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