Development of a Holographic Directional Volumetric Display Prototype

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ABSTRACT

This study developed a prototype system that combines electronic holography and directional volumetric display, thereby enabling the observation of holographic projection images. Consequently, we confirmed that it was possible to observe different holographic reconstruction images from both directions of a volumetric display.

1 Introduction

Holography [1], a technology that uses interference and diffraction of light, is a representative three-dimensional (3D) display technology. It can display 3D images that satisfy all physiological factors of human stereoscopic perception, which accounts for its being actively researched for practical uses. The medium that records 3D image information in holography is called a hologram. Based on previously established principles, a hologram generated by simulating light interference within a computer is called a computer-generated hologram (CGH), and the technology that realizes holography electronically, using a computer, is called electronic holography [2, 3]. Since the reconstruction of 3D images via holography uses light diffraction, the special light modulator's (SLM) pixel pitch displaying the CGH must be sufficiently narrow, but this has not yet been put to practical use, making it difficult to observe holographic projection images from 360° in all directions.

Another representative 3D display technology is the volumetric display [4-6]. Volumetric displays have a display volume that enables users to observe 3D images from a wide area around the display by displaying these images on various media inside the display. Examples of research include displays that project images onto falling water droplets with a projector [7], including those that depict images by rotating an LED array [8]. However, in volumetric displays, the continuity, image quality, and real-time performance of the displayed images are issues to be addressed. Our previous work developed a display that simultaneously presented different two-dimensional images in multiple directions [9]. This display superimposed 3D images at a depth direction, eventually presenting two-dimensional images in arbitrary directions. As shown in Fig. 1, since the overlap in the depth direction changed when the direction of observation changed, images at the original position were no longer visible. Thus, this display was called a directional volumetric display because it could display images only in arbitrary directions. A thread-type directional volumetric display [10], in which images were projected by a projector, using a thread placed in space as the display medium, is shown in Fig. 2. By applying this system, we have also developed an interactive system that changes the direction in which images are displayed according to the movement of a specific observer [11], including a multilingual signage system that changes images displayed by identifying the speaker's language [12]. However, thread-type directional volumetric displays have two problems in improving image quality: One is that the projector projects images onto threads arranged in 3D, making it impossible to focus between the front and rear threads, and the other is that the spread of the projected light varies according to depth, resulting in differences in pixel size. Nevertheless, electronic holography can solve these problems by generating and displaying images at arbitrary focal points. Therefore, this research aimed to construct an image display system that mutually solves the research problems of volumetric displays and electronic holography. Consequently, a prototype holographic directional volumetric display that combined electronic holography and volumetric display technologies was developed.
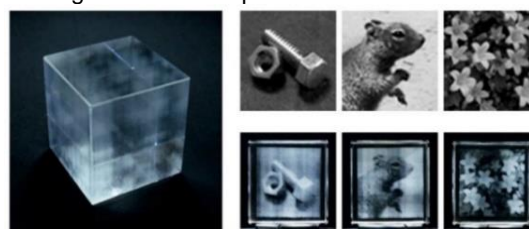

Fig. 1 Directional Volumetric Display [9].

Fig. 2 Directional Volumetric Display Using Threads and Projector [10].

2   Proposed Method

2.1 Designing directional volumetric display

This study used a volumetric display with threads as the medium for diffusing light from the projection. The design of the display is shown in Fig. 3.
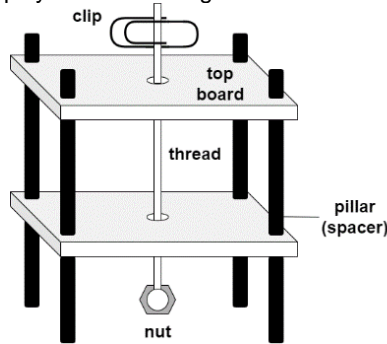

Fig. 3 Blueprint of the Proposed Volumetric Display.

The volumetric display consisted of three parts: a top board, a column, and a thread. While the top board was modeled using a 3D software blender and fabricated by a 3D printer, two other top boards were fabricated and placed at the top and bottom of the display. The drawing of the top board is shown in Fig. 4(a).
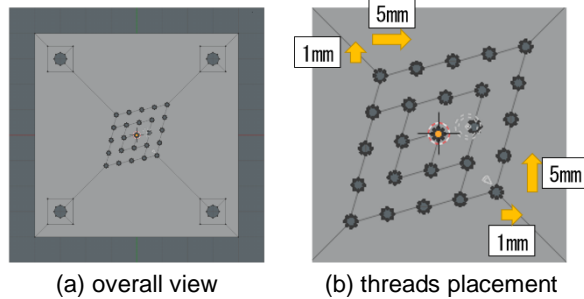

(a) overall view   (b) threads placement
Fig. 4 3D Model of Top Board.

The top board had spacers as pillars with holes for the thread. Then, at the center, four holes for the pillars were placed in each of the four corners, with 25 holes for the threads. Notably, the threads were arranged evenly in 5 rows × 5 columns so that they do not overlap when viewed from the front and sides, as shown in Fig. 4(b), and a nut was tied to one end to serve as a weight. Finally, the threads were fixed to the top and bottom boards with clips at the top and nuts at the bottom to keep threads straight.

2.2 Electronic holography

The technology for handling holography virtually in a computer is called electronic holography. Compared with conventional holography, electronic holography is superior in that it can record object images without using either the object images themselves, a dark room, or special chemicals. It can also play back moving images by switching holograms.

To this end, this study adopted a point light source method [3] for generating CGH. In the point light source method, the object image to be recorded is treated as a set of numerous light points in 3D coordinates, after which the interference from each light point to the hologram is recorded by computational simulation and superimposed to generate a hologram. Finally, the created holograms were displayed on an SLM.

2.3 Projection image

For projection, the process of creating the projected image and hologram based on the images to be displayed on the front and sides of the display is described.

The original images presented at the front and side of the display are shown in Fig. 5. We observed that the original image was a word represented by 5 × 5 pixels in white letters on a black background. Furthermore, as shown in Pattern 1, Fig. 5(a), the front image displayed "A," and the side image displayed "B," as shown in Fig. 5(b). On the other hand, in Pattern 2, "1," shown in Fig. 5(c), was presented at the front image, and "2," shown in Fig. 5(d), was presented at the side image.
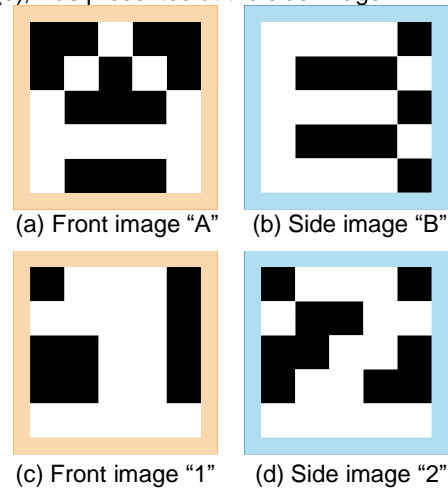

(a) Front image "A"   (b) Side image "B"

(c) Front image "1"   (d) Side image "2"
Fig. 5 Original Images of the Projection.

Subsequently, voxel values were calculated from the two original images to create the projection image [13, 14]. The resulting images are shown in Fig. 6.
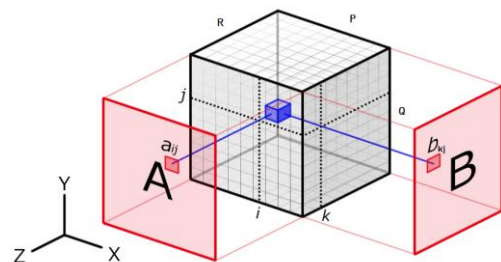

Fig. 6 Voxel calculation.

From the original image, "A" was projected at the front, and "B" was on the side, considering the space in the volumetric display and the corresponding virtual space. Subsequently, the voxel value $V_{i,j,k}$ at coordinates $(X, Y, Z) = (i, j, k)$ in the virtual space, represented by the blue cube in Fig. 6, was expressed using pixel values a_{ij} at coordinates $(X, Y) = (i, j)$ of the source image A and b_{kj} at coordinates $(Z, Y) = (k, j)$ of the source image B as follows:

$$V_{i,j,k} = \lambda(a_{ij} + b_{kj}), \tag{1}$$

where λ is a constant for normalizing the voxel values.

Next, based on the derived voxel values, a point light source was assigned to the corresponding thread. In converting from voxel values to point light sources, the pixel values were expressed in terms of the number of light points per pixel. Consequently, the pixel with the largest pixel value ($V_{i,j,k} = 255$) for the vertical thread direction had five light points. On the other hand, the pixels with small pixel values were represented by reducing the number of point sources and placing them randomly.

2.4 Optical system

A schematic showing the optical system used for projection is displayed in Fig. 7.
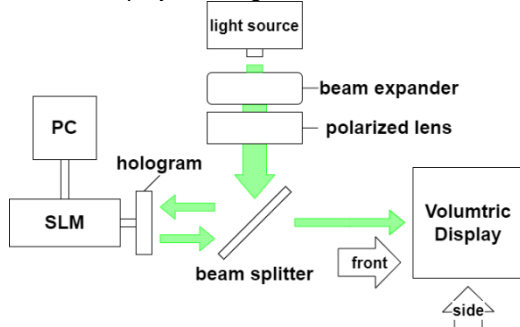

Fig. 7 Holographic Optical System Outline.

The process by which the reconstruction image is formed is described. The light emitted from the laser source first passes through a beam expander and a polarized lens. The beam expander and polarized lens are instruments that enlarge and collimate the laser light that passes through them and adjust the brightness of the light that strikes the SLM, respectively. The laser beam that passes through the SLM reaches the beam splitter. The beam splitter splits the incident light into transmitted and reflected light at a specified ratio. The reflected laser light enters the SLM, which is connected to a PC and displays a hologram, where diffraction occurs on the hologram and the reflected rays pass through the beam splitter again before forming an image on the volumetric display. The direction in which the rays are incident is set as the front direction and the right side is set as the side direction as the direction in which the reconstruction image is observed.

3 Results and Discussion

3.1 Volumetric display

The fabricated volumetric display is shown in Fig. 8. The total height of the volumetric display was 18 cm, and the area of the thread that was projected was 9 cm (length) × 2.5 cm (width) × 2.5 cm (depth).

Fig. 8 Volumetric Display.

3.2 Results of projection

The simulation results of the projection by diffraction calculation based on the hologram obtained from the original image and the actual projection results with the optical system are shown below.

The results of the projection simulation for Pattern 1 with A for the front image and B for the side image are shown in Fig. 9.
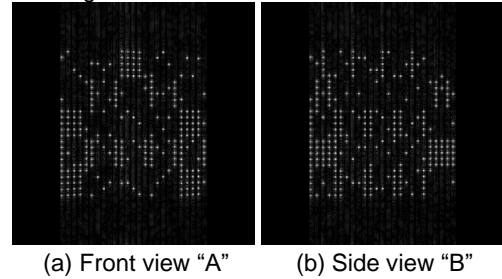

(a) Front view "A"   (b) Side view "B"
Fig. 9 Pattern 1 Simulation Results "A" and "B".

Then, the front and side images resulting from the projection of the reconstruction images by the hologram on the volumetric display are shown in Fig. 10.
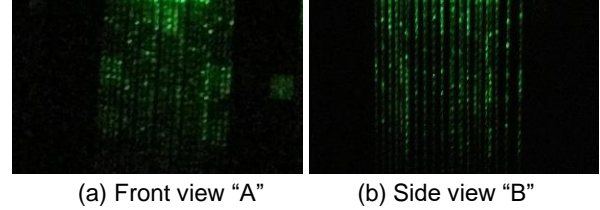

(a) Front view "A"   (b) Side view "B"
Fig. 10 Pattern 1 Projection Results "A" and "B".

Contrastingly, the results of the projection simulation for Pattern 2 with 1 for the front image and 2 for the side image are shown in Fig. 11.
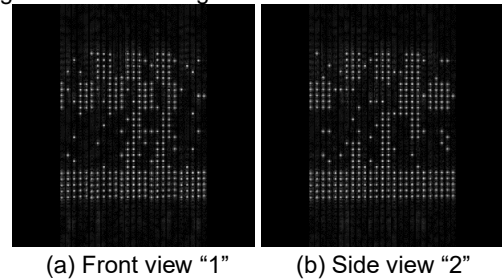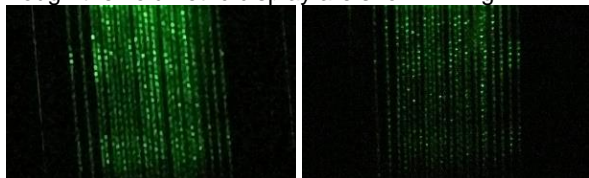

(a) Front view "1"   (b) Side view "2"
Fig. 11 Pattern 2 Simulation Results "1" and "2".

Finally, the front and side images resulting from the projection of the reconstructed image by the hologram through the volumetric display are shown in Fig. 12.

(a) Front view "1"   (b) Side view "2"
Fig. 12 Pattern 2 Projection Results "1" and "2".

3.3 Discussion

When projecting holography onto a volumetric display, it was observed that the volumetric display became slightly smaller in relation to the projected light. This event is proposed to be due to shrinkage during the creation of the volumetric display's top board, where with a 3D printer, plastic filaments were melted at high heat and stacked in layers and then cooled and hardened to print the object. Thus, the expansion and contraction during this process may have caused a slight deviation from the original modeling. For the same reason, the top board also warped. Therefore, a method of fabricating volumetric displays that avoids the problem of thermal contraction should be considered for more accurate projections.

4 Conclusions and Future Work

This study developed a prototype image display system that mutually compensates for the narrow viewing angle (a research issue for electronic holography) and low image quality (research issue during volume displays) using a thread and a projector. Toward this end, we constructed a holographic directional volumetric display and its system, using a directional volumetric display as a presentation medium for electronic holography. Consequently, different electron holography reconstruction images were simultaneously produced at the front and side of the volumetric display.

Prospects include increasing the display size and improving image quality. In the future, we also consider projecting images on display like a person's size.

Acknowledgement

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