

# INTERACTIVE ELECTRONIC HOLOGRAPHY AND 300-CAMERA ARRAY IN DENSE ARRANGEMENT

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**Abstract**— We will describe interactive feature on an electronic holography system in this paper. In addition, we will introduce our developed 300-camera array in dense arrangement, the images captured by which are used to generate the holograms for the electronic holography system. Since the observer can specify viewpoint for observing the 3D objects using interactive feature, he or she could intuitively understand the 3D information more easily. This approach would have a variety of applications such as, for example, enabling a precious object in a museum to be viewed from desired direction.

## I. INTRODUCTION

Since holography is a technique that can reproduce the same conditions of light as when an object actually exists, it seems to reproduce all the physiological factors required by the human visual system to perceive three-dimensionality such as binocular parallax, convergence, and motion parallax. Therefore, holography is expected to be the ideal 3D imaging method. Conventionally, holography dealt with still images such as photographs or printed images, but recently many groups have been conducting research on electronic holography, which implements holograms by electronic means in order to deal with video images.

When acquiring ray information for display on a high definition 3D display such as those used for the electronic holography, the ray information to be acquired should be highly dense. However, it is not simple to acquire the highly dense ray information since the sizes of the cameras themselves, the sizes of the attachments for securing the cameras, and error related to the geometrical placement of the cameras are all issues affecting the camera array. Therefore, the highly dense ray information must be calculated, i.e. generated, with high quality from captured ray information by view interpolation using camera parameter and depth estimation techniques. The techniques used for generating this highly dense ray information are even now challenging topics on 3D technology.

On these backgrounds, our research group has previously created an electronic holography system that produces 4 cm 3D images having a viewing-zone angle of 16.8 degrees [1] and 300-camera array in dense arrangement each camera in which has  $1600 \times 1200$  pixels. The cameras are located on a circle at intervals of approximately 32 mm, which is expected

to generate the highly dense ray information with relatively high quality [2]. In this paper, we are introducing interactive feature on electronic holography system that handles the images captured by 300-camera array. Since the observer can specify viewpoint, he or she could intuitively understand the 3D information more easily.

This paper is organized as follows. We first present a simple explanation of holography and electronic holography in Section II. We then describe our interactive electronic holography system in Section III, our 300-camera array in Section IV, and the experimental results in Section V. Finally, we present conclusions in Section VI.

## II. HOLOGRAPHY AND ELECTRONIC HOLOGRAPHY

Holography consists of a technique that uses interference phenomena to record light and a technique that uses diffraction phenomena to reconstruct that light [3]. When used for a 3D display, light beams that are reflected by the object are recorded and reconstructed later to reproduce a 3D image of the object. Figure 1 depicts the principles of holography.

During recording, a coherent light beam (laser beam) is split in two as shown in Figure 1(a) so that one part irradiates the object and the other part irradiates the recording medium (this is called the reference beam). The light beam that irradiated the object is reflected by the object (this is called the object beam) and reaches the recording medium. The reference beam and object beam interfere with each other to produce a bright and dark striped pattern on the recording medium (this is called an interference fringe). The state of the object beam is captured by recording this interference fringe. If the object is stationary, the interference fringe is a fixed striped pattern. However, if the object is moving, the interference fringe will vary. Therefore, since the varying interference fringe can be recorded if an electronic imaging device is used as the recording medium, the motion of the object can be recorded. If  $O(x, y)$  represents the complex amplitude distribution of the object beam at the recording medium and  $R(x, y)$  represents the complex amplitude distribution of the reference beam, then the interference fringe  $H(x, y)$  that is to be recorded can be

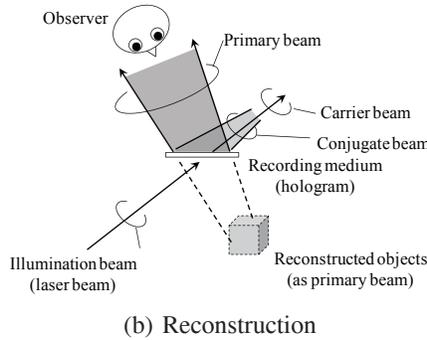
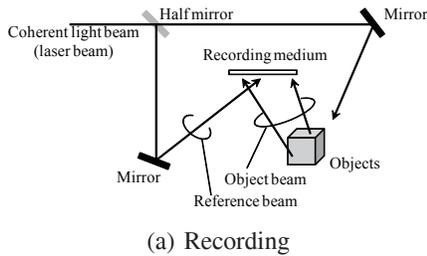


Fig. 1. Holography

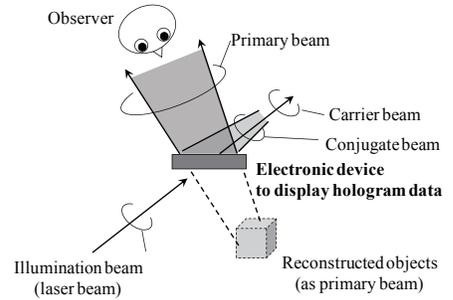


Fig. 2. Electronic Holography

represented by the following equation:

$$\begin{aligned}
 H(x, y) &= |O(x, y) + R(x, y)|^2 \\
 &= |O(x, y)|^2 + |R(x, y)|^2 \\
 &\quad + O(x, y)R^*(x, y) + O^*(x, y)R(x, y) \quad (1)
 \end{aligned}$$

where,  $O^*(x, y)$  and  $R^*(x, y)$  represent the complex conjugates of  $O(x, y)$  and  $R(x, y)$  respectively. The medium in which this interference fringe is recorded is called a hologram. Also, in this paper, the electronic information of the interference fringe is called hologram data.

During reconstruction, the same beam (laser beam) as the reference beam strikes the hologram as shown in Figure 1(b) (this is called the illumination beam). The illumination beam is diffracted by the interference fringe of the hologram and becomes light (this is called the reconstructed beam) that contains the same beam as the object beam. When this process is expressed as equations, the reconstructed beam  $U(x, y)$  is represented by the following equation:

$$\begin{aligned}
 U(x, y) &= H(x, y)R(x, y) \\
 &= (|O(x, y)|^2 + |R(x, y)|^2)R(x, y) \\
 &\quad + O(x, y)|R(x, y)|^2 + O^*(x, y)R^2(x, y) \quad (2)
 \end{aligned}$$

where, the second term on the right hand side of equation (2) is a beam that is proportional to the object beam  $O(x, y)$  if the intensity of the reference beam  $|R(x, y)|$  is constant. This shows that the light from the object can be reproduced directly with the total intensity varying according to the intensity of the reference beam. In other words, since light that links the virtual image of the object to the location where the object had existed is reconstructed, it appears to the observer as if the object were at that location. That summarizes the principles of holography.

Electronic holography is a technique that displays hologram data using an electronic device during reconstruction as shown in Figure 2. It can reconstruct video by continually rewriting the hologram data. The hologram data that is displayed may be hologram data that is recorded optically using an electronic imaging device according to holography principles or may be calculated by a computer from 3D information of the object. Holography that uses the first kind of hologram data mentioned

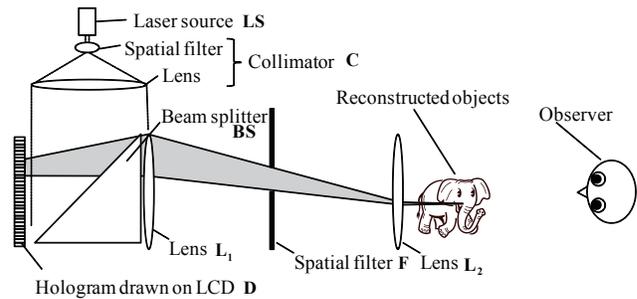


Fig. 3. Basic Configuration of the Optical System

above is called digital holography and holography that uses the second kind is called computer-generated holography (CGH). Although the hologram data generally is recorded or calculated in advance before it is displayed, a live-action video, real-time electronic holography system that captures and then immediately displays holograms has already been developed [4], [5].

### III. ELECTRONIC HOLOGRAPHY SYSTEM

#### A. Overview

We developed an electronic holography system having an interactive feature. The system consists of a disk recorder for storing the holograms and later outputting them as video, and an optical system for reconstructing the holograms to display 3D images. Both components are described in the following sections.

#### B. Disk Recorder

The disk recorder is a device for storing video images in advance and playing them in real-time according to instructions. A computer (PC) and disk recorder can be directly coupled so that instructions can be sent from the PC to perform operations such as transferring video images between the PC and disk recorder. Instructions are included for starting and stopping playback or specifying the frame to play.

A normal disk recorder sequentially plays all frames from a pre-specified starting frame to a pre-specified stopping frame. However, to enable interactivity, we improved it so that the frame that is to be played can be specified continuously from

the PC. A joystick is attached to the PC, which the observer can use to convey his or her intentions to the PC. The PC calculates the frame that should be played at any moment and continuously specifies that frame to the disk recorder. The disk recorder displays the specified frame. The result of these actions enables a 3D image to be presented from the observer's desired viewpoint.

### C. Optical System

Figure 3 shows the basic configuration of the optical system. First, light issued from the laser source is converted to collimated light of the required width by the collimator **C**. It then passes through the polarizing beam splitter **BS** and strikes the LCD **D**. Since the hologram data **H** is displayed on **D**, the laser beam reflected by **D** contains the primary beam, carrier beam, and conjugate beam. All of the beams pass through the beam splitter **BS** and lens **L<sub>1</sub>** and reach the spatial filter **F**. **F** is placed at a location corresponding to the focal length  $f_1$  of **L<sub>1</sub>** so that the beams on the optical axis are isolated from the beams above and below the optical axis. Therefore, if half-zone-plate processing [6] is executed for the hologram, the primary beam will pass through, but the conjugate beam and carrier beam, which are unnecessary beams, will not. Lens **L<sub>2</sub>** is placed at a location that is separated from **F** by the focal length  $f_2$ . Since  $f_1$  and  $f_2$  were chosen to be the same, a 4-f optical system is created by **L<sub>1</sub>** and **L<sub>2</sub>**. As a result, the primary beam that emerges from LCD **D** will move, in principle, by a distance of 4 times  $f_2$  without distortion. In other words, the reconstructed image will appear to be floating to the right of **L<sub>2</sub>**. This is the basic configuration of the optical system. In reality, to create color 3D images, three sets of the basic configuration described above are provided for RGB, and beam splitters were used to superimpose the 3D images for each of the RGB components to produce color. For further details, refer to Reference [1].

## IV. CAMERA ARRAY

### A. Features and configuration

The most important feature of this camera array is that it contains many cameras, which are densely arranged with an interval between cameras of 31.4 mm. Therefore, we expect that it will be able to calculate and generate higher quality ray information than can be achieved with a sparse arrangement. We also expect that acute variations in light such as with metallic luster called specular can also be acquired with higher fidelity than by a sparse arrangement. Although there are some camera arrays that can acquire ray information similarly, our camera array differs in that it is equipped with attachments that enable camera directions to be adjusted, color can be corrected with 19 knee points, and LEDs are mounted for camera identification.

Our camera array consists of 12 control boards and 300 sensor boards, with 25 sensor boards connected to a single control board by a special-purpose cable. Each sensor board has a light receiving element and 2 LEDs for identification purposes, and each control board has a memory unit for

storing three frames per sensor board and a network interface. Because of the limitation of the memory unit, cameras are not video cameras but snapshot cameras. The operator can send commands from another PC to the camera array via the network to change the shutter speed, turn on/off the identification LEDs, capture 300 images at once, send captured images to the PC, and so on.

The cameras are arranged on a circle with a radius of 1500 mm at intervals of 1.2 degrees. All cameras are aligned to face the center of the circle. Therefore, the interval between cameras is 31.4 mm. The angle of view of each camera was designed to be suitable for capturing a human face. Figure 4 (a) and (b) show the camera array, and (c) and (d) show the control board and sensor board. For further details, refer to Reference [2] for the array and [7] for its calibration.

### B. Hologram Generation

Holographic stereograms can be used to generate holograms from ray information [8]. This method calculates holograms (called elemental holograms here) that can reconstruct multiple directional rays in various directions simultaneously and then arranges a great number of these elemental holograms to create a single hologram. Ray information that passes through a desired point is calculated (view interpolation) from the captured ray information, and elemental holograms that can reconstruct those rays are calculated and used as part of the hologram. The entire hologram is created by reiterating this calculation at various points.

An important technique used in view interpolation is depth estimation of the subject. Various methods have been investigated for estimating depth from images captured by a camera array such as, for example, a method that takes into consideration the continuity of the depth of adjacent pixels [9]. We performed view interpolation here by simply estimating depth as if the subject were a cylinder. As a result, the incorrect depth was used in some areas.

## V. EXPERIMENTAL RESULTS

We captured human face by 300-camera array, generated holograms, and stored them in disk recorder. The observer can use the joystick to specify any angle among 360 degrees from which to view the reconstructed human face. The observer can also vary the angle continuously. In other words, the observer not only can stop the human face at a desired position, but he or she can also rotate it clockwise or counterclockwise. The video consists of approximately 360 frames for 360 degrees.

Since hologram calculations require a massive amount of computations, research has been conducted concerning special-purpose hardware [10] or high-speed computational algorithms [11]. However, we simply used a Fresnel transform for the calculations here. Calculating approximately 360 frames required approximately one day. Although the electronic holography system that we used in this experiment can reconstruct a viewing-zone angle of 16.8 degrees, we only calculated 5.6 degrees for the hologram. As a result, the viewing-zone angle is 5.6 degrees in this experiment.

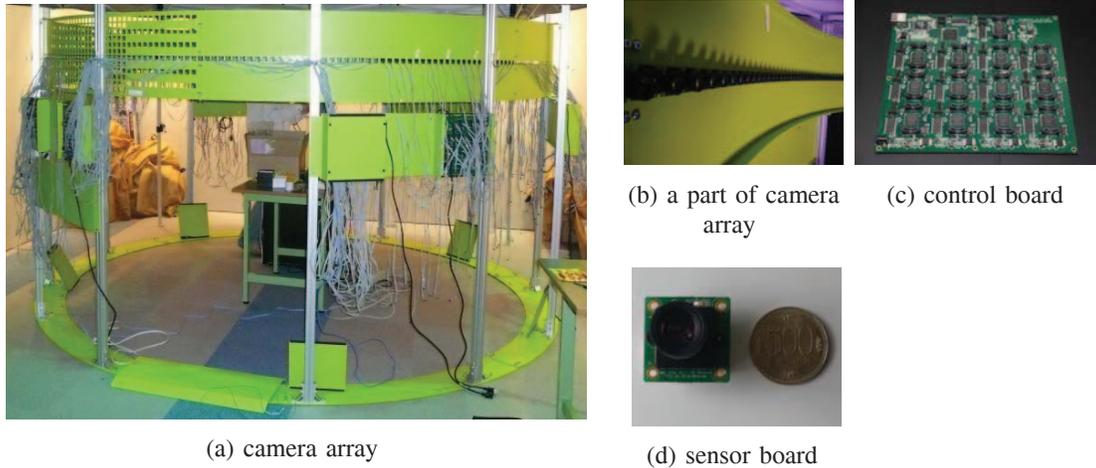


Fig. 4. Overview of 300-Camera Array

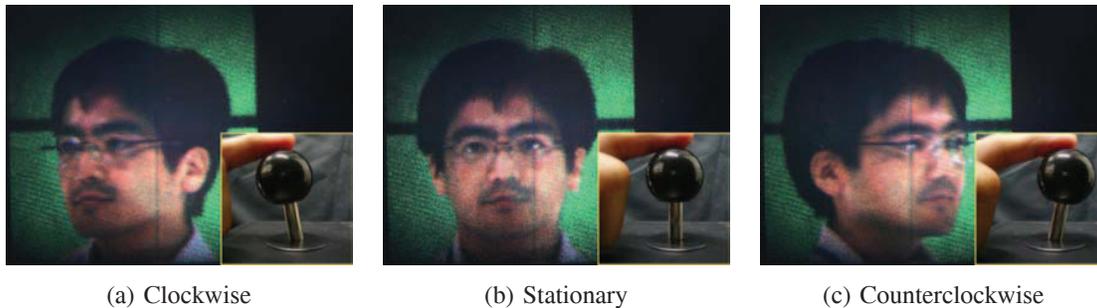


Fig. 5. Experimental Results

Figure 5 shows the experimental results. Figure 5(a) shows the human face turning clockwise, (b) shows it stationary, and (c) shows it turning counterclockwise. At the bottom right of each figure is a photograph showing the joystick position at that time. Although you cannot really tell from the figure that the human face is rotating clockwise or counterclockwise, we verified that it was actually moving. During our presentation at the conference, we will show a video of the actual interactive behavior.

## VI. CONCLUSION

We added an interactive feature to the electronic holography system which we have been considering as an ideal 3D display. This enables the observer to specify any desired viewpoint and observe the object from that viewpoint with an electronic holography system. If this system is further developed, we expect it to have a variety of applications such as, for example, enabling a precious object in a museum to be viewed from desired direction. The holograms here are generated from the images captured by 300-camera array, which means the 3D objects can be reconstruct by holography technology even if the original 3D objects are not captured by holography in a dark room but by cameras under natural light.

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