Development of A Directional Volumetric Display for High Resolution Using Water Drops

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ABSTRACT

In this study, we attempted to develop a directional volumetric display that does not require the manual attachment of projection media for high resolution. *As a result, we developed the directional volumetric display using a projector and water drops through holes made in a plate by a laser beam machine.*

1 INTRODUCTION

Recently, information display technology has made significant progress, and the range of applications has expanded dramatically making it an indispensable tool in various aspects of our daily lives. Among them, volumetric displays, which can represent 3D (three-dimensional) images, has a high degree of artistry and confidentiality and is expected to be used for media art and other applications. As the display medium, researchers have employed various media such as water drops [1], fog [2,3], bubbles [4], and plasma [5]. For example, Ochiai et al. represented a volumetric display using plasma induced by a femtosecond laser [5].

Our research group has proposed a method that uses a volumetric display to simultaneously display different 2D information for multiple directions [6]. A display made by this method is called a directional volumetric display because it can convey information only in a specific viewpoint direction. In previous studies, we demonstrated the projection of directional images using a 3D crystal, shown in Fig. 1, and threads and a projector, shown in Fig. 2 [6]. The directional volumetric display using a 3D crystal can display relatively high-resolution images of 64×64. However, this has can only display predetermined black-and-white images and cannot be used for video. The directional volumetric display using threads and a projector eliminates those shortcomings and can currently display images with a resolution of 20×20 [7]. Matsumoto et al. also succeed in displaying a directional image only to a person while tracking the person with a directional volumetric display using threads and a projector in real-time, as shown in Fig. 3 [8].

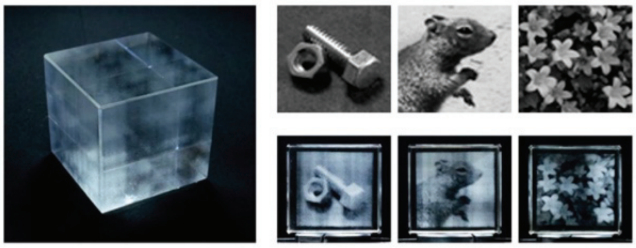


Fig. 1 Directional volumetric display using a 3D crystal [6]

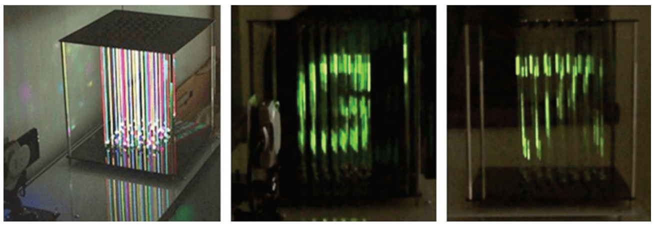


Fig. 2 Directional volumetric display using threads and a projector [6]

However, there is a problem that the directional volumetric display currently being developed cannot display high resolution and full-color images. For example, the directional volumetric display using threads and projector can only display images with a resolution of up to 20 × 20. It is also difficult to attach more threads because of the high possibility of noise caused by human error. Therefore, it is difficult to improve the horizontal resolution.

The purpose of this study is to develop a directional volumetric display that does not require the manual attachment of the projection medium in order to accomplish higher resolution. As a method to achieve this purpose, we develop a directional volumetric display using water drops as a projection medium and verify its utility.

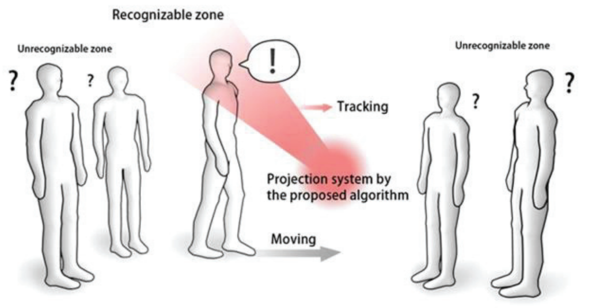


Fig. 3 Directional volumetric display which can track a person and display a directional image only to the person in real-time [8]

2 PROPOSED METHOD

2.1 Overview of a directional volumetric display with water drops and a projector

Figure 4 shows that an apparatus for dropping water drops is made, and water drops are dropped using the apparatus. A projection image C made from two original images A and B with a resolution of 7 x 7 projects onto the water drops from a projector. Then, we observe front and side views. Also, we create simulation images A' and B' and compared them with the actual projection results in order to confirm the visibility when the light hits the projector correctly.

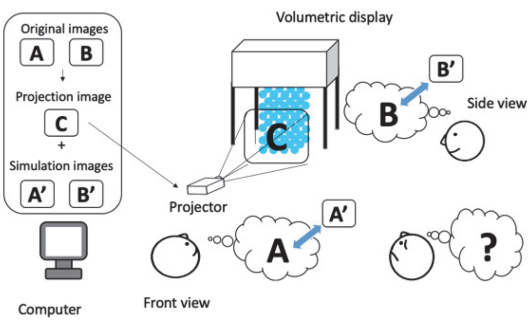


Fig. 4 Overview of a directional volumetric display with water drops and a projector

2.2 Apparatus for dropping water drops

The apparatus for dropping water drops mainly composed of a submersible pump, a solenoid valve, an Arduino, and an Acrylic plate perforated with holes for directional display. The method for dropping water drops uses a method proposed by Eitoku et al. [1]. The inflow of water from the submersible pump is controlled in a very short time by opening and closing solenoid valves, as shown in Fig. 5, after filling the box with water. The water drops are simultaneously dropped from holes in the acrylic plate. The voltage is controlled by Arduino to open and close the solenoid valve at 90 [ms] intervals.

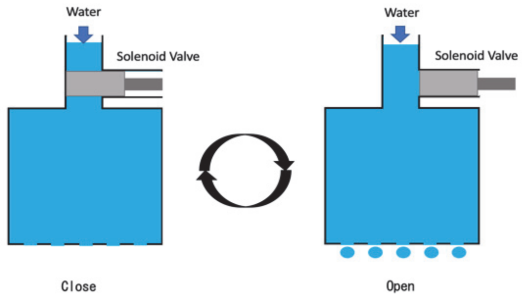


Fig. 5 Mechanism for dropping water drops [1]

2.3 Placement of the holes

The placement of holes is determined provided that the following three constraints, as shown in Fig. 6.

- Constraints 1: The entire outline of the holes is a square.
- Constraints 2: The square is divided evenly between the length and the width, and that one hole is placed within the divided section.
- Constraints 3: One ray from the projector must correspond to one water drop.

In this study, the placement of a total of 49 holes (7 x 7) is determined according to the three constraints.

We used a laser beam machine to make holes in an acrylic plate of 3 [mm] in thickness based on the placement of holes. A directional image can be displayed by attaching this perforated acrylic plate to the bottom of the apparatus for dropping water drops.

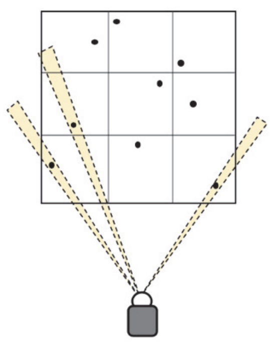


Fig. 6 A placement of holes

2.4 The Projected image of a directional volumetric display

As a method of creating a projected image, we first consider a P x Q x R virtual space, as shown in Fig. 7. By multiplying the pixel values a_{ij} and b_{kj} of the two images to be displayed, the voxel value V_{ijk} of the volumetric display shown in blue in Fig. 6 is determined. Therefore, the voxel value is given by Equation (1). where $(i,\ j,\ k)$ is an arbitrary coordinate of the system (X, Y, Z) and λ is a constant for normalizing the voxel value. This volumetric display creates simulation and projection images based on the voxel values and the locations of the holes in the water drops.

Because the rays of light from the projector have an elevation angle, when it is projected as it is against the water drops, the point and size of the light change depending on the position of the water drops, as shown in Figs. 8 (a) and (b). Therefore, considering the distance between the water drops and the projector, the height of the projected image is corrected by shrinking the corresponding rays of light and lowering the height, as shown in Figs. 8 (c) and (d).

$$V_{ijk} = \lambda\, a_{ij} b_{kj} \qquad (1)$$

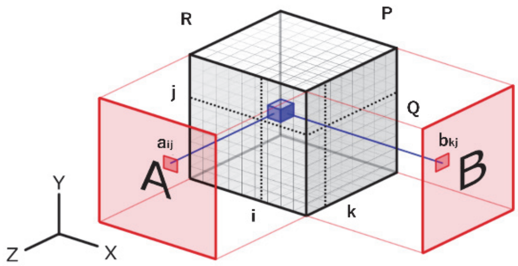
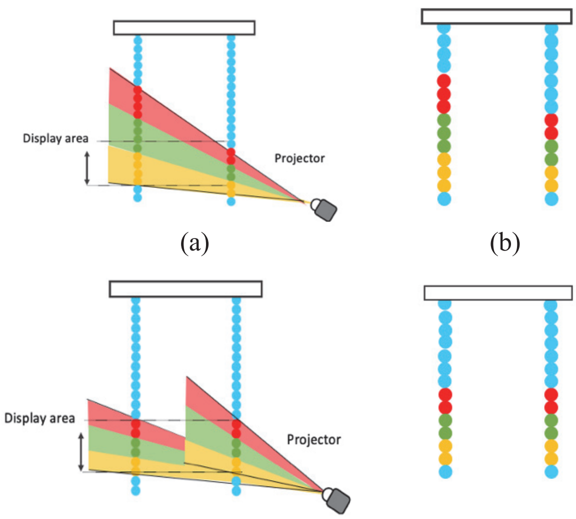


Fig. 7 Virtual space of images recording algorithm



(c) (d)

Fig. 8 Adjusting height of light's ray
(a) Side view before adjusting the height
(b) Front view before adjusting the height
(c) Side view after adjusting the height
(d) Front view after adjusting the height

3 RESULTS AND DISCUSSION

Figure 9 shows the apparatus for dropping water drops fabricated in this study. Fig. 10 shows the two original images (A and B), Fig. 11 shows the simulation images obtained from the front and side views, and Fig. 12 shows the results of the projection onto the actual volumetric display fabricated in this study. The projection results were

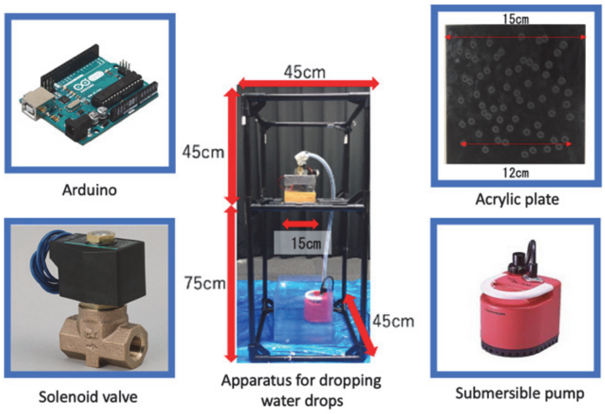
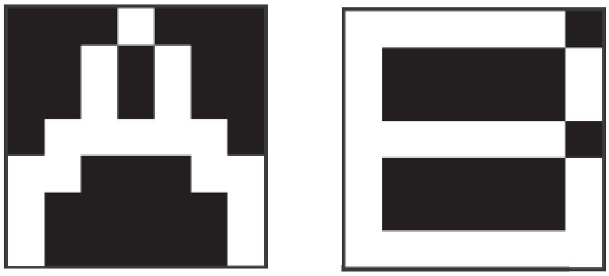
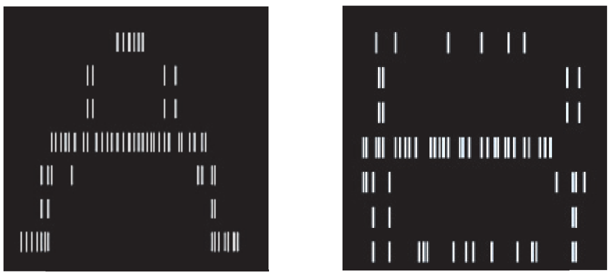


Fig. 9 Apparatus for dropping water drops



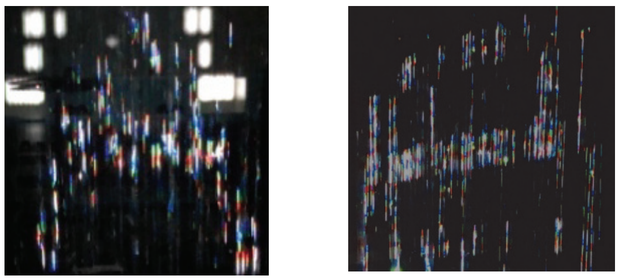
(a) (b)

Fig. 10 Original images
(a) Image A
(b) Image B



(a) (b)

Fig. 11 Simulation images
(a) Front view
(b) Side view



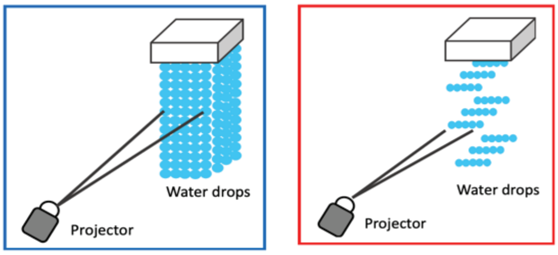
(a) (b)

Fig.12 Projection results
(a) Front view
(b) Side view

close to the simulation results. As these images could not be seen from any other directions, we could display directional images with a directional volumetric display using water drops. In addition, the volumetric display was made by simply making holes in the acrylic plate with a laser beam machine and dropping water drops from the holes.

Although we used the method of Eitoku et al. to drop water drops into all the holes simultaneously as shown in Fig. 13 (a) [1], there is noise in the projection results as shown in Fig. 12. This is because the rays of light do not correspond one-to-one with the water drops due to the misalignment of the projector's position and angle. We think that this noise can be reduced by using the method proposed by Barnum et al. [9]. As shown in Fig. 13 (b), this method is to use multiple solenoid valves to stagger the timing of dropping water drops and switch the image depending on the position of the water drops. This method allows us to develop a directional volumetric display with less noise, using the after-image effect of the eyes.

In this study, we also used the algorithm based on multiplication to create the projected image. However, this algorithm cannot record images that are composed of many black pixels (pixel values '0'). This problem can be solved by using the addition-based algorithm proposed by Shiraki at el. [10].



(a) (b)

Fig. 13 Two methods for fabricating the volumetric display with water drops
(a) System proposed by Eitoku et al. [1]
(b) System proposed by Barnum et al. [9]

4 CONCLUSION AND FUTURE WORK

The purpose of this study is to develop a directional volumetric display that does not require the manual attachment of a projection medium in order to achieve higher resolution. As a result, we developed a directional volumetric display that does not require the manual attachment of a projection medium by using a projector and water drops from holes drilled in an acrylic plate by a laser beam machine.

In the future, we will develop a new directional volumetric display using the method proposed by Barnum et al. to reduce noise [9]. We will also use the addition-based algorithm to record all images when creating the projected image [10].

ACKNOWLEDGEMENT

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