

The Proposal of Image Quality Improvement Method for Directional Volumetric Displays Using Deep Learning

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ABSTRACT

The currently used directional volumetric display, which uses threads, and a projector has the issue that when light rays with an elevation angle are projected from a projector, the height of the irradiation position changes depending on the depth at which the thread is placed, even if the height is the same. In this study, aiming at solving the above-mentioned problem, a projection image was created using a new approach that uses deep learning to adjust light rays.

1 INTRODUCTION

Recently, information display technology has significantly been developed, and its application range has dramatically expanded, making it an indispensable tool in various aspects of our lives. Researchers have employed various display media, such as water drops [1], fog [2,3], bubbles [4], and plasma [5]. For example, Eitoku et al. [1] developed a display that can be observed three-dimensionally by projecting images from below falling water droplets, and Yagi et al. [2] developed a display that can recognize three-dimensional (3D) shapes using a cylindrical fog display and multiple projectors. Moreover, Kumagai et al. [4] represented a volumetric display by generating microbubble voxels in a liquid through femtosecond laser pulses, and Ochiai et al. [5] represented a volumetric display using plasma induced by a femtosecond laser.

Our research group has developed a method to simultaneously display different two-dimensional information in multiple directions, and the display developed using this method is called directional volumetric display [6,7], as it can display images only in a specific direction. In general, directional volumetric displays have potential applications in media art and encryption owing to their artistic and confidential properties.

There are two types of volumetric displays currently used: 3D crystals and threads combined with a projector as shown in Figs. 1 and 2, respectively [6,7]. The

directional volumetric display using 3D crystals consists of 64×64 pixels and can display relatively high-resolution images. However, the directional volumetric display using 3D crystals can only represent black and white images that cannot be animated. Nevertheless, the directional volumetric display using threads and a projector can also display color images and moving images, as the projector projects onto the thread however, it has the issue that when light rays with an elevation angle are projected onto the thread, the height of the irradiation position changes depending on the depth at which the thread is placed, even if the light rays are projected from the same height.

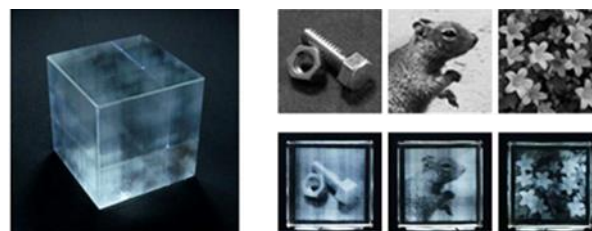


Fig. 1. Directional volumetric display using 3D crystals [7].

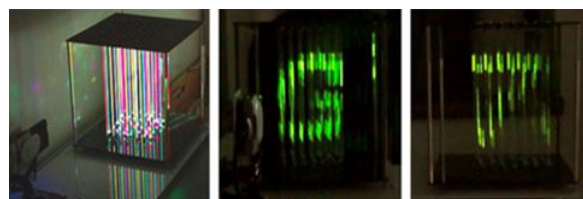


Fig. 2 Directional volumetric display using threads and a projector [7].

The previous study adjusted the vertical reduction of the rays corresponding to each thread according to the depth of the thread in the thread placement created by the simulation. However, as the thread arrangement must be performed manually, it is difficult to place the threads as simulated and to adjust the rays corresponding to the depth of the actual thread

placement.

In this study, a projected image was created using a new approach based on deep learning to adjust the light rays corresponding to actual thread placements.

2 PREVIOUS RESEARCH

As shown in Fig. 3, the directional volumetric display using threads and a projector generates one projected image from two different original images and projects it onto the thread using projection mapping, allowing different images to be recognized from two directions. The number of threads is required for the square of the horizontal resolution of the original image to be projected, and the threads must be arranged to satisfy the following constraints as shown in Fig. 4.

- Constraint 1: When observing, each thread must not overlap in the observation direction.
- Constraint 2: All rays from the projector must have one-to-one correspondence with all threads.
- Constraint 3: When viewed from above, the overall shape of the thread arrangement must be a square.

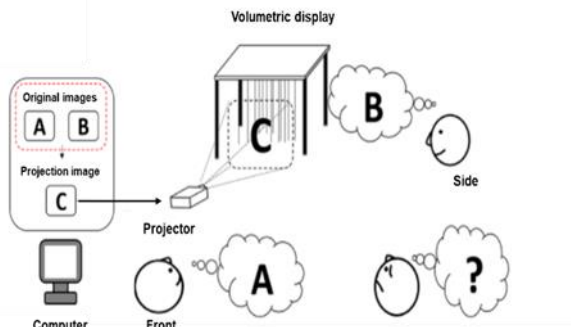


Fig. 3. Overview of a directional volumetric display using threads and a projector.

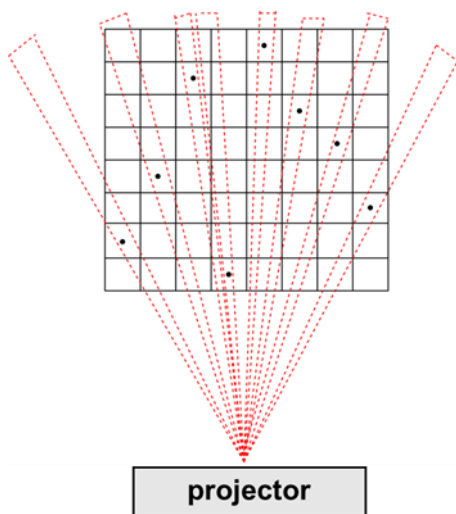


Fig. 4. Placement of threads.

Moreover, the light rays of the projector have an elevation angle. Thus, if a projected image is directly projected onto the volumetric display, the illuminated area and size change based on the depth at which the threads are placed. Therefore, the projected image is corrected by reducing and dropping the corresponding rays based on the thread depth information, as shown in Fig. 5.

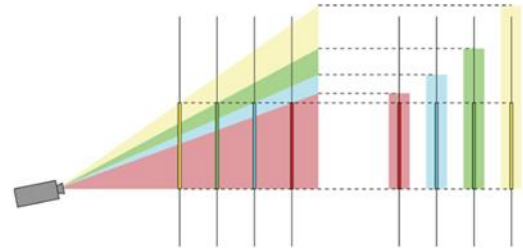


Fig. 5. Adjusting the height of rays.

3 PROPOSED METHOD

3.1 System configuration

Figure 6 shows the system configuration of this study. First, the height adjustment variables corresponding to each thread were randomly generated, and projection images were created based on the height adjustment variables. Thereafter, the projection images were projected in front of the volumetric display using a projector and were captured from the side using a web camera. The process of generating height adjustment variables and capturing images using a web camera was repeated 5,000 times to create 5,000 different sets of height adjustment variables and projection results. Then, a deep learning model was built based on the created datasets, and its task was to attempt to adjust the height to suit the actual thread placement.

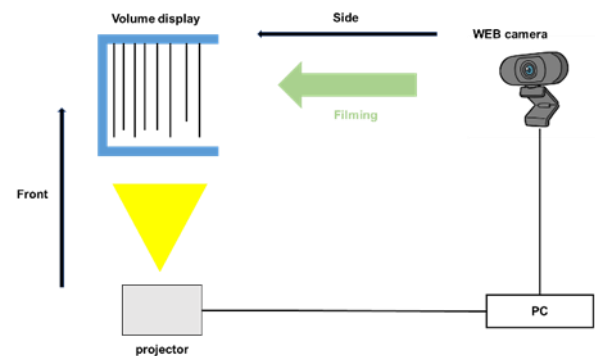


Fig. 6. System configuration.

3.2 Creating dataset

Figure 7 shows an example of a projection image and a projection result created based on Section 3.1. As shown in Fig. 7(a), T_n , the variable for height adjustment

corresponding to the top of the ray projected on the n th thread, and B_n , the variable for height adjustment corresponding to the bottom of the ray, were prepared. A dataset was created, and it consists of the prepared variables and the projection results of the projection images created based on the prepared variables.

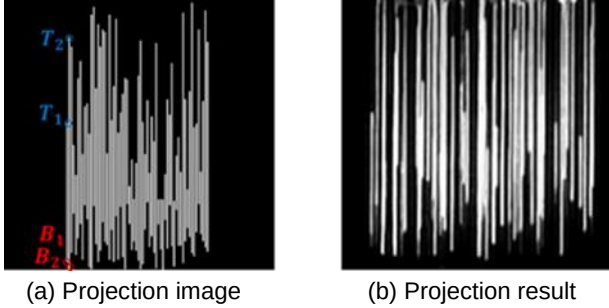


Fig. 7. A projection image created based on the variables for height adjustment and a projection results.

3.3 Building and running the deep learning model

Using the prepared dataset, a deep learning model is built with the image data of the projection results as the input and the height adjustment variable as the output.

When running the constructed model, the 5,000 dataset was divided into 4,000 training data and 1,000 evaluation data. In this study, the deep learning model was performed with a batch size of 100 and an epoch of 200.

3.4 Obtaining variables for height adjustment

After the model was trained, a pseudo-created ideal projection result image was input into the trained model. By inputting the pseudo-created ideal projection result, it is expected to obtain variables for height adjustment to achieve the ideal projection result. In addition, the image of the ideal projection result was pseudo-created by superimposing multiple projection results in the dataset and aligning the top and bottom heights of the rays.

4 RESULTS AND DISCUSSION

4.1 Height adjustment results

Figure 8 shows the volumetric display. Figure 9(a) shows the pseudo-created ideal projection result, and Fig. 9(b) shows the projection image created based on the obtained height adjustment variables.

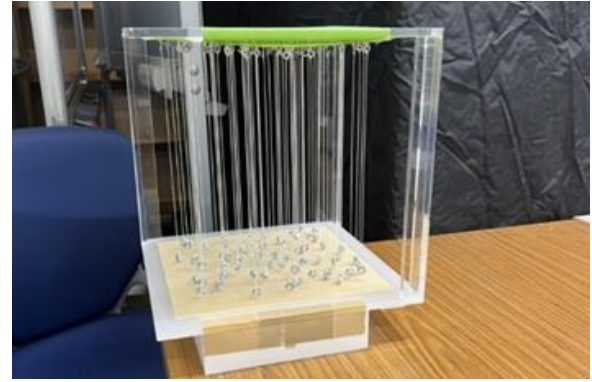


Fig. 8. Volumetric display.

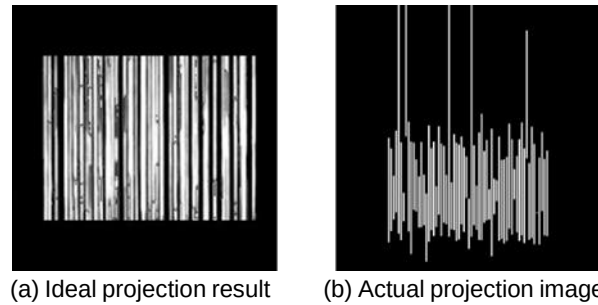


Fig. 9. Ideal projection result and actual projection image.

The projection image in Fig. 9(b) was projected onto the volumetric display. Figure 10(a) shows the projection result taken from the front and Fig. 10(b) shows the projection result taken from the side. In addition, Fig. 11 shows the projection result of the height-adjusted projection image using the conventional method.

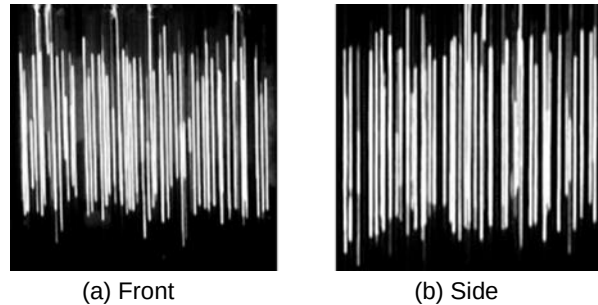


Fig. 10. Projection results of the proposed method.

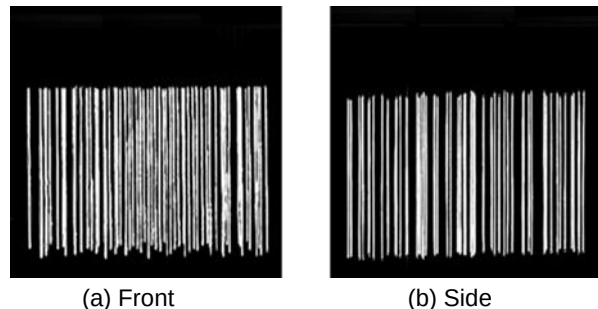


Fig. 11. Projection results of conventional methods.

4.2 Discussion

The results in Section 4.1 show that the conventional method can adjust the height in both the front and side directions. In contrast, the proposed method cannot adjust the height in both the front and side directions. There are two possible reasons for the inaccurate height adjustment.

The first reason is the lack of a vertical size for the volumetric display. The bottom of the rays fits into the display. However, the top of the rays was out of the display when the generated random height adjustment variable was below a certain value. Thus, the dataset contained projection result images with missing features. The inclusion of the projection result images with missing features in the dataset is considered to have reduced the model's evaluation efficiency. However, a volumetric display of sufficient size is expected to improve the image quality of the dataset and provide very accurate height adjustment.

The second reason is that the performance of the deep learning model is not sufficient. Since Adhesh Garg et al. [8] improved the accuracy of image recognition in MNIST using a convolutional neural network (CNN), which is used in image recognition, the use of CNN is expected to improve the performance of the used deep learning model.

5 CONCLUSION

The main purpose of this work was to resolve the height adjustment issue of directional volumetric displays. A projection image was created using a new approach that uses deep learning to adjust the light rays corresponding to actual thread placement. As a result, a dataset was created, and a deep learning model was built. However, an ideal projection image could not be created.

In the future, CNN will be used to improve the performance of the deep learning model, and the image quality of the dataset will be improved using a large enough volumetric display. Furthermore, the effectiveness of this research will be demonstrated in directional projection imaging.

ANCKNOWLEDGEMENT

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