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# Real-Time Interactive Visualization of 3D Models from Bioimaging in a Holographic Pyramid

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***Abstract*—With modern microscopes, nowadays, in the biomedical domain large numbers of 3D images are acquired. In order to understand the content of these 3D images, suitable interactive visualization techniques are required. Holographic display techniques are potentially suited to this task, as these allow objects to be displayed as true 3D images without the requirement of additional devices for the observers. Additionally, this visualization technique has advantages in a team setting because it allows simultaneous observation of a 3D image in different viewpoints by multiple observers. 3D images are simplified to 3D models, however, these are still complex. The visualization task of 3D models, focusses on the capability to visualize both the outline and inside parts of such models. Conventional implementations of holographic displays fall short with respect to these visualization tasks as the display area is limited and edge effects distract from the real image. In this paper, we propose a real-time interactive visualization method using a holographic pyramid setup and we implement this method in Unity3D. In order to supply interactivity to the setup, a Leap Motion is added. An evaluation of the system performance shows that compared with the conventional method, our method allows models to be visualized in a display area that is 2.25 times as large, without having to increase the size of the display source. Moreover, the boundary of the display area will not be observed on the pyramid surface which contributes to a positive visualization experience. The user evaluation resulted in a SUS score of 73.75, suggesting that the usability level of this interactive visualization system is good. This setup also is applicable to common 3D models which are created from a variation of 3D modelling software.**

***Keywords—Holographic pyramid, 3D models, bioimaging, interactive data visualization, Unity3D, GPU.***

## I. Introduction

In the biomedical imaging domain, visualization is an important research topic. Large numbers of 3D images are acquired by modern microscopes and these contribute to the understanding of diseases. Interpretation of microscopy images requires an interactive visualization method to interact with the content. Normally, the visualization of reconstructed data is displayed on a 2D screen. However, when 3D data is visualized in 2D space, part of the spatial information is lost. Special display technologies, such as virtual reality (VR), augmented reality (AR) [1, 2], holographic display [3], improve upon traditional 2D display. 3D models could be displayed in a VR environment with a VR headset and increase the immersive feeling. AR is a technology in which users observe the 3D object projected on the real-world through special glasses or a mobile phone. Using holographic display technologies, objects can be displayed as true 3D objects, without requiring the observers to wear a headset or special glasses. The most popular holographic display technique is to project the imagery on a holographic pyramid, allowing the 3D object to be simultaneously observed from multiple viewpoints.

In biomedical imaging, 3D models are derived from 3D images so that the content of the 3D images is simplified and can be visualized. A typical characteristic of a 3D model is that it consists of annotated parts that are obtained through some segmentation procedure. In this paper, a 3D model is represented by a set of triangular meshes. The model portrays outline and inside parts and it is important that the comprehensive complexity of these models can be properly visualized. It must be possible for separate labelled parts to be highlighted. These labelled parts can be organs, tissues or cells; e.g., for the study of an infective disease, both the whole object and the infected part must be observed. To observe all labelled parts of a 3D model, in general, we start from the outline of the 3D object which as a reference is amplified. Zooming in, or playing with transparency of the outer mesh, makes the inside parts appear. Therefore, standard manipulations on the display model, i.e., zoom in or out, move and rotate, must be available to the display method; and thereby to the user.

These aforementioned requirements can be achieved with VR and AR. However, a VR headset is still expensive and in a

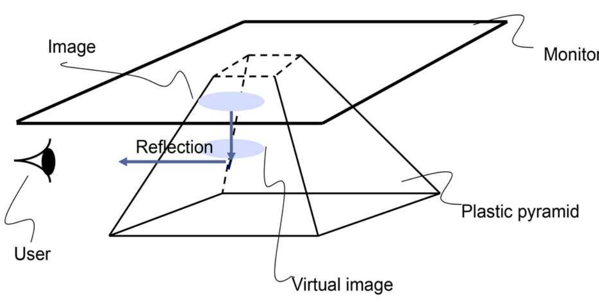


Fig. 1. Holographic pyramid system.

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VR environment observers sometimes get motion sickness. An important disadvantage to both VR and AR technology is that these can only be used by a single individual at a time when using one device. In a research environment, interpretation and discussion of visualizations in a team is part of the standard workflow. An interactive holographic display system will fulfill the requirements and allows a 3D model to be observed from different angles by multiple observers. At the same time, as there is no requirement for specific devices, the barrier for its use is lower compared to VR and AR.

The holographic display is an attractive display technology which provides a straightforward manner to achieve a feeling of true 3D visualization. In Fig. 1 a typical holographic pyramid setup is depicted, consisting of a flat-panel display and a quadrangular pyramid. The pyramid surface reflects the light from the flat-panel display into the eyes of the observer thereby creating the illusion that the 3D object floats in the center of the pyramid. The basic principle of this setup is an optical illusion referred to as Pepper's ghost, first presented by John Pepper in the 19th century [4].

Holographic displays are already applied in various fields: i.e., education [5, 6], museum exhibitions [7, 8] and architecture [9]. For these applications, the main aim is to visualize the surface of a whole 3D object. Although these setups could be used for the display of 3D models from bioimaging, they are, however, not suitable to display the inside of the models which is the interest of the researchers in the biomedical domain. The limited display area with this setup complicates the use of this technique for the type of 3D models we work with. The display area is smaller than the area available within the pyramid, and only allows zooming in the 3D object as long as it remains within this display area. To be able to zoom in to the inside of the object, it is required to enlarge the object beyond this limited display area. However, with the current techniques, this would result in the boundary of the display area to be clearly observed which does violate with a satisfactory visualization experience.

In this paper, we present a holographic display setup targeted specifically at the visualization of 3D models obtained from bioimaging. We improve upon earlier work by describing a software solution to increase the display area available for the models. This enables larger holograms to be visualized without having to increase the size of the 2D flat-panel. As a case study we use a model of a zebrafish larvae and we demonstrate that these 3D models can be interactively visualized in our system. Additionally, our system allows for adequate visualization of all labels present in the 3D model, as opposed to earlier methods.

The remainder of this paper consists of four more sections. The related work is discussed in Section 2. In Section 3 we describe our methodology to achieve real-time interactive visualization of 3D models in a holographic pyramid. The results and user evaluation are presented in Section 4. Conclusions are presented in Section 5.

## II. Related Work

The visualization of 3D models in a holographic pyramid is achieved by projecting images of different angles of a 3D object onto a transparent pyramid. This holographic visualization can be achieved both using flat-panel projection [3 - 10, 14] or using integral photography [11 - 13].

In holographic projection, if a flat-panel screen is used as display source, this projection method is referred to as flat-panel projection. In prior work, the application of this method has been described for education, museum exhibitions, architecture, and the medical field [3 - 10]. Sumpeno et al. [8] presented an approach to display museum objects on a holographic pyramid including a Leap Motion for interaction. Through feedback from users, they concluded that this system provided a more interesting and immersive way to help users acquire knowledge related to the museum exhibition. Salih et al. [3] presented a new lighting system to emphasize shape features by employing non-photorealistic rendering as an alternative to traditional lighting. Mahfud et al. [10] present a method for virtual objects floating in the mid-air (outside of the pyramid). This is achieved by placing the pyramid glass inside two parabolic mirrors. Compared to traditional setups, this setup is more costly and more difficult to scale up for displaying objects at a larger size.

Integral photography (IP) display is an autostereoscopic display method which includes horizontal and vertical parallax [11]. An IP display can be used instead of a normal flat-panel display to increase the depth information of 3D objects. As can be seen in Fig. 2, a fly's eye lens is positioned between the flat panel and the pyramid [11 - 13]. This causes the depth information of the virtual object to be preserved when the user observes the virtual scene from close by. However, when the user looks from a far distance, the object appears to fade.

To allow interactive visualization, Anraku et al. [12] introduced a game engine to control the 3D object. A keyboard was considered as a controller. This complicates a natural interaction with the hologram display. Alternatively, Dalvi et al. [14] used flat-panel projection and presented a gesture control pattern to make the interactive operation more natural. Their hand gesture recognition system uses Infrared Radiation for the detection of the position of the hand. This gesture recognition system has an effective range of about 30 centimeters under dim conditions of light.

To display larger objects, Anraku et al. presented a method [13] that rotates the square pyramid 45 degrees with respect to the display panel. In this manner, the size of the displayed object can be increased by approximately 1.4 times. A disadvantage of

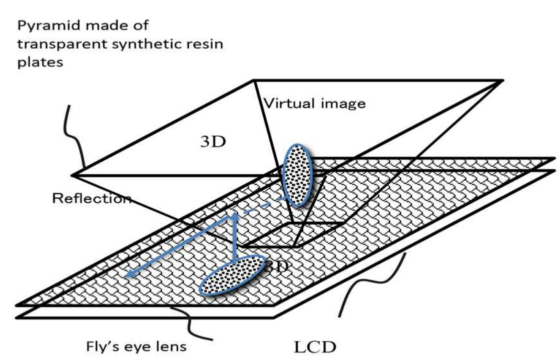


Fig. 2. Holographic pyramid system using IP [11].

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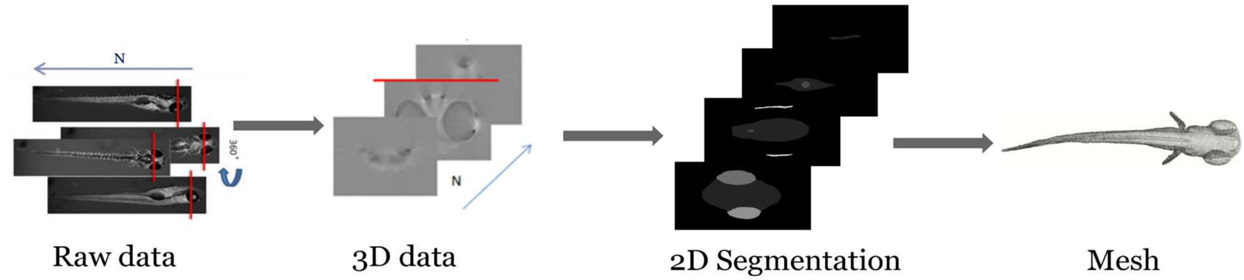


Fig. 3. Pipeline for the generation of 3D models from bioimaging: a zebrafish larvae as a case study.

this method is, however, that the support sticks used to position the flat panel on the top of setup may cause occlusion on the pyramid. Moreover, this method is most suitable for animations or videos in which the position of the 3D object is static. If the 3D objects are moved to other positions the display area of other positions is limited as well.

## III. Method

Our study aims to design and develop an interactive visualization system for 3D models with a holographic pyramid. The methodology of this work is divided into three parts: 3D model generation, visualization system design and interaction module design. Visualization system design includes device design and the display method. The control device and control algorithm are covered by the interaction module design. The visualization system and interaction module together form the interactive holographic display system.

### A. *Generation of 3D models from 3D images*

In many cases, 3D models are obtained from 3D volumetric image acquisition. Throughout this paper, we will consider 3D images of a zebrafish larvae as a case study. In Fig. 3 the pipeline for the acquisition of images with the OPT system [15], including the 3D volumetric reconstruction and the 3D mesh model generation, is depicted. For a zebrafish larvae, first a tomogram is produced which is reconstructed to a 3D image. Although the reconstructed 3D volumetric image results in high-quality output, rendering it is computationally quite expensive. Therefore, a segmentation procedure is applied to extract the relevant labels in each layer of the volumetric image. This results in a stack of contours for each label and subsequently a surface is reconstructed using the Boissonnat method [16]. In the surface reconstruction a polyhedral volume is derived from the planar contours for each label. From the volume only the surface

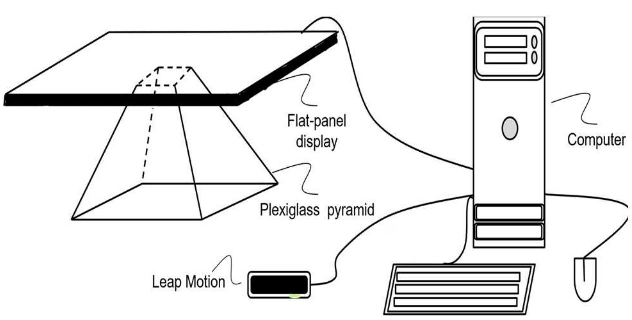


Fig. 4. Components of the interactive holographic display system.

triangles remain after a pruning procedure. In this manner we obtain a mesh which is very suitable for our interactive visualization setup.

### B. *System setup*

Fig. 4 shows the system setup consisting of a computer with a 2D flat-panel display and a plexiglass pyramid. For interactive input, a Leap Motion will be used. The display is generated from a software application which renders the holographic visualization and processes the input gestures from the Leap Motion. The application is implemented in Unity3D (vs. 2019. 2. 0b7). With respect to the system performance, a contemporary workstation with a dedicated Graphics Processing Unit (GPU) is powerful enough for good interactive visualization.

### C. *Display method*

An overview of the required image processing before projection is shown in Fig. 5. The front image of the 3D object should be placed on the top of the output image and flipped upside down. The back image of 3D object is placed on the bottom of the output image and flipped left and right. After a 90 degrees clockwise rotation, the image of the left size of the 3D object is set to the left area of the output image. Similarly, the image of the right side of the 3D object is rendered to the right side of the output image after a 90 degrees counterclockwise rotation. Summarizing, four sides of the 3D object are composed into a single output image that is displayed on the 2D flat-panel.

In prior work, the output image consists of four rectangles in which the model is rendered. We refer to each of these rectangles as the display area. In Fig. 6(a) the positioning of the display areas (in gray) in the display result are depicted. The short side of each of the display areas cannot exceed one third of the short side of the output image. This limits the size of the display areas and causes a large part of the output image to be left unused (indicated in black). In our improved implementation we change the display areas to triangles instead, as is shown in Fig. 6(b). In doing so, we can enlarge the display area without having to enlarge the output image. Therefore, we can use the enlarged display area to display larger models as well as allowing to zoom in a model without being cut off before reaching the boundary of the pyramid.

To produce an output scene, first sub-scenes are obtained from four sides of the 3D object. We refer to these sub-scenes as $V_f$, $V_b$, $V_l$, $V_r$. Second, we need to generate projection images for each of these. To do so, a scaling matrix is used to flip and/or

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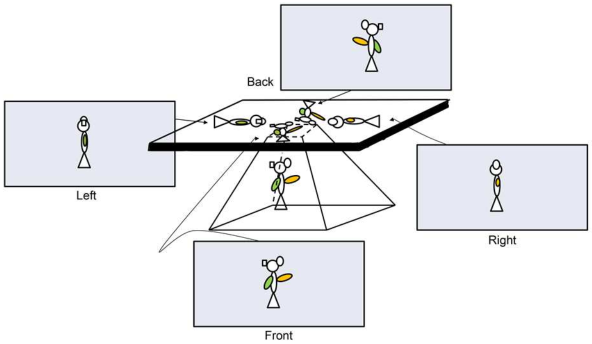


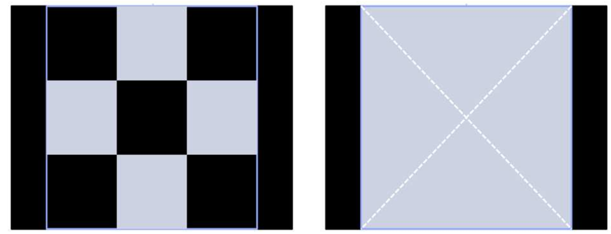

Fig. 5. Overview of the required image processing before projection.

rotate the image. The projection images are computed using the equation $P_x = V_x * M_x$ for $x$ in $\{f, b, l, r\}$. The scaling matrices $M_f$ and $M_b$ are shown in Equations (1) and (2) respectively. To decrease processing time, $P_l$ and $P_r$ are rendered by rotating the camera 90 degrees separately. $f_x$ is an output image in a certain resolution transformed from $P_x$. For instance, to generate an output image at a resolution of $N$x$N$, $f_x$ for $x$ in $\{f, b, l, r\}$ must have a resolution of $N$x($N$/2), $N$x($N$/2), ($N$/2)x$N$, ($N$/2)x$N$ respectively. Finally, $f_x$ is mapped to the final result $f$ using Equation (3).

$$M_f = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$M_b = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

$$f(x, y) = \begin{cases} f_f(x, y), & (x + y < N, x \geq y) \\ f_b(x, y\text{-}N/2), & (x + y \geq N, y \geq x) \\ f_l(x, y), & (x + y < N, x < y) \\ f_r(x\text{-}N/2, y), & (x + y \geq N, y < x) \end{cases} \quad (3)$$



(a) (b)

Fig. 6. Positioning and size of the display areas (in gray) in the display result. (a) shows the rectangular areas as used by conventional methods; (b) the triangular areas used by our proposed method.

### D. *Display method implementation*

For the implementation of our proposed display method, five virtual cameras are used as is illustrated in Fig. 7. Four virtual cameras are used to obtain the scenes of the four sides of the 3D object at the same time. The output image is rendered on a plane. A main virtual camera acquires the image of the surface of the plane on which the output image is rendered.

In the Unity3D environment, virtual cameras always render to a rectangular buffer. From each of the four rectangular buffers, the triangular display area is then extracted. We need to ensure that the rectangular buffers created by the virtual cameras are large enough to be able to extract triangles that will cover the entire surface area of the pyramid. The extracted triangles are combined into a single output image using Equation (3). The resulting output image is displayed on the surface of the display plane.

To implement the combination of triangles into a single output scene, we employ a compute shader in Unity3D such that this operation is performed on the GPU. This is important to be able to obtain satisfactory performance for our real-time visualization. Each of the rectangular buffers is stored in a Unity RenderTexture class, which signifies a texture stored on the GPU. The compute shader is handed references to the four RenderTexture instances that correspond to the four camera scenes. The shader computes the output scene, which is another

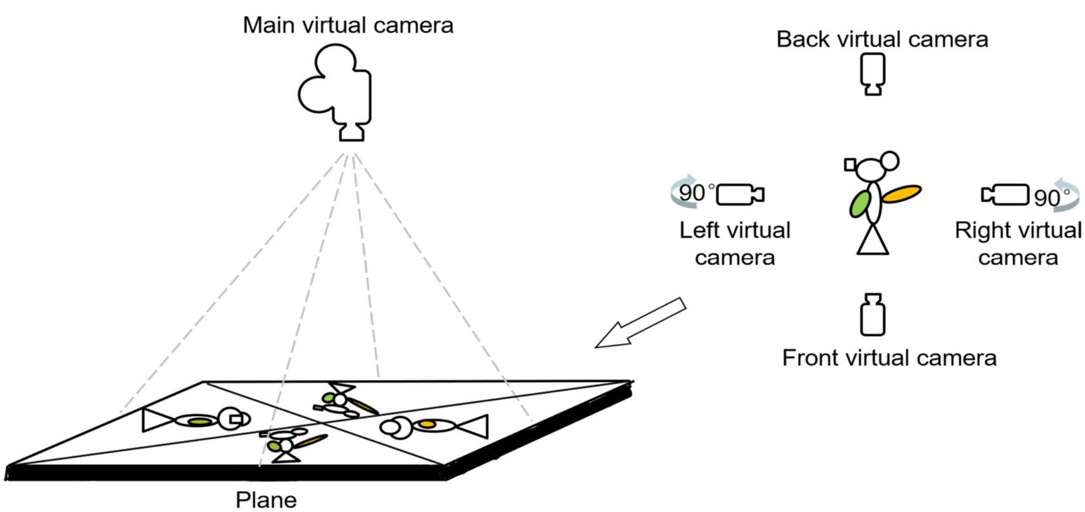



Fig. 7. Scene used in Unity3D to implement our proposed display method.

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RenderTexture, by retrieving the correct pixel value from one of the virtual camera RenderTextures for each pixel (x, y) according to Equation (3).

### *E. Interaction module design*

In our setup, the displayed holographic model can be manipulated with hand gestures. To link the gap between the physical presentation, i.e., gesture, and digital representation, i.e., the 3D model, a lookup table can be used to connect the relationship between the movement of the virtual object and the gestures. The design pattern for this kind of implementation is called the MCRpd model, as shown in Fig. 8. Where Rep-p means physical representation and Rep-d means digital representation [17].

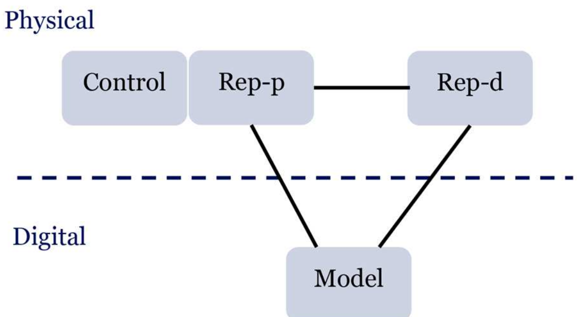
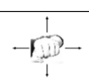
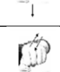
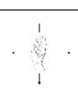



Fig. 8. MCRpd model.

We have chosen the Leap Motion for the input of the gestures. The Leap Motion controller can work in both dim and normal light environments and is capable of tracking hands within a 3D interactive zone that extends up to 60 cm or more, extending from the device in a 140x120° typical field of view [18]. The Leap Motion detects the hand conditions including hand type and gesture. Digital representation refers to the state of the digital 3D model as rendered on the flat-panel display. Using the current hand condition and gestures obtained from a Leap Motion, the next motion of the 3D object is retrieved from the gesture lookup table (cf. Table 1). Finally, the state of the 3D model is changed. For instance, if the user makes a fist with the left hand, the position of the 3D virtual object is fixed, and the 3D object will follow left hand movements to change position. If the user's right hand forms a fist, the 3D object is rotated following the rotate direction of the right hand. Other parts of the object can be displayed by moving the palm of the right hand.

TABLE I. GESTURE TYPE AND 3D OBJECT MOTIONS.

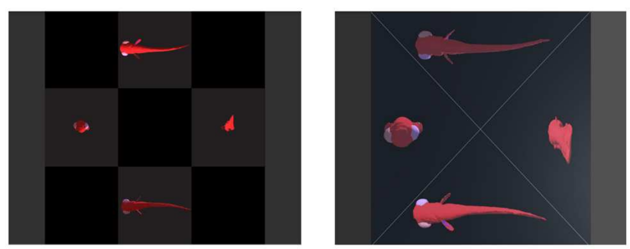
| Schematic | Gesture description | 3D object's motion |
|---|---|---|
|  | Left hand fist and hand up, down, left, right | Move object up, down, left, right |
|  | Left hand fist and hand forward, back | Zoom out, zoom in object |
|  | Right hand fist and rotate wrist down or up | Rotate object |
|  | Right hand open and hand up, down, left, right | Display different parts of object (change scene) |

## IV. EVALUATION

In this section, we evaluate the improved holographic display method proposed in this paper, as well as the usability of the interactive holographic display system for the visualization of 3D models. First, we determine the increase in display area between the conventional and proposed display methods. Second, we benchmark the performance of our display method implemented in Unity3D on a desktop-class computer with a dedicated GPU. And, finally, we present the results of a user evaluation of our system.

### *A. Display result*

To illustrate the effect of the triangular display area, we have enlarged the model until it hits the boundaries of the display area. The result of the conventional display method and the method proposed in this paper are shown in Fig. 9. Both are rendered at a resolution of 1024x1024. This resolution can be configured in Unity3D. Fig. 9(a) shows the result of the view of four virtual cameras which are rendered to four rectangular areas directly. As can be seen in the figure, the side of each of these rectangular areas is one third the size of the side of the output image. So, the display area for each rectangle is one ninth of the size of the output image. The display result of the new method is shown in Fig. 9(b). This image is the result of composing the views of the four virtual cameras into a single output image, using the method described in Sections III. C and III. D. In this case, each display area is a quarter of the output image. Compared to the conventional display method, the available display area is enlarged by a factor of 2.25. In other words, the three-dimensional (3D) object can be displayed 1.25 times larger compared to the conventional setups.



(a) (b)

Fig. 9. (a) The result of conventional display method. (b) The result of display method proposed in this paper.

The visualization results of a zebrafish larvae in the holographic pyramid are shown in Fig. 10. Fig. 10(a) and Fig. 10(b) show the whole zebrafish larvae using the conventional and the new method. The boundary of the display area can be clearly observed in the conventional display method. To observe the labelled parts inside the 3D object, amplification of the outline of the 3D object is required. Fig. 10(c) shows that the 3D object is cut and consequently the entire volume available in the pyramid is not used. In Fig. 10(d), the edge of the virtual object matches the boundary of the pyramid. When inside parts appear, Fig. 10(e) shows the display area is limited, whereas our method allows for a larger and clearer inside view as can be seen in Fig. 10(f).

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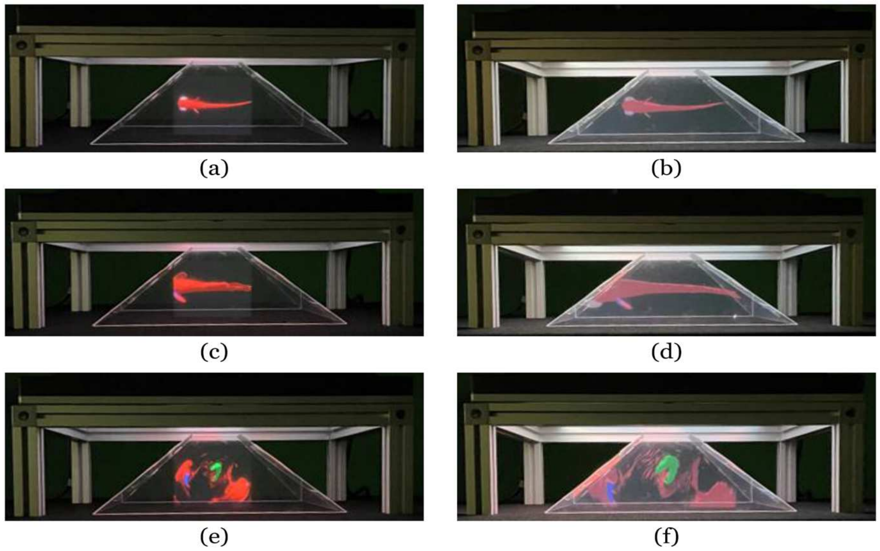


Fig. 10. Display results: (a) a whole zebrafish larvae is displayed using the conventional display method; (b) a whole zebrafish larvae is displayed using our proposed method; (c) 3D object is cut and entire volume of pyramid is not used; (d) edge of virtual object matches the boundary of the pyramid; (e) display area is limited when inside parts appear; (f) the larger display area enabled by our method allows for a larger and clearer inside view.

## *B. Performance*

The human visual system can process 10 to 12 images per second and these are perceived individually, while higher rates are perceived as motion. A frame rate of 24 FPS is used in games and image acquisition, to deliver film-like motion characteristics. So, we consider a frame rate higher than 24 FPS as real-time, so there will be no obvious observable latency.

TABLE II. FRAME RATE IN DIFFERENT OUTPUT RESOLUTIONS.

| **Resolution (Pixels)** | **Frame Rate (FPS)** |
|---|---|
| 64x64 | 100.8 |
| 128x128 | 99.3 |
| 256x256 | 99.1 |
| 512x512 | 98.8 |
| 720x720 | 86.2 |
| 1024x1024 | 67.2 |
| 1280x1280 | 51.1 |
| 1600x1600 | 36.4 |
| 2048x2048 | 24.1 |
| 2160x2160 | 23.0 |
| 3840x3840 | 3.0 |
| 4096x4096 | 2.4 |

To investigate whether real-time visualization can be achieved with our proposed implementation, we have benchmarked our application in a computer equipped with an NVIDIA Quadro K2000 GPU. We configured Unity3D to use varied sizes of the output image and recorded the main frame rate (frames per second, FPS) from the statistics function of Unity3D. In the conventional method, the resolution of the output image is limited by the screen resolution. The frame rate of the resolution of an output image at 1024x1024, which is the largest resolution we measured in the conventional method, is 69.6 FPS. Table 2 shows the frame rate of different output resolutions. From these results, it can be concluded that our application can visualize 3D models in real-time for resolutions up to 2048x2048, as a frame rate above 24 FPS is achieved in these cases. Moreover, compared to the conventional method only a minor reduction of the frame rate is seen, from 69.6 FPS to 67.2 FPS, for the 1024x1024 resolution.

## *C. User evaluation*

To evaluate the usability of this interactive visualization system, potential users, in the age group of 25 to 35, were invited to participate in an evaluation. During the experiments, observations were made about the interactions of the participants. In addition, after the experiment a questionnaire was completed by the participants.

First of all, users had to become familiar with the tracking behavior of the Leap Motion. Only two participants had prior experience with Leap Motion. The participants were asked to complete the following tasks:

- Move the 3D object up, down, right and left.
- Rotate the 3D object.
- Zoom in to observe the inside parts of the 3D object.
- Zoom out to observe the surface of 3D object.

After completion of all manipulations, the participants were asked to complete the System Usability Scale (SUS) questionnaire [19] as an indication for usability. This questionnaire has 10 questions. Participants rate each question on 5-point Likert scale (Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree). The calculated score of SUS is 73.75 indicating that the level of the usability of our interactive visualization system is good. 90% of participants had a positive attitude to use this system frequently and 95% of participants had a positive response with respect to the ease-of use of this system. All participants confirmed that they can quickly learn how to use this system.

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## V. Conclusion

In this paper, we presented a holographic display setup specifically aimed for the visualization of 3D models. We improved the conventional display method for a holographic pyramid by proposing a solution to increase the display area available for the models. The proposed method was implemented in Unity3D. Compared to the conventional method, our method allows models to be visualized in a display area that is 2.25 times larger, without having to increase the size of the 2D flat-panel. Additionally, the boundary of the display area will not be observed on the pyramid surface which contributes to a satisfactory visualization experience. Using zebrafish larvae as a case study, we demonstrated that 3D models can be interactively visualized in this system and enables a good visualization of all labels present in the 3D model. A SUS score of 73.75 was achieved from a user evaluation and this score indicates that the usability level of this interactive visualization system is good. This setup also is applicable to 3D models created from a variety of design software. In the future, we would like to further investigate how to enlarge the size of the setup by using a larger 2D flat-panel or projector technology.

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## References

[1] Y. Wang, Q. Li, L. Liu, Z. Zhou, Z. Ruan, L. Kong, et al. “TeraVR empowers precise reconstruction of complete 3-D neuronal morphology in the whole brain,” Nat Commun 10, 2019, 3474.

[2] M. Venkatesan, H. Mohan, J. R. Ryan, C. M. Schürch, G. P. Nolan, D. H. Frakes et al. “Virtual and augmented reality for biomedical applications,” Cell reports medicine, vol. 2, issue. 7, 2021, 100348.

[3] S. Qahtan, P. Sulaiman, R. Mahmod, R. Wirza, “3D holographic rendering for medical images using manipulates lighting in a 3D pyramid display,” Journal of advanced science and engineering research, vol. 7, no. 1, 2017, pp. 14-26.

[4] J. C. Sprott, “Physics demonstrations: A source book for teachers of physics”, Univ of Wisconsin Press, 2006.

[5] Y. Fan, T. Lin, L. Li, Y. Chang, “ Development of a lunar-phase learning system based on holographic projection technology,” In Proceedings of ICALT, 2021, pp. 386-388.

[6] H. Ghuloum, “3D hologram technology in learning environment,” In Informing Science & IT Education Conference, 2010, pp. 693-704.

[7] F. Bovier, G. Caggianese, G. Pietro, L. Gallo, P. Neroni, “An interactive 3D holographic pyramid for museum exhibition,” In 12th International conference on signal-image technology & internet-based system, 2016, pp. 428-434.

[8] S. Sumpeno, F. Hasna, A. Zaini, “3D object visualization using interactive holographic projection,” In International Conference on Computer Engineering, Network, and Intelligent Multimedia (CENIM), 2020, pp. 155-161.

[9] K. Kalarat, “The use of 3D holographic pyramid for the visualization of sino-portuguese architecture,” Journal of information system and technology management, vol. 2, issues. 5, 2017, pp. 18-24.

[10] J. Mahfud, T. Matsumaru, “Interactive aerial projection of 3D hologram object,” IEEE International conference on robotics and biomimetics, 2016, pp. 1930- 1935.

[11] T. Yamanouchi, N. Maki, K. Yanaka, “Holographic Pyramid Using Integral Photography,” In Proceedings of EECSS'16, Paper No. MHCI 109, 2016, pp. 1– 4

[12] S. Anraku, T. Yamanouchi, K. Yanaka, “Real-time photography holographic pyramid using a game engine,” In Proceedings of VISIGRAPP 2018, vol.v4, 2018, pp. 603-607

[13] S. Anraku, T. Yamanouchi, N. Maki, K. Yanaka, “Holographic pyramid using integral photography suitable for displaying tall objects,” In proceedings of EECSS’18, Paper No. MHCI 108, 2018, pp. 236-240

[14] A. Dalvi, I. Siddavatam, N. Dandekar, A. Patil, “3D Holographic projections using prism and hand gesture recognition,” ICARCSET’ 15, 2015, article no. 18, pp. 1-5.

[15] X. Tang, D. M. Zwaan, A. Zammit, K. F. D. Rietveld, F. J. Verbeek, “Fast Post-Processing Pipeline for Optical Projection Tomography,” IEEE transactions on nanobioscience, 2017, Vol. 16, Issue. 5, pp. 367-374.

[16] J. Boissonnat, B. Geiger, “Three dimensional reconstruction of complex shapes based on the Delaunay triangulation,” Proc. SPIE 1905, Biomedical Image Processing and Biomedical Visualization, 1993, pp. 964-975.

[17] D. Benyon, Designing interactive systems: a comprehensive guide to HCI and interaction design, 2nd ed. Pearson Education (US), 2010.

[18] “The Leap Motion Controller.” [Online]. Available: https://www.ultraleap.com/datasheets/Leap_Motion_Controller_Datasheet.pdf

[19] J. Brooke, "System usability scale (SUS): a quick-and-dirty method of system evaluation user information." Reading, UK: Digital Equipment Co Ltd 43, 1986, pp. 1-7.

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