3D Holographic Rendering For Medical Images Using Manipulates Lighting in a 3D Pyramid Display

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ABSTRACT

3D data visualization and 3D display have received extensive attention from researchers due to the rapid growth in computer graphics in the human's daily life. Despite the massive studies efforts consumed for 3D visualization, the shape perception of a 3D model has not yet been satisfied. In this study, we enhanced the visualization of 3D data for a hologram pyramid display by proposing a procedure named the hololighting style which consists of two steps. The first step is enhancing the shape perception of the 3D data. We proposed a new lighting system to emphasize the shape feature by employing non-photorealistic rendering as an alternative to the traditional lighting. The second step in the procedure is 3D hologram rendering for the hologram pyramid display. The screen is split in this step into nine segments for creating four viewports to contain 3D object from four views which are front, back, left and right. These steps are created and implemented using Visual C++, OpenGL 4.5. The results showed the enhancement of the 3D data as a hologram floating inside a transparent pyramid. The quality of the hologram is reported to be preferred when compared to a traditional 2D display. Moreover, the shape of the 3D data was reported to be enhanced by the new lighting style when compared to traditional lighting.

Key words: **Image processing, 3D visualization, Lighting, 3D holographic display.**

1. Introduction

Advancement of multimedia technologies and applications has been increasing in a wide variety of fields from education to marketing. In education, using 3D as a teaching tool in classrooms are thrilling both students and teachers. It attracts students' attention and makes learning more enjoyable and, therefore, more memorable. Recently, advertising companies have started using Holocube (hologram pyramid display) that attracts people by using holograms for the products of many important companies.

There are many types of 3D display technologies, such as 3D stereoscopic displays that need additional equipment to be viewed like special glasses. Also autostereoscopic displays can gain 3D perception without the need for such equipment, but it reduces 3D resolution. However, holographic displays offer an opportunity for users to perceive 3D images in natural depth perception (Geng, 2013) and are considered as the next generation of 3D display technology (Yang, Dong, Alelaiwi, & El Saddik, 2015). The main conflict of these technologies is that it relies on the human vision (Karaman, Çetîn, & Yardimci, 2010).

The human vision depends on a diversity of cues to perceive the depth, shape, and distance of the object in the scene when the brain receives different images from each eye and combines them together (Teittinen, 1993).Vast studies include methods to improve the rendering quality by applying shadows, lighting, transparency or developing illustrative techniques of non-photorealistic techniques to mimic model features. For instance, Wang et al. (Wang & Kaufman, 2013) have proposed a lighting system for volume rendering to increase the visual cues and shape perception.

Therefore, The invention of the hologram pyramid began as an optical illusion when Henry Dircks and John Pepper developed a technique called "Pepper's Ghost" during the 19th century ("Pepper's ghost could bring videoconferences to life," 2009; Sprott, 2006). To date, few studies have been established to measure the effectiveness of the hologram pyramid. Lately, Tiro et al. have made hologram pyramid with three sides of glass and a projection at the top to compare with technical drawings. They found that the hologram pyramid provides better visual perception than technical drawings (Tiro, Poturiović, & Buzadjija, 2015). Rendering for such displays requires the appropriate color, projector, and design to make the hologram appear in the correct position, clear, and understandable.

In this work, we focused on improving the shape perception for the viewer of 3D medical objects by proposing new lighting positions that use point lights delivered via a transparent hologram pyramid display. In this article, we employed a hologram pyramid display with four sides of suitable reflective plastic, and a projector was placed on the top of the pyramid. Two different sizes of pyramids were used for displaying our enhanced 3D object. Moreover, a mobile phone and tablet were employed as a projector to find out which one of the two pyramids enhanced the shape perception of the 3D model. Our method provided four views of the free moving naked eye with viewers seeing virtual 3D objects floating inside the pyramid. Accordingly, the main contributions of this study include:

- Proposing a new lighting position system that employs multiple point light sources and manipulates specular intensity to enhance shape perception and produce proper light for projecting our 3D object on the hologram pyramid.

- Creating four viewports to contain four views of the 3D object from a different angle for a hologram pyramid display.

The proposed method consists of two major phases which are the lighting hologram style and 3D hologram rendering. These phases are discussed in section III.

2. **Review of literature**

2.1 **Three dimension visualization**

Computer graphics mimic painting, or drawings of technical illustrations by employing non-photorealistic rendering (NPR) techniques. The capability of NPR to offer various visual appearances and different styles have inspired a huge number of researchers.

The NPR lighting model proposed by (A. Gooch, Gooch, Shirley, & Cohen, 1998) for technical illustrations purposes was based on a cool-to-warm shading algorithm, which depended on the fact of a cool color receding depth cues and a warm color advancing them (Browning, 1994). Besides creating a color scale by using tones (Birren, 1976) that were produced by adding gray to a specific color or adding a complement of a color, this shading algorithm cleared shape information by using Phong shading to add highlights to the object and drawing edge lines in black. However, (Northrup & Markosian, 2000) found their algorithm complex and not easy to implement. Moreover, it was unsuitable to utilize with changing meshes due to relying on expensive pre-computation. Later, (B. Gooch, Sloan, Gooch, Shirley, & Riesenfeld, 1999) developed their shading method to present interactive technical illustrations that were manipulated with lights, and object movement or a viewer's position. Incorporating their previous study and augmenting with a new shading algorithm produced many illustration techniques that improved the shape and depth.

Tietjen et al. (Tietjen, Pfisterer, Baer, Gasteiger, & Preim, 2008) combined a weight of illustrative rendering techniques to improve the depth and shape of medical data. A shading map that fused many illumination and surface details controlled the weight. The light warping approach was presented by Vergne et al. (Vergne, Pacanowski, Barla, Granier, & Schlick, 2009) to improve the view-dependence of 3D objects. Each point of the surface was warped by the light ray for compressing the reflected light patterns.

Recently, Jordane, Farès and Vincent (Jordane, Farès, & Vincent) introduced a hatching technique in a 3D scene taking into account three criteria, which were the lighting, the object geometry, and its material. These criteria provided tone, geometric motif orientation and geometric motif style respectively. The implementation was full GPU and provided real-time hatching on the large scene. They took into account these three criteria to establish a coherent and consistent model texture mapping. The triangle adjacency deduced easily from any 3D models at the loading step by indexing the model vertices.

Lately, an interactive modeling tool was introduced by Xu, Gingold and Singh (Xu, Gingold, & Singh, 2015) using the isophotes of a discretely shaded 2D image to design a smooth 3D normal field. Block or cartoon shading or different tone image, or even de novo were a visual style in which artists depict a variety of shapes and smooth 3D objects by using a small number of discrete brightness values and manifested as regions or bands of constant color. Their algorithm first projected light directions and calculated 3D normals along the object silhouette and at intersections from different light sources between isophotes. Then, they diffused the normals throughout the interior of the shape by propagating these 3D normals smoothly along the isophotes. This algorithm described the user interface for editing isophotes and correcting the unintended normals produced. A perceptual experiment and comparisons to the ground truth data were conducted to check the validity of the approach

2.2 **Three dimension display technology**

3D display technology had been industrialized from 1850 to 1930 when Brewster invented stereoscope (Zhu & Zhen, 2009). Nowadays 3D techniques and technologies have seen rapid advancements in the recent years. Hardware has improved and become significantly inexpensive and, produced 3D interaction in real-time. The improvements in computer graphics have been in speed, resolution, and economy. In addition ancient methods have enhanced, and innovative ones have developed. It has rapidly become important in computer graphics, visualization, virtual reality, and computer gaming (McAllister, 2002). Traditional display technologies can show flat images (2D) that are missing depth information whilst the world around us is three-dimensional. The ability of humans to observe and understand the complex objects in the real world is significantly limited by this fundamental (Geng, 2013). The state of arts presented by (Geng, 2013; Urey, Chellappan, Erden, & Surman, 2011; Yang et al., 2015) and the publication by (Kim et al., 2014), compared many types of 3D displays such as stereoscopic, autostereoscopic, volumatric and holographic displays. They found that most of these technologies have many limitations in resolution, depth cues and multiviews. Also, there is a need to wear spatial equipment such as head trackers or glasses that can cause eye fatigue and sickness. However, holographic displays provide all the depth cues that human eyes can observe and allows one to move the eyes freely without the need to wear any kind of viewing device. In addition to that, it enables one to generate 3D images that change as the position of the viewer changes exactly the same way as if the object was still present. Holographic displays have inspired researchers for years until the present and are considered as a very promising technology.

The study by Agus et al. (Agus et al., 2009) improved the understanding of massive 3D data and supported real-time rendering with unrestricted size on light field displays to generate dynamic observer independence. Nishi, Matsushima, and Nakahara (Nishi, Matsushima, & Nakahara, 2011) proposed a new method for creating realistic computer-generated holograms (CGHs) by using a polygon-based method to render specular surfaces. Specular reflection was imitated by a modified spatial spectrum of the imitated light. The Phong reflection model was utilized to control the shadowy shape of the imitated light. The technique satisfied fast computation to create several specular polygons and was significant for creating high-definition computer generated holograms (CGHs). An algorithm for producing 3D computer-generated holograms (CGHs) was presented by Zhang, Zhao, Cao and Jin (H. Zhang, Zhao, Cao, & Jin, 2013). The algorithm was proved by optical reconstruction and using multiple shading effects. They employed Phong reflection model to simulate the realistic lighting influence and calculate holograms. A phase-only spatial light modulator (SLM) was used in this study to achieve the optical reconstruction. Recently, they developed their algorithm (H. Zhang, Zhao, Cao, & Jin, 2015) for fully computing holographic stereogram to calculate full-parallax (CGHs) and to provide all the depth cues of the three dimensional scene. A precise accommodation cue and occlusion were reconstructed to improve the image fidelity.

Nowadays many researchers have used Pepper's Ghost (Sprott, 2006) technique that has been measured as the most popular technique to produce a holographic illusion and create holograms (Alves et al.; Pantoja et al., 2015). It has been used in theater, museums and concerts (Pantoja et al., 2015). The technique principle is using special light effects with a plate of glass rotated at a 45 degree angle to the viewers (Figueiredo et al., 2014). The result created by this technique gave the impression of an object floating in the air without the need for special glasses and gave a sense of depth perception. However, the holograms that were generated using Pepper's Ghost technique were considered as not true 3D displays because of the concepts of light fields, volumetrics, or the reconstruction of light wavefronts using diffractive interference (Geng, 2013).

3. **Proposed Method**

The display in this work is based on Pepper's Ghost technique, which used a mobile phone or tablet as a projector with two different sizes of pyramids for displaying our enhanced 3D object. The pyramid was built with four sides of suitable reflective plastic, and the projector was placed on the top of the pyramid. This technique was used special light effects with four plates of glass or plastic shaped as a pyramid and rotated at a 45 degrees angle to support four views of the 3D objects. The shape details were limited by using a single light source in the standard position. In order to demonstrate the efficiency of the hologram pyramid display, we proposed a new lighting illustration style to improve the shape perception. The final result presented the Hololighting style, which combined the lighting hologram style with 3D hologram rendering to produce a hologram floating in a hologram pyramid display.

3.1 **Lighting Hologram Style**

Our lighting system is based on the NPR lighting model that focuses on enhancing the shape features and producing suitable light to project the hologram. The physical relations between light sources, objects’ positions, and surface materials can create many effects of lighting models. According to Strothotte and Schlechtweg (Strothotte & Schlechtweg, 2002), a single light source in a typical position which is in the upper left corner in front of the object, is often not sufficient to emphasize the shape features. There has been need to come out with a new lighting system suitable for producing the hologram and enhancing the shape of the object. The point light was selected for our lighting system because it brightens a certain space close to the light source with the ability to attenuate light intensity. Generally the following equation calculates attenuation based on the distance to the light source:

$$att = 1.0 / (K_c + K_l * d + K_q * d^2) \qquad (1)$$

When d represents the distance from the object to the light source and Kc, Kl and Kq represent a constant, a linear and a quadratic respectively. The constant Kc is kept at 1.0 and never becomes smaller than one because the intensity increased with certain distances. The linear and the quadratic factors are used to decrease the intensity by multiplying them with distance; as so, the quadratic is less significant when the distance is small. Nonetheless, the linear is less significant when the distance grows.

To maximize the shape perception, six point light sources (above, upper left, upper right, bottom, lower left and lower right) were added to the object as shown in Fig. 1. The intensity was attenuated for each point light over the distance by the attenuation equation. According to the fact of the quadratic being insignificant at small distances compared to the linear factor, the quadratic factor was removed from the attenuation equation as shown in equation (2).

$$att = 1.0 / (K_c + K_l * d) \qquad (2)$$

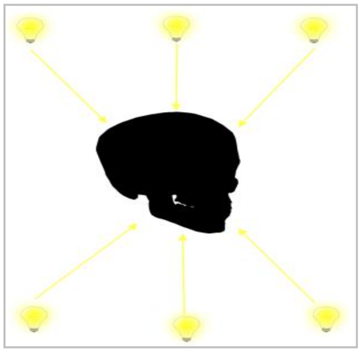


Fig. 1. The lighting system consist of six point lights source.

The procedure of adding lights to the object to produce a new lighting system is given in Fig. 2. The input was a 3D skull model; first, the polygons were rendered optionally by using the glPolygonMode. Then, the skull model was rendered three times with single, three, and six lights, respectively to show the impact of adding light to the object.

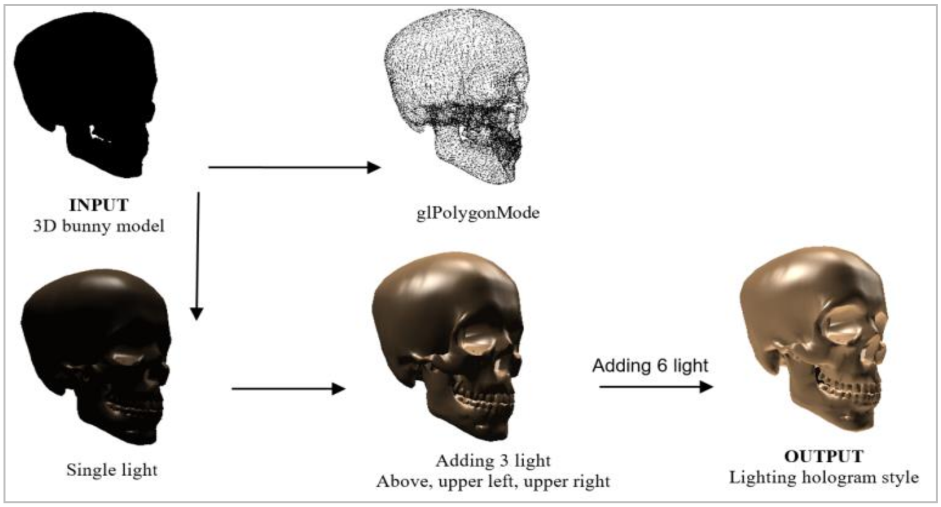
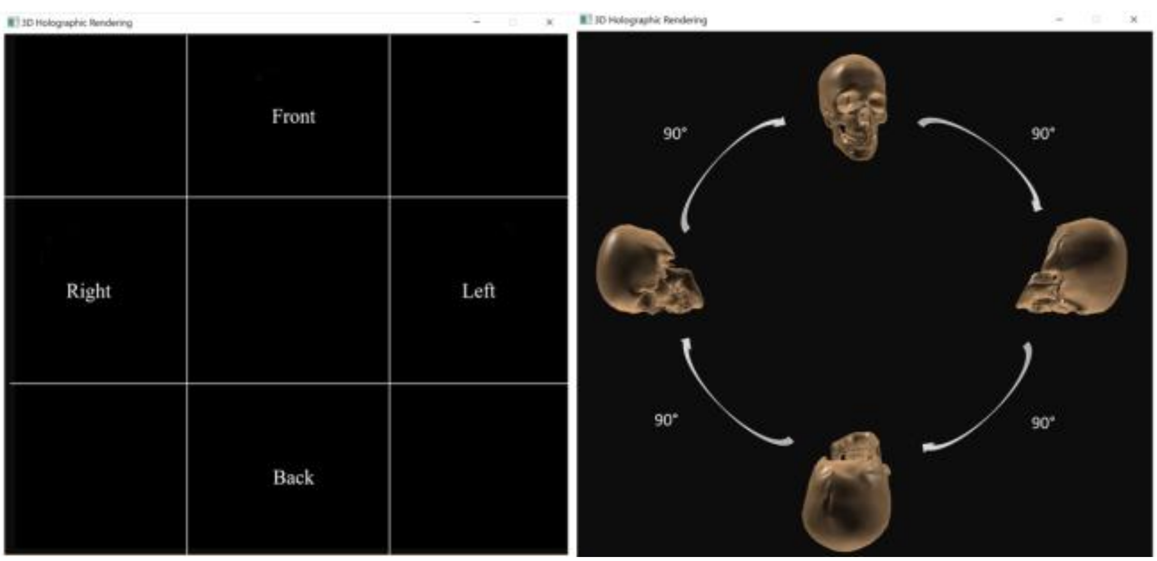


Fig. 2. The procedures of adding lights to the object.

3.2 3D Hologram Rendering

Rendering a 3D model for the hologram pyramid display required dividing the OpenGL screen into nine segments by using glViewport to get four viewports that can contain the object from four views. Fig. 3(a) illustrates the holographic screen, the four view port should contain the front, back, left, and right views of the 3D model. The four views of the object which are the front, back, left and right obtained by rotating the camera around the object by 90 degrees as Fig. 3(b) shows.



(a) (b)

Fig. 3. Holographic screen (a) screen segmentation (b) object rotation.

3.3 **Hololighting Style**

The hololighting style gets the name from the hologram and lighting, where lighting hologram style and 3D hologram rendering were combined to produce the hololighting style. Fig. 4 shows the output of the hololighting style compared to the standard lighting rendered by 3D hologram rendering. In the lighting hologram style, the objects were clearer, more dominant and had better shape compared to the standard lighting. Besides, the light appeared equal and smooth in the four different view of the objects when the lighting hologram style was used. In contrast, the object rendered by using standard lighting observed the opposite.

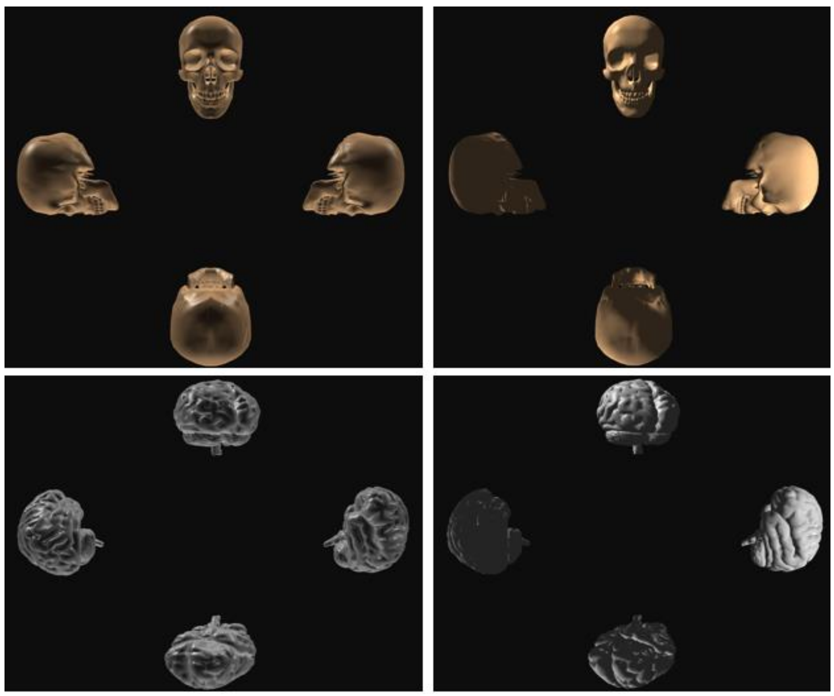


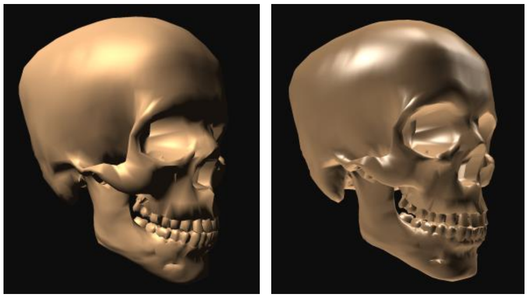
Fig. 4. The hololighting from the left lighting hologram style and the right traditional lighting style.

4. **Experiment, Results and Discussion**

Different studies have used different measurements to validate NPR visualization. Some researchers (Mendoza, Mata, & Pastor, 2015; Raab, Schäfer, Brost, Stamminger, & Pfister, 2013; Wood et al., 2012) evaluated their output by a questionnaire-based approach to obtain qualitative feedback. Other researcher (Lum & Ma, 2002; Vergne et al., 2009; Xie et al., 2007; L. Zhang, Sun, & He, 2014) compared their output to the styles that they wanted to achieve. Therefore, it was hard to validate the 3D illustration because as the old saying goes “beauty is in the eye of the beholder”. None the less, in this study, the experiments were checked by the user’s acceptance of the hololighting style method.

A survey was carried out with the purpose of seeing the preference of the respondent to 3D data visualization and to introduce a new method for visualizing and displaying 3D data on a hologram pyramid display. The survey had been set-up for computer graphic students in the Faculty of Computer Science and Information Technology, University Putra Malaysia with the number of respondents being 124 students. Before the respondents answered the given questionnaire, a brief presentation was given explaining the purpose of this survey and validating the hologram pyramid display and NPR visualization against the traditional display and traditional rendering method respectively. The overall respondents were between the age of 22 and 24, and constituted 55 male and 69 female respondents.

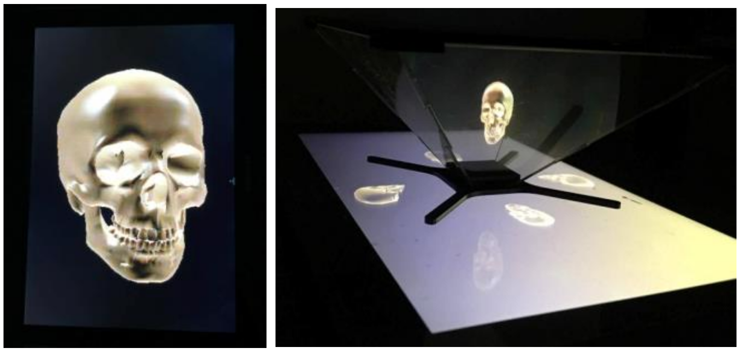
The shape perception validation was designed to compare between the lighting hologram style and standard lighting style as shown in Fig. 5. The subjects were asked their opinions on which lighting style offered a better shape perception between these images. The new lighting style was 97 percent compared to standard lighting which was 3 percent. Overall, the respondents believed that the new lighting style could give better shape details of an object.



(a) (b)

Fig. 5. Comparison between (a) standard lighting and (b) lighting hologram style

Then, the subjects were asked an additional question on how well the shape perception appeared on the 2D display and the hologram pyramid display as shown in Fig. 6; where, 1 represented as not well and 5 represented as very well. The respondents provided the following answer as illustrated in Fig. 7. The means for the 2D display and 3D hologram pyramid display were 3.46 and 4.18 respectively. Overall, the respondents believed that the 3D hologram pyramid display could give better representation of the object compared to the 2D display.



(a) (b)

Fig. 6. Comparison for shape perception on (a) 2D display (b) 3D hologram display.

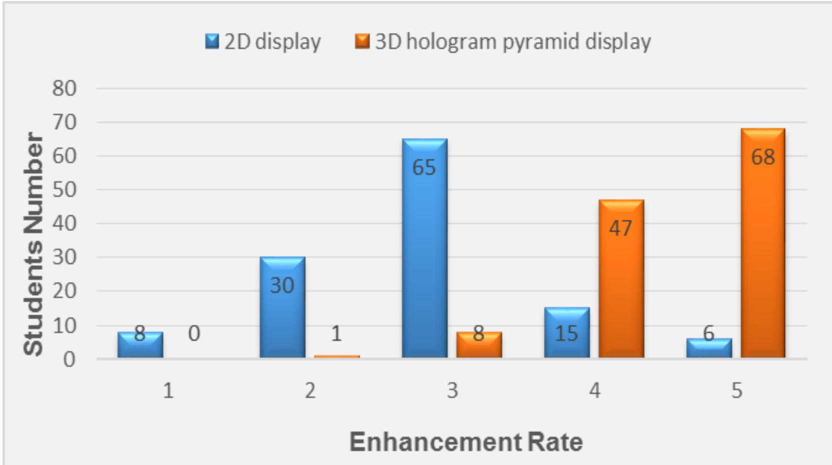


Fig. 7. The enhancement rate of the shape perception.

The last question to evaluate the shape perception was which one of the following rendering provided better shape perception inside the hologram pyramid display, traditional lighting or the new lighting style. Fig. 8 illustrates the impact of both styles of lighting on the medical object inside the hologram pyramid display for the respondents. The images have been noted to be slightly blurred due to the surrounding environment, which was dark, to present the hologram inside the hologram pyramid display very clearly. The difference between both lighting styles were very clear; where the impact of the light was not equal from each view and the left side for the pyramid, which showed that the back of the object was barley seen. The respondents preferred the new lighting style at a rate of 90.3 percent compared to the traditional lighting rate that was 9.7 present.

5. **Conclusions**

The goal for this study was focused on producing an alternative lighting illustration style for visualizing 3D data. The difficulty in producing this alternative lighting illustration style was finding the best way to enhance the shape details of the 3D data. Therefore, a new lighting position for the alternative traditional lighting method has been developed which added six point light sources (above, upper left, upper right, bottom, lower left, and lower right) to the 3D object. Then, the intensity of each point light had been attenuated over the distance by a linear equation, which is called attenuation. The second goal in this study was displaying a 3D model on a hologram pyramid display. Rendering for such a display required segmenting the screen to contain four views of the 3D model from different angles. This rendering was implemented using the OpenGL shading. Based on the questionnaire conducted, the lighting hologram style was preferred compared to the standard lighting and the previous study. The combination of the lighting hologram style and 3D hologram rendering produced a new style named the hololighting style.

6. **Acknowledgment**

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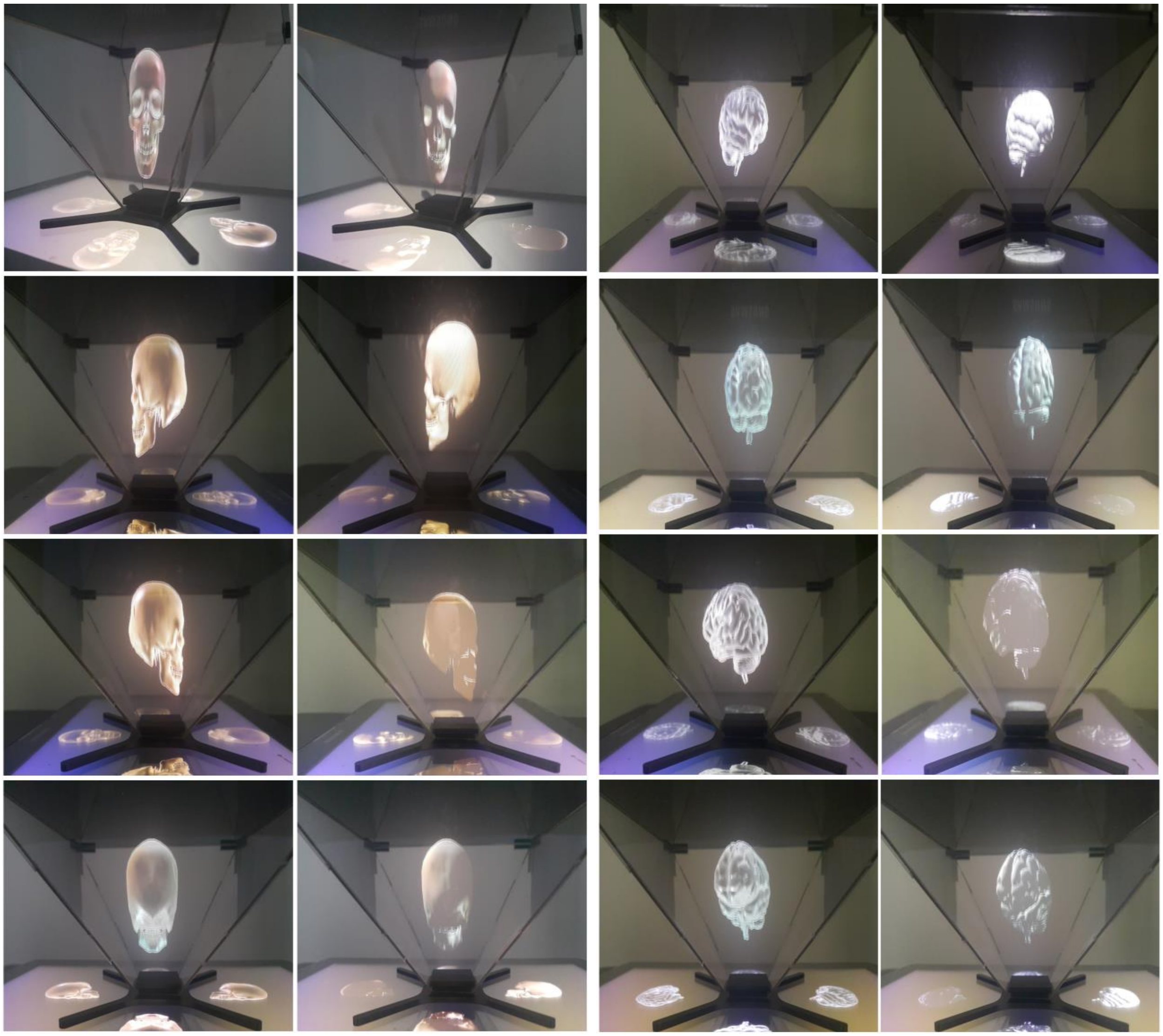

Fig. 8. The medical object inside the hologram pyramid display from the left lighting hologram style and from the right traditional lighting style