Assessment of Differences in Human Depth Understanding in Cube Displays Using Light-Field Displays

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Abstract—**Three-dimensional (3D) digital content continues to be a favored field of study both for academics, as well as businesses around the world. Virtual and augmented realities have received much consideration. The Light-Field Display (LFD), which allows users to view stereoscopic images from multiple viewpoints at the same time, provides a novel 3D experience. LFDs are complicated to set up, but this display has been made available for personal use. This study aims to evaluate the differences in task accomplishment between stereo versus motion-parallax cues for users performing 3D interactions on a multi-screen display. Our task scenario involves user tests for 3D depth understanding and questionnaires about the experience during the test. For each task, 3D contents are presented using stereo and motion parallax cues, using four LFD "Lume Pad" developed by Leia Inc. Results showed that depth understanding is aided by stereo cues. The Questionnaire showed that depth understanding was aided by the stereo cues from the LFD. Future work will include tests designed to further understand how beneficial stereoscopic cues are in a 3D display.**

Keywords-3D; Light-Field Display; Fish Tank VR; 3D human perception; stereoscopic vision.

I. INTRODUCTION

The human ability to view and understand three dimensions allows us to interact with the world in detail. Translating this to the digital field has not been an easy task. A Two-Dimensional (2D) screen is flat and as such does not have true depth, so the human eye does not interact with objects on a screen the same as it would with an object in the real world [1]. Steps have been taken to advance the perceived depth shown on these screens.

In recent years, the popularity of Virtual Reality (VR) and Augmented Reality (AR) headsets has greatly increased. Meta's Oculus and Apple's Apple Vision Pro have allowed people to immerse themselves in digital 3D worlds in ways that were only dreams a decade ago and the productivity advancements of such devices are only now being realized. AR specifically is being studied heavily for this purpose.

Advancements are also being made with hand-held displays, such as smartphones and tablets. While most of these advancements are being made with applications, some devices are being designed to be dedicated AR displays. One such device is an LFD. LFDs use curved lenses, known as lenticular lenses, to bend the light coming from the screen so that each of the user's eyes is shown a different image. This is similar to how a head-mounted display functions, but without the need to wear a headset. Another benefit is that multiple users can use a singular device to experience the stereoscopic visual cues.

Another form of virtual reality display is known as a Fish Tank VR display. These displays are 2D screens put together to form a 3D shape. The displays use their shape to introduce real depth to enhance the illusion of 3D depth shown on the 2D screens. While cubes and spheres are common, any shape could in theory be constructed using displays.

This study aims to measure a user's understanding of perceived depth with the use of a 3D display. Proposing Dice, a Fish Tank VR constructed with LFDs. Four LFDs are positioned to create the sides of the cube with an open top and bottom. By using LFDs, stereoscopic depth cues can be added to a cube display and their contribution to perceived depth can be measured.

The rest of the paper is structured as follows. In Section II, we present the details of the LFD hardware used in the experiment. Section III details the experiment methodology, such as the design concept, as well as the software and hardware used. The results of the experiment and the questionnaire are given in Section IV. Finally, we conclude our work in Section V, with our conclusion, discussion, and future work.

II. RELATED WORK

Kato and Prima [1] studied gaze characteristics in Mixed-Reality Environments. In this study, the researchers observed the gaze position of subjects when looking at an approaching target in a virtual space. Their research was conducted in two different types of rooms, one that had depth cues and one without. They showed that these rooms did not cause a significant difference in gaze accuracy. In their research, a head-mounted display was used to create stereoscopy. Dice does not use a head-mounted display but by creating stereoscopy with an LFD, similar results can hopefully be achieved.

One of the first cube displays is known as pCubee [2]. This display was constructed from five displays, one for each side of the cube and one to form the top of the display. It uses a gyroscope to measure users manipulating the display as well as head tracking to inform the display what orientation

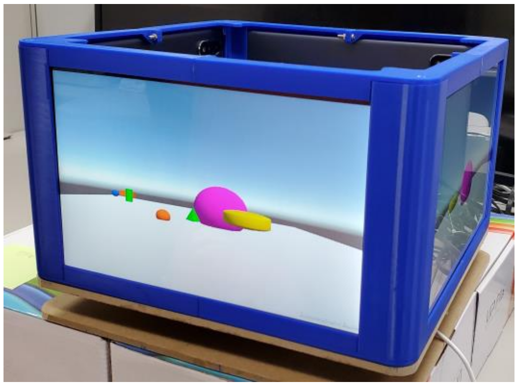

Figure 1. Dice.

each screen should show. This allows for many forms of interaction with the display. It was shown that pCubee helped their users to perform tasks faster and with fewer errors than when using a standard computer with a 2D screen.

A key drawback of many VR and AR devices is that they only allow for a single user to have access to each device. CoGlobe [3] overcomes this by using active shutter glasses and user tracking. This display is designed to appear to be a 3D sphere, giving the illusion of depth without the edges and seams found in a cube display. Projectors generate images for each user while the active shutter glasses allow the user to only see the images that are intended for them.

III. OUR PROPOSED CUBE DISPLAY: DICE

Dice is designed with four tablets, as seen in Figure 1, with each screen representing a side of the cube. The top is open. A magnetic encoder was used to determine the rotation of the cube and to send that data to the computer. The Lume Pad uses vertical lenticular lenses, so users were asked to only rotate the cube and not to change its pitch or yaw. If the user could alter the pitch and yaw the Lume Pad's displays would struggle to create realistic stereoscopic images.

The tablets used in this research were the Lume Pad, an LFD tablet made by Leia Inc. This allows users to see the illusion of depth inside of a 2D screen by showing each eye a different image, creating stereopsis. The tablet boasts a 10.1-inch screen with a resolution of 2560x1600 pixels. To create the light field effect, the tablet displays four views at a time and uses its lenticular lenses to allow users to see two of these images at a time. This gives the user the stereoscopic images of an HMD-typed VR setup as well as the portability and ease of use of a tablet-typed AR device. The Lume Pad has a forty-degree viewing window, measured from the center of the display, producing what looks like a real 3D image to multiple users at one time.

To generate the different views, the Lume Pad generates four views in 2x2 grids. Each image has a resolution of 640x400 pixels but is displayed in such a way as to be perceived as having a higher resolution [4].

The device dissects the images and displays them under lenticular lenses so that the user sees different images with each eye. This achieves stereoscopy and gives the user the perception of depth within the 2D screen.

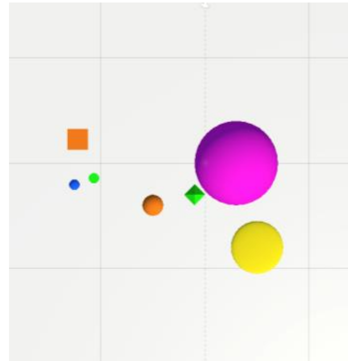

Figure 2. Layout of scene 1.

When Dice is rotated, a computer receives the rotation data and then informs each tablet display how to alter its display. To lessen the processing needed for each tablet the frame rate was reduced to twenty-four frames per second from the sixty frames per second that the tablets use natively. Also, when the LFD is turned on the resolution is reduced as four images are displayed on one screen. To reduce the impact of the graphics being diminished when the LFD is turned on, the graphics are set to 640x400 pixels when the LFD is turned off.

To assess the subject's understanding of the simulated depth within the screen, a 3D scene was created to be interacted with. The scenes include objects of differing sizes, shapes, and colors. In each scene there was one green pyramid and one green cylinder. The subjects were asked to pick which objects they believed were closest to the two green objects. The layout for scene 1, used for the first two tests, can be seen in Figure 2, while Figure 1 shows the same scene displayed on Dice. For each scene, the objects were moved and the sizes of some of the objects were changed. The scenes were designed in such a way as to emphasize different visual cues to find the correct answer.

This experiment was designed with Unity, using the Leia Unity Software Development Kit (SDK) [5]. Unity allows for easy setup of the scenes and the SDK facilitates the use of the Lume Pad's lenticular camera. This camera is complicated as one camera creates all four of the views for the LFD. Moreover, the stereoscopic display could be turned on and off as the experiments demanded.

IV. ASSESSMENT OF HUMAN DEPTH UNDERSTANDING

The experiment was carried out as follows. First, the user sat at a table, positioned between 45 – 50 cm from Dice. This is the distance that Leia Inc. states is the best viewing distance for the Lume Pad tablet. Then the subject was shown a sample scene and asked to rotate the cube to understand how rotating the cube would change the display. At that time, the tablets were not displaying stereoscopic images. Then the subjects were shown their first scene and asked to determine which objects they thought were closest to the green objects. This was repeated five times before the stereoscopic display was turned on and five more scenes were shown to the user. In total each user performed twenty tests so a total of sixty tests were conducted. At the end, a short questionnaire was given to the user to gauge how they felt each style of display aided or hindered them.

Three volunteers participated in this experiment. Their ages ranged from 21 to 25 with a mean age of 23. All had normal or corrected-to-normal vision. Each layout had two answers, one for each of the target green objects, so a total of sixty answers were collected.

V. Results

At the conclusion of the experiment, subjects were given a questionnaire to ascertain how well they believed they had understood the test as well as how the test made them feel. The questions were as follows:

a. With the LFD turned off, how well do you feel that you understood the scene? Did you know where everything was?
b. With the LFD turned on, how well do you feel that you understood the scene? Did you know where everything was?
c. How confident were you in your understanding?
d. How much discomfort did you feel? Did your eyes hurt? Did you feel sick?

Subjects stated that they felt the scenes were difficult to understand in both settings. The LFD helped them to feel more confident in their understanding of the scenes, but they were still often uncertain about which objects were closest to the green objects. Most said that this came from needing to look far into the perceived depth of the display. No subjects stated any ill effects from the experiment. If the subject made any errors, these errors were discussed with the subjects to try to understand why the subjects made their decisions.

Despite the small sample size, an interesting trend can be observed. The number of errors using the LFD display cube was smaller than with the standard display cube. Five errors were recorded for the standard display cube while only two were recorded for the LFD display cube. The respective error rates are 17% for the standard display cube and 7% for the LFD display cube.

Out of the sixty tests performed, only test four was failed 100% of the time. In this test, stereoscopic cues were not shown and the user was asked to find the object closest to the green pyramid at the center of the scene. A yellow cylinder was placed 1.5 units from the pyramid while an orange sphere was positioned 2.25 units from the pyramid. Every user chose the orange sphere as the closer object. The reasoning for this was that other objects obstructed the view of the pyramid from many angles. The best angle to view the distance between these objects places the yellow sphere further from the camera than the other objects, making the perceived depth difficult to feel confident about. A similar test layout was presented later when the LFD was turned on and none of the subjects made an error on this test. It cannot be said with certainty that the stereoscopic cues from the LFD made this situation easier to understand.

VI. Conclusion And Future Work

In this study, we examined the users understanding of a 3D scene, given some constraints, with and without stereoscopic depth cues. While the subjects were more accurate with the stereo attempts, it is not conclusive that the human brain understands distance in the light field display more so than on a motion parallax display. These findings are preliminary and require further study.

In our next experiment, we will work to improve our tests. Firstly, more care must be taken to design tests that fit the constraints of Dice. In this experiment, the size of the screen was not originally considered as a limiting factor for depth perception, but subjects stated that the screen size made objects feel farther away than they would like.

Designing new tests that can emphasize the difference between an LFD and a standard display is also a priority. Firstly, it was shown that the LFD may help users perceive depth when other depth cues are removed. To this end, we wish to remove depth cues so that more focus is be placed on stereoscopy. This should give clearer data on the benefits of an LFD cube over a standard display cube. Improvements to the cameras can also be achieved. A better balance between the perceived depth of the scene and the convergence distance of the Lume Pad camera will make objects in the scene more in focus when not at the center of the scene.

More ways to interact with the scene will also be researched. There are multiple ways to interact with other cube displays, such as pCubee. Not all these forms of interaction can be utilized with our cube, but inspiration can be drawn from their concepts. Measuring the speed at which tasks are performed would also be noteworthy.

A point to be weary of is how much this technology relies on stereoscopic vision. There is an overabundance of depth cues that can confuse the human brain [7]. It is unclear if this affected the subjects in this test.

Finally, we wish to expand both the types of interactions as well as explore how multiple users can make use of our display. These are key features that similar displays make use of. With our preliminary findings being promising we believe that these can be implemented into our display as well. The use of an LFD instead of the standard 2D screen should facilitate interesting options without the need for user tracking of any kind.

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