# Assessment of Differences in Human Depth Understanding Between Stereo and Motion Parallax Cues in Light-Field Displays

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***Abstract*—As Three-Dimensional (3D) digital content has become widely recognized, virtual and augmented realities have received a lot of attention. The Light-Field display (LFD), which allows users to view stereoscopic images from multiple viewpoints at the same time, provides a new 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-view display. Our task scenario involves user tests for 3D alignment accuracy and questionnaires about the experience during the test. For each task, 3D contents are presented in stereo and motion parallax cue presentation, respectively, using the LFD "Lume Pad" developed by Leia Inc. Results on six subjects showed that task alignment could be achieved with greater accuracy when stereo cues were available. Questionnaires showed that depth perception appeared to be easier with stereo cues. Future work will include observing whether LFDs provide better 3D perception than current Virtual Reality (VR) devices.**

***Keywords-3D, Light-Field Display; 3D human perception; motion-parallax; 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 does not have true depth to it, 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].

There are nine widely agreed upon sources of information that the brain uses for perceiving depth. They are as follows, binocular disparity, convergence, occlusion, relative size, height in the visual field, relative density, aerial perspective, accommodation, and motion parallax [2]. To a greater or lesser extent, they are used in conveying depth in a 2D screen, and it is the manipulation of these sources that forms the basis of 3D displays. There are many different types of 3D displays, each being varied to suit different tasks.

VR headsets are Head Mounted Displays (HMDs) that have had the most exposure in popular culture. Popularity of products such as the HTC VIVE and Facebook's Oculus are seeing use both in entertainment as well as scientific research. Augmented Reality (AR) headsets, such as HoloLens by Microsoft, are becoming more well-known as well. VR and head-mounted AR displays use similar concepts where they display slightly different images to each eye. Both rely heavily on binocular disparity to create stereopsis, as well as motion parallax.

Hand-held displays are largely composed of smartphones and tablets. Some are specifically designed as AR devices while others have apps, such as Pokémon Go and IKEA Place, that use the inbuilt camera to give the appearance of projecting their scenes into the real world. These rely largely on height in the visual field for the user to believe that what they are looking at is real.

Another form of 3D display is LFDs. An LFD uses lenticular lenses to bend the light coming out of the screen of the display, giving a different view to each eye. In this way, they work similarly to head mounted displays but perform this job without the need for a headset.

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 for the experiment and the questionnaire are given in Section IV. Finally, we conclude our work in Section V, with our conclusion and future work.

## II. LUME PAD

This research was performed on the Lume Pad, the LFD tablet 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 the lenticular lenses to allow the user to see two of these images at a time. This gives the user the best of both the HMD-typed VR set up, as well as the tablet-typed AR device. The Lume Pad displays 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 [3].

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.

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Figure 1. Sony Dual Sense Controller - Button layout.

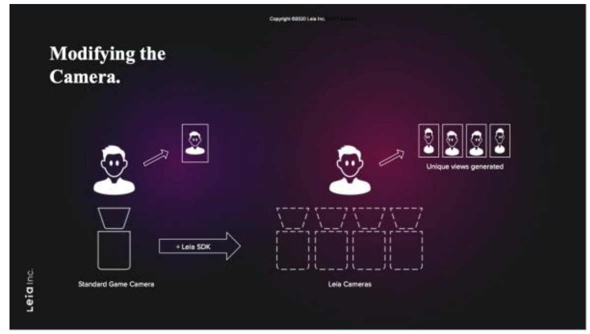


Figure 2. Scene-Camera layout for optimal Lume Pad experience [3].

(a) Top view.

(b) Side view.

Figure 3. Scenes from different angles used in the experiment.

## III. Experiment

In this study, the test was conducted using the Lume Pad for the display and a Sony Dual Sense controller for user input. Subjects were given control of an arrow and needed to aim it at a target that appears at a point above the arrow. This target is at a set *y* position and is offset by some distance in the *x* and *z* directions. The right control stick controls the arrow, allowing the user to rotate it to be facing the target to the best of their ability. The left stick controls the scene rotation, but it can only rotate the scene-camera around the center point on the horizontal axis. The right shoulder button zooms the camera in while the left zooms the camera out. The southern button is used to fire the arrow while the western button changes the display from stereo to motion parallax mode and back again. The button layout can be seen in Figure 1.

Subjects were forced to focus on horizontal angles because the scene could only be rotated horizontally. Since the Lume Pad has four horizontal and two vertical views, the decision was made to put more focus on the horizontal axis. To further increase the difficulty of the test, a large rock is placed behind the arrow so that the subject must view the scene from different angles to understand the direction that the arrow is facing. There are five trees that are placed within the scene, so that some sight lines will be blocked. In addition, the target starts relatively close to the center of the scene, near the arrow's starting point, and gets further away with each attempt.

Our experiment was designed using the Leia Unity Software Development Kit (SDK) [4]. The SDK allows to utilize the Lume Pad's features, such as the special lenticular camera, as seen in Figure 2. Moreover, the screen can be switched from stereo to motion parallax mode with a press of a button.

The experiment was carried out as follows. First, the subject is presented with a scene where the target is in random positions *x* and *z* and the trees are all in random positions. This allows the subject to learn the controls of the experiment and familiarize themselves with how to look around the scene. The results of this first attempt are ignored so the subject was encouraged to take their time and ask questions. After this practice, the subject was asked to perform three more attempts. These attempts will be the same for every user, with no random elements. The layouts for these attempts can be seen in Figure 3.

Each subject was seated at a desk, positioned between 45-50 cm from the tablet. This is the distance that Leia Inc states is the best viewing distance for the Lume Pad tablet. The tablet was then angled towards the subject's face to maximize the light-field effect.

For the experiment, there were 12 subjects (three females and nine males). They ranged in age from 22 to 31 with an average age of 25. All had normal or corrected-to-normal vision. They were split into two groups, one group would see the scene in motion parallax first, followed by the scene in stereo. This group did their practice attempt on the motion parallax version and then after their three actual attempts, the display was switched to stereo mode for the final three attempts. The second group was shown the stereo version for their practice attempt and first three actual attempts, followed by the motion parallax version for the final three attempts.

Accuracy is measured based on Euclidean distance, with a lower score being desirable.

$$Distance = \sqrt{(x_1 - x_2)^2 + (z_1 - z_2)^2} \qquad (1)$$

Here, $x_1$ and $z_1$ correspond to the position of the target while $x_2$ and $z_2$ to the final location of the arrow. The unit of measure for the experiment is Unity units (m).

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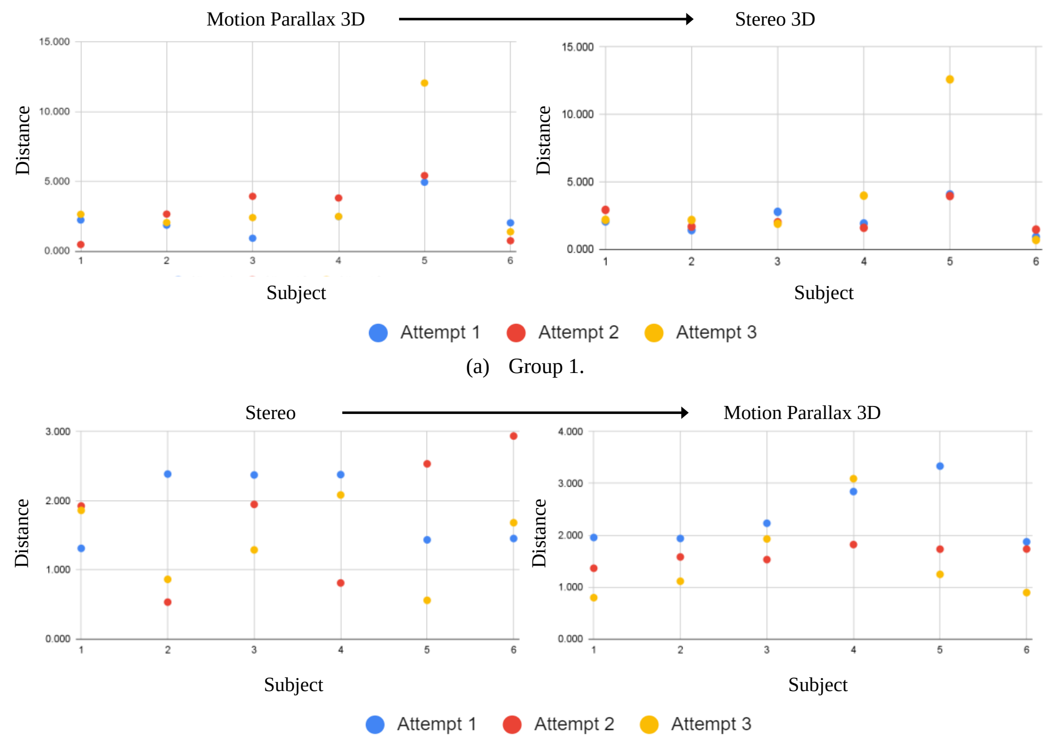


(a) Group 1.

(b) Group 2.

Figure 4. Experiment results.

## IV. RESULTS

Figure 4 shows the results of the experiments. Each subject is displayed on their own line, where attempts 1, 2, and 3 are in blue, red, and yellow, respectively. The direction of the arrows in the figure indicates the order of the experiment performed by the subject. Group 1 shows the results for the motion parallax attempts followed by the stereo attempts, while Group 2 shows the results for the stereo attempts followed by the motion parallax attempts. Group 1 was more accurate than Group 2. There is an argument to be made that Group 1 learned the test during the motion parallax attempts so it made sense that they would do better at the second round of attempts, the stereo portion of the test. The fact that Group two was more accurate during the stereo attempts as well, even though it is marginal, disproves this at least to some level.

Subjects were also 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. How well do you feel that you understood the scene? Did you know where everything was?
b. How confident were you in your aim? Did you think you would be close to the target?
c. How much discomfort did you feel? Did your eyes hurt? Did you feel sick?
d. Could you see the 3D effect? Do you feel a 3D sensation?

Subjects were given the same questions to answer after both the stereo and motion parallax tests. They were asked to give an answer on a Likert-typed scale from 1 to 5, where 1 was not at all or no and 5 was completely. On average subjects felt like they understood the scene more in the stereo mode as well as feeling more confident in their accuracy. Some users felt discomfort or sickness from the test, specifically in the stereo mode. More subjects from Group 1 felt discomfort than in Group 2. One subject stated that they felt dizzy after switching from motion parallax to stereo mode. Another subject said they could not see the 3D effect, though they had very high accuracy and moved the camera around frequently in the tests to make sure they were as accurate as possible.

## V. CONCLUSION AND FUTURE WORK

In this study, we examined how accurate a user could be, given some constraints, in a stereo and a motion parallax environment. 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.

To improve on this test, the next step will be to add eye tracking. We did not measure eye movement and eye vergence in this test. Both would give us a better understanding of how well individuals understood the scene they were interacting with [5].

Another concept which we plan to investigate is a multiscreen display. The pCubee [6] display is a cube shaped display, created by the University of British Colombia, that utilizes trackers to alter the display for a single user's perspective. Combining this with the light field effect should make for a very believable 3D display.

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.

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