Perceptual Distortions Between Windows and Screens: Stereopsis Predicts Motion Parallax

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Abstract

Stereopsis and motion parallax provide depth information, capable of producing more realistic user experiences after being integrated into a flat screen (e.g. immersive virtual reality). Extensive research shows that stereoscopic screens increase realism, while few studies have investigated users' responses to parallax screens without stereopsis. In this study, we examined users' evaluations of screens with only parallax or stereopsis. We found that with only parallax, the mapping between observer motion and viewpoint change should be around 0.6 for a more realistic perceptual experience, and observers were less sensitive to stereoscopic distortions as a result of a different interpupillary distance scaling.

Keywords: motion parallax, stereopsis, space perception

Index Terms: Applied computing—Law, social and behavioral sciences—Psychology; Human-centered computing—Visualization—Visualization design and evaluation methods

1 Introduction

Two types of visual information that human observers use to recover depth are stereopsis and motion parallax, e.g. [1,3]. While stereopsis relies on binocular disparity, motion parallax requires the coupling between one's own body movements with updates of the display that simulate the effects of observer motion in space. Such coupling, sometimes being referred to as a form of sensorimotor contingency [2], can give rise to a sense of occupying a location in visual space [6]. People have implemented these two types of visual information on a flat screen display, which adds additional information about the depth of depicted objects and the structure of the space depicted on the screen. In addition, researchers found that doing so also improves performance on certain tasks, such as path tracing [7].

Various techniques have been developed to implement these two types of visual information on a flat screen. For instance, Nvidia and Texas Instruments both had stereoscopic display technologies using shutter glasses, while the film industry has been applying polarized 3D systems to various blockbuster movies. However, these techniques require additional equipment and may produce user discomfort [5]. Similarly, motion parallax has been implemented in the form of super multi-view display, which simultaneously produces multiple views of the same scene that are selectively visible from specific viewing locations [4]. Developing such technology to make it commercially feasible is still an active area of research. More recently, commercially available head mounted displays (HMD) seamlessly integrates the power of stereopsis and motion parallax, providing users with a true immersive experience.

The asymmetry between the state of development of stereopsis-only and parallax-only displays and each type of visual information's respective role in depth perception raises the question of whether it would be worthwhile to develop a motion-parallax-only screen in the first place. Although numerous studies have examined user experiences on flat screens with stereopsis, few have looked at how only having motion parallax in the absence of stereopsis affect user's perceptual experience. If the screen only provides stereopsis, a lack of motion parallax creates perceptual distortions if the observer moves away from the intended viewpoint [8]. On the other hand, if the screen only provides motion parallax, stereopsis would still indicate the flat screen and thus generate an inconsistency that may also result in perceptual distortions. In this study, we measured how viewing a scene with only motion parallax or stereopsis is compared to viewing with both by asking observers to adjust the gain of each so that both displays appear to be identical.

2 Methods

We used the Unity game engine to construct a virtual scene that contained a hexagonal-shaped gazebo in the middle of a forest (Figure 1). Trees were randomly placed for each trial. We used two adjacent openings of the gazebo to display the forest. The left one behaved like a window that provided both stereoscopic and motion parallax information about the forest. The right opening could either 1) behave like a window with regards to motion parallax, but like a flat screen with regards to stereopsis (Parallax Screen), or 2) behave like a flat screen with regards to parallax, but like a window with regards to stereopsis (Stereoscopic Screen).

	Left	Right
Cond. 1	Window	Parallax Screen (Binocular Viewing)
Cond. 2	Window	Parallax Screen (Monocular Viewing)
Cond. 3	Window	Stereoscopic Screen

For the Parallax Screen, the image was captured from the observer's cyclopean eye. The screen continuously updated in real time as the observer moved such that the depicted scene always matched the view from the location of observer's cyclopean eye. We either presented the virtual environment to participants' both eyes (Condition 1) or only to their dominant eye (Condition 2). For the Stereoscopic Screen, two images were captured based on an interpupillary distance (IPD) of 6.5 cm. However, unlike the Parallax Screen, the images did not update in real time.

The virtual scene was presented in the HTC Vive Pro. We used two SteamVR Lighthouse base stations to track the position of the headset and a controller that participants used interact with the display and to register their responses. The system was calibrated using the SteamVR standing-only room calibration procedure.

During the experiment, participants wore an HMD and held a controller in their right hand. At the start of the experiment, we

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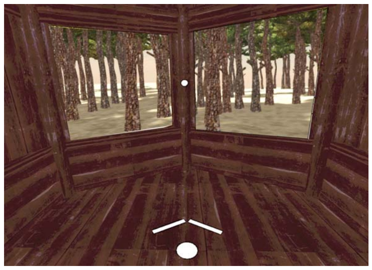

Figure 1: Screenshots of the virtual scene. Participants were standing at the centre of the gazebo facing two openings. They were encouraged to make lateral movements to adjust the gain of parallactic motion or the stereoscopic disparity to make the two views identical.

adjusted the height of the openings based on observer's eye height. In each trial, participants adjusted the motion parallax or stereopsis gain in the right opening to match what they saw in the left by pressing the up/down button on the controller. Adjusting the gain for the Parallax Screen changed the mapping between the observer's head movement and the rendered viewpoint on the screen. For instance, at a gain of 0.5, if the observer's head moved 10 cm to the right, the camera that generated the renderings on the Screen moved only 5 cm. Adjusting the gain for the Stereoscopic Screen changed the IPD. A gain of 0.5 would change the IPD of 6.5 cm to 3.25 cm. There was no time limit for responses. Participants pulled the trigger on the controller to confirm and proceed to the next trial. Six adults (1 female, 5 males), all with normal or corrected-to-normal vision, participated in the experiment. The study was approved by York University's Office of Research Ethics. We ran each condition as a separate block, the order of which was randomized across participants. There were ten trials in each block. The entire experiment took approximately 30 minutes.

3 Results

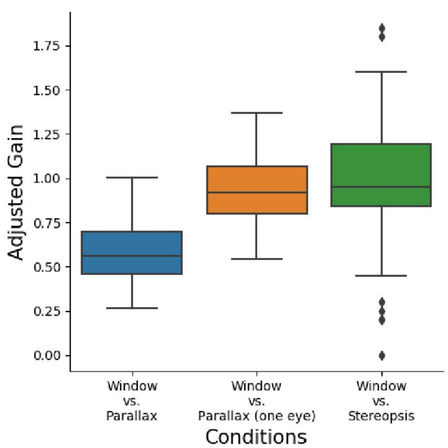

Figure 2: Box plot for adjusted gain for different conditions.

Figure 2 shows the adjusted gain for each condition. For Condition 1 (Window vs. Parallax Screen, Binocular Viewing), the mean adjusted gain was 0.59 (SE = 0.023, 95% CI = [0.55, 0.64]). This suggests that if the screen only provides motion parallax information about the depicted scene, observers see the induced parallactic image movement being almost twice as large as in the Window display. However, if the entire scene was viewed monocularly (Condition 2), the adjusted gain became approximately 1 (mean = 0.92, SE = 0.023, 95% CI = [0.88, 0.97]). Together, these two conditions suggest that when the screen only conveys motion parallax while stereopsis still specifies a flat surface, the perceived motion is twice as fast as in the Window display. In other words, for a flat screen that only provides motion parallax information, the amount of head movement has to be scaled by 0.6 to make the depicted scene look realistic.

On the other hand, when the screen provides only stereoscopic information about the scene (Condition 3), participants, on average, adjusted the gain to closely match the correct IPD (mean = 0.96, SE = 0.043, 95% CI = [0.87, 1.05]). However, the variability of performance was large, almost twice as the variability observed in the motion parallax conditions. This implies that observers have a high tolerance for changes in IPD, where the scene looks realistic even if IPD differed from their actual IPD.

4 Conclusions and Future Work

In this study, we used virtual reality to manipulate the availability of motion parallax and stereopsis on a flat virtual screen to examine the effects of disassociating them on perceiving a depicted scene, compared to viewing the same scene through an aperture. We found that when the screen only renders the scene with motion parallax, one has to reduce the amount of motion mapping between the observer and the rendered scene by a factor of 2 for the scene to look realistic. When the screen only renders the scene with stereopsis, observers could perceive the scene to be realistic with a correct IPD, but their tolerance for incorrect IPD was also large.

Results from this study demonstrate an asymmetry between stereopsis and motion parallax. On the one hand, stereopsis predicts motion parallax and generates expectations about how parallax should behave. For the Parallax Screen, the amount of parallactic motion was identical to that in the Window condition, but because stereopsis specified a flat screen, observers did not expect seeing such motion and therefore perceived its amount to be larger compared to viewing through the Window. On the other hand, an analogous relation was not observed, where a lack of motion parallax did not affect perceived depths from stereopsis. Nevertheless, results of this study suggest the possibility that only incorporating motion parallax can provide enhanced user experience, without the need of a special screen or head-gear. Future studies should examine these effects using a flat screen in real life.

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