Impact of Floating Windows on the Accuracy of Depth Perception in Games

Brodie Stanfield[a], Chris Zerebecki[a], Andrew Hogue*[a], Bill Kapralos[a], and Karen Collins[b]
[a]University of Ontario Institute of Technology, Oshawa, ON, CA, L1H 7K4.
[b]The Games Insititute, University of Waterloo, Waterloo, ON, N2L 3G1.

ABSTRACT

The *floating window* technique is commonly employed by stereoscopic 3D filmmakers to reduce the effects of window violations by masking out portions of the screen that contain visual information that doesn't exist in one of the views. Although widely adopted in the film industry, and despite its potential benefits, the technique has not been adopted by video game developers to the same extent possibly because of the lack of understanding of how the floating window can be utilized in such an interactive medium. Here, we describe a quantitative study that investigates how the floating window technique affects users' depth perception in a simple game-like environment. Our goal is to determine how various stereoscopic 3D parameters such as the existence, shape, and size of the floating window affect the user experience and to devise a set of guidelines for game developers wishing to develop stereoscopic 3D content. Providing game designers with quantitative knowledge of how these parameters can affect user experience is invaluable when choosing to design interactive stereoscopic 3D content.

Keywords: stereoscopic 3D, video games, floating window, design, perception

1. INTRODUCTION

The recent growth of stereoscopic 3D (S3D) within the entertainment industry has created the impetus for stereoscopic 3D in video games. The video game industry has relatively little experience in the use of stereoscopic 3D, which has created the need for guidelines and standards for the creation and the use of stereoscopic 3D in games. Game developers have largely ignored the need to design their games specifically for stereoscopic 3D technology, instead often building 2D games and then converting them to 3SD. The problem has been described by games journalist Richard Leadbetter: "With Nintendo 3DS, you would hope that we would be seeing more games uniquely tailored to the strengths that 3D offers - after all, every unit has the required 3D hardware. However, the vast majority of the titles we have played once again follow the same pattern we have seen on existing games: a window of depth is placed into the game world, which can be visually appealing but has very little practical appliance in the interface between player and software"[†]. Game developers typically rely on evaluating solutions used in other media, such as film, to correct perceptual problems such as window violations and "ghosting" (crosstalk), and modify or create new solutions to work within an interactive framework.

One problem with stereoscopic 3D relates to edge violations, where an object has a negative parallax (it appears in front of the screen's plane), and exits the screen in one eye before it appears in the other eye. The *floating window* technique, as described by Spottiswoode, (1952)[1], reduces the perceptual effects of window edge violations as objects move out of the screen-plane and was originally described as a static/fixed border in the film itself. Gardner, (2011)[2] extended the static floating window technique to a dynamic floating window technique that provides the filmmaker more control over the stereoscopic presentation and reduces perceptual effects as objects reach the borders of the virtual proscenium. Following up on our previous work in Zerebecki et al, (2011)[3], where we used the floating window in a mobile application to enhance the negative parallax experience on S3D capable mobile devices, we attempt to quantify the effects that the floating window has on user depth-perception in video games.

---

[*] andrew.hogue@uoit.ca; http://faculty.uoit.ca/hogue
[†] http://www.eurogamer.net/articles/digitalfoundry-what-went-wrong-with-stereo-3d

Stereoscopic Displays and Applications XXIV, edited by Andrew J. Woods, Nicolas S. Holliman, Gregg E. Favalora,
Proc. of SPIE-IS&T Electronic Imaging, SPIE Vol. 8648, 864814 · © 2013 SPIE-IS&T
CCC code: 0277-786X/13/$18 · doi: 10.1117/12.2004423

In this paper, we describe a study that investigates quantitatively how the floating window technique affects users' depth perception in a simple game environment. Our goals are to determine how these stereoscopic 3D parameters modify the user experience, and to determine the level of engagement and performance that a user will receive should a developer choose to add or omit the floating window technique. Providing game designers and developers with quantitative knowledge of how these parameters can affect user experience within a stereoscpic 3D gaming environment is invaluable when choosing to design interactive S3D content.

1.1 Floating Window

The floating window technique is a commonly employed by filmmakers to reduce the effects of window violations by masking out or cropping portions of the screen that contain visual information that does not exist in one of the two eye's views. The technique has been described by Spottiswood[1], Gardner[2], and Mendiburu[4] and extensively used in the film industry. However, despite its benefits in reducing edge violations, the technique has not yet been widely adopted by video game developers to the same extent, possibly due to the lack of understanding of how the floating window can be used in interactive media. Because such edge violations are often corrected in post-production in film, where cropping or masking can be adjusted after-the fact, when it comes to real-time (dynamic) adjustments, the problem is much more difficult. Gardner (2011)[2] showed how the fixed floating window could be made dynamic whereby the borders change shape/size/thickness throughout the film. This enables the filmmaker to have more control over out-of-screen effects, reducing window violations, and bringing the audience closer to the action. Previously[3], we suggested that the floating window technique could be extended further into the interactive domain in a variety of ways. More specifically:

- Use in cut-scenes to have objects *break the mask* and protrude further out of the screen
- Reduce clutter to direct players'eyes to a particular depth
- Interactive control of the window center. This enables the use of the floating window as a game mechanic. For example, one can imagine a cluttered scene where the player must move the window around the scene to find objects in depth similar to a flashlight.
- Over the shoulder shot where the character in the foreground protrudes further out of the screen due to the lack of clutter in the background and the other character is beyond the screen plane and viewed through the window.
- Using augmented reality to position the floating window interactively on mobile devices.
- Third person viewpoints. The player character could protrude out of the window always in front of the screen plane while the action occurs through the window.

While there are certainly many uses of floating window masks in video games, game designers must have a good understanding of how employing this technique affects the players' depth perception. How does the size and shape of the mask change the experience? Is there an effect on the player's ability to judge depths? If so, how strong is the effect? In the remainder of this paper, we describe a study developed to investigate these questions in order to develop an understanding of how the size of the floating window mask impacts users' depth perception, and whether there is a difference in depth perception in the presence of out-of-screen effects.

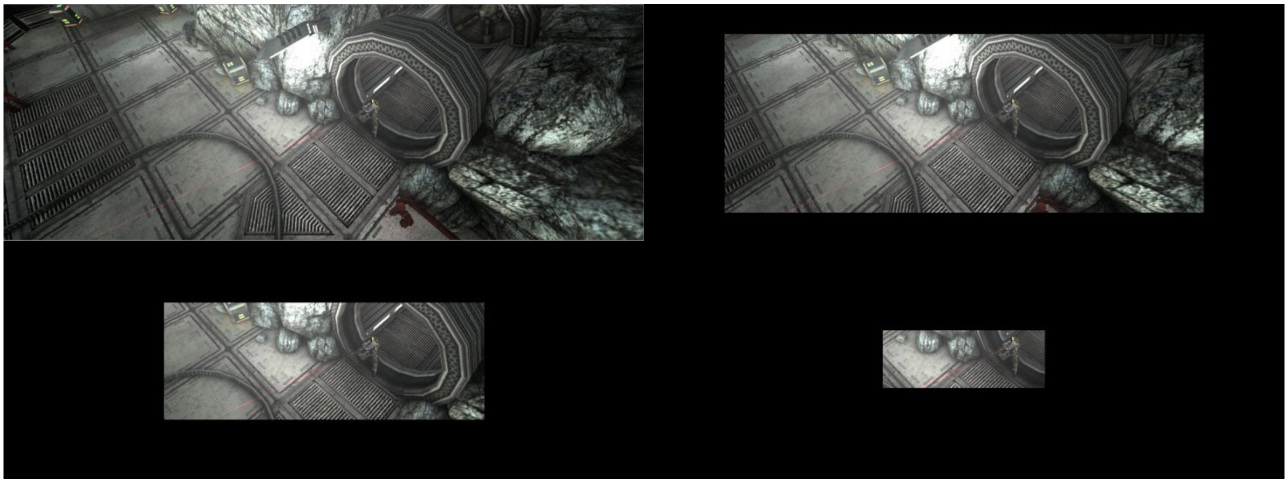


Figure 1: Examples of Different widths and heights of a floating window mask. Top Left: (width,height) = (0,0), Top Right: (width,height)=(0.25,0.25), Bottom Left: (width,height) = (0.5,0.5), Bottom Right: (width,height) = (0.75,0.75).

2. OUR STUDY

2.1 Study design

In order to study the effects of the floating window on user perception, we developed a visual test environment using the Unity3D game engine. The environment contains a cluttered environment to ensure we have enough visual information to achieve stereoscopy and be relatively similar to typical video game environments. We placed a bridge such that it is aimed directly at the user, goes deep into the scene and emerges from the zero-parallax plane. In this scene, we place black bars to mask out the environment at different positions essentially manipulating both the width and height of the floating window. This creates the effect of looking through a window into the game environment. A game character is placed on the bridge at different distances from the user. Users are asked to determine how far the game character is positioned relative to the screen plane and must indicate this using a slider with a Likert scale at the end of each trial. The independent variables present in the study are *width*, *height*, and *bridge*. Width represents the size of the floating window along the *x-axis* and height represents the size of the floating window along the *y-axis* and are valued at the percentage of the scene they occlude. Bridge is a binary variable representing whether the bridge is visible or not visible in the scene. The dependent measure is the perceived error of the position of the game character presented to the user, namely:

$$\textit{Perceived Error} = \textit{Actual Position} - \textit{Perceived Position} \tag{1}$$

The actual position is the actual metric distance of where the game character was positioned relative to the virtual stereoscopic camera. The perceived position is the value indicated on the Likert scale representing where the user perceived the character to be relative to their head.

2.2 Stereo Settings

The stereoscopic camera rendering parameters were set as follows, interaxial: 0.25 m, zero parallax: 10 m, field-of-view: 60 degrees, convergence: None (parallel cameras were employed). We used a large (0.25 m) interaxial setting due to the large size of the scene. More specifically, in order to accommodate the amount of desired parallax, we had to adjust our interaxial to be larger than human eyes.

2.3 Floating Window Settings

To create a floating window in the scene, we placed flat black bars in our scene at different positions. Four black bars are required (top, bottom, left, right) to create a rectangular window looking into the scene. By altering their positions we can alter the width and height or shape/size of the floating window. To minimize the number of variables in the study, we chose to study only the width and height of the window while future studies may look at the orientation of the window as well. The values of both width and height of the window can be adjusted to values representing the amount of the screen that is occluded by the black bars along their respective axes. Per trial, the width/height variables may take on four (4) values, namely 0, 0.25, 0.5, 0.75 which indicate 0%, 25%, 50% and 75% of the screen is occluded by the black borders (see Figure 1).

2.4 Observed Character

The character was positioned at randomized distances along the bridge and was placed between 3 m and 16 m from the stereoscopic camera. We used a 3D model from one of the main Unity3D tutorials (Lerpz).

2.5 Scene

The scene was filled with multiple objects behind the zero parallax plane to create a fairly cluttered, but typical, game environment (see Figures 2 and 6). The only asset that has out of screen effects in the environment is the bridge on which the character is situated. To determine if the participant is using the bridge as a major cue instead of the stereoscopic effects on the character, we ran tests with the bridge visible or not visible (see Figure 2).

2.6 Experimental Trials

In total, 96 trials were conducted comprised of of 32 unique conditions, each repeated three times to ensure repeatability. The trials were comprised of the following variations:

1. Floating Window Width
    a. 0%, 25%, 50% or 75% screen occlusion from the zero parallax screen depth.
2. Floating Window Height
    a. 0%, 25%, 50% or 75% screen occlusion from the zero parallax screen depth.
3. Bridge: Visible or Not Visible.

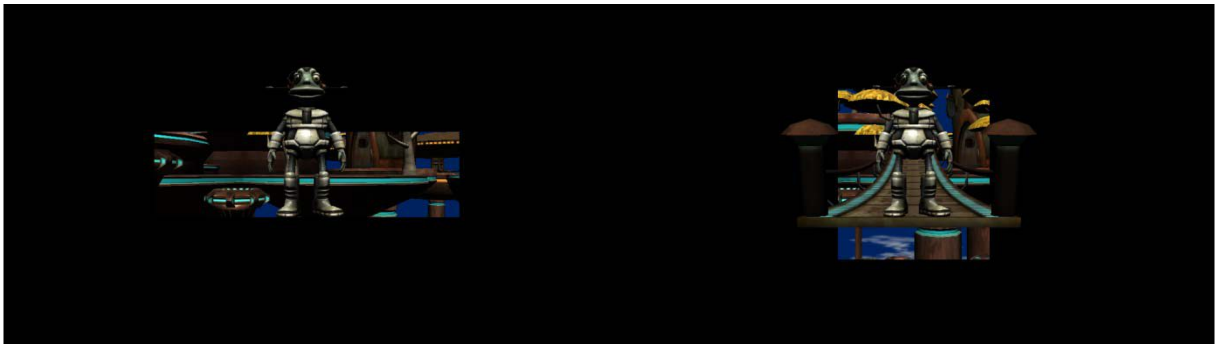


Figure 2: The Left image shows a trial without a visible Bridge and the Right image has a visible Bridge.

2.7 Participants

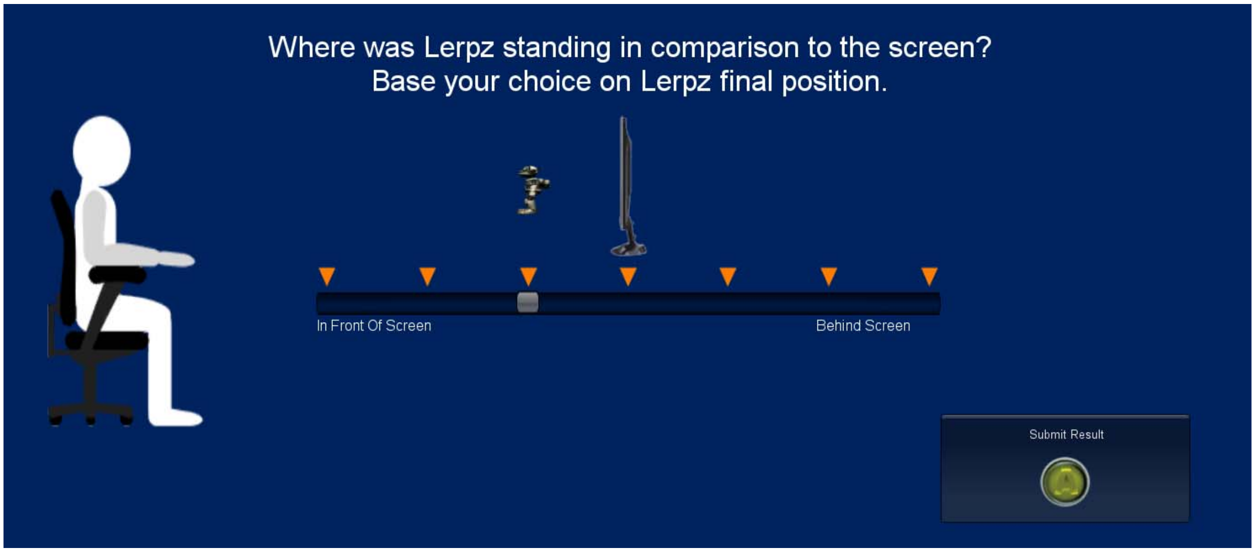
18 males and 2 females participated in this experiment. Of the 20 participants, 16 were students from the Game Development and Entrepreneurship program at the University of Ontario Institute of Technology. All of the participants were 18 or older, with 30% between ages 18-20, 30% between 21-23, 15% between 24-26, 15% were older than 27. All participants began playing video games between the ages of 2-13 with 55% of participants beginning their video game playing experience between the ages of 6 and 9. 55% of the participants spend less than five hours each week playing video games. Only 15% of the participants reported between 16 and 20 hours of game playing per week. 50% of the participants had prior experience with stereoscopic 3D video games, while 95% of participants had previously experienced a stereoscopic 3D film. Finally, 80% of the participants own a video game console. The experiments abided by the University of Ontario Institute of Technology Research Ethics Review process. All participants were initially screened using the standard Randot Stereo Test to determine normal stereoscopic depth perception.

2.8 Setup

The study utilized Zalman ZM-M240 24” stereoscopic 3D monitors with a 5 ms response time for visual display and emplyed a 1920 × 1080 pixel resolution. Stereoscopic images were presented using horizontal interlaced rows in the rendered images and the user was required to be positioned 0.30-0.60 m away from the monitor. To achieve the best stereoscopic 3D viewing with these particular monitors, the line from the user to the monitor was maintained at 90 degrees on the horizontal, and 12 degrees on the vertical. Viewers wore a pair of passive (polarized) stereoscopic glasses provided with the Zalman monitor. Participants were seated comfortably with the monitor adjusted to maintain the above viewing requirements. They sat in a lighted room and interacted with the testing environment using an Xbox 360 game controller. The PCs used were standard Dell XPS 720 computers with ATI Radeon 6970 video cards. The game used was developed using Unity 3D Pro v3.0 and we used the *Stereoskopix 3D* plugin (now called FOV2GO) from the user community to provide stereoscopic rendering support.

2.9 Experimental Procedure

Participants were seated comfortably in the Game User Research Lab at the University of Ontario Institute of Technology and wore stereoscopic glasses for the duration of the study. They first completed a demographic questionnaire to determine their demographic information. Prior to running the experiment, the participant was shown the maximum positive and negative parallax settings to enable them to adjust their seating position appropriately. The participant was then instructed that they were required to determine how far in or out of the screen the character is positioned at the end of the trial: this was accomplished as indicated on the screen after the trial is complete (See Figure 3) using the Xbox 360 controller.



Where was Lerpz standing in comparison to the screen?
Base your choice on Lerpz final position.

Figure 3: Data collection. The user inputs the depth that they perceived the character Lerpz was at relative to the screen based on a 7 point Likert scale.

2.10 Testing Environment

Given access to multiple Zalman S3D monitors, we were able to run up to three participants simultaneously. Participants were seated apart from each other and could not interfere with each other. To limit the potential effect of sound on the users perception of depth[5], and any floating window effects, our study did not include any sound effects and therefore, there was no risk of sound interference between the separate sessions. Furthermore, there was no interaction or communication between participants.

2.11 Results

The data were analyzed using a three-way, repeated measures ANOVA, (width) × (height) × (bridge). Both the within-subject width and the within-subject height variables were comprised of four levels each (0, 0.25, 0.50, and 0.75). The bridge variable was comprised of two levels (Visible and Not Visible). All post-hoc comparisons were conducted with a Bonferroni correction. The dependent variable was each participant`s perceived error score, calculated as the difference between the actual position of the character and the perceived position of the character as reported by each participant. The difference score was averaged over three identical trials randomly interspersed across all trials. A ***negative*** value of the error score indicates that the participant perceived the character at a ***further*** distance than the actual distance. A

positive value of the error score indicates that the participant perceived the charcter at a ***closer*** distance than the actual distance.

The three-way ANOVA indicated that all main and interaction effects were significant. The main effects included width, *F*(3, 17) = 12.64, *p* = .001, height, *F*(3, 17) = 31.85, *p* <.001, and bridge, *F*(1, 19) = 12.63, *p* = .002. The two-way interactions included (width) x (height), *F*(9, 11) = 15.24, *p* < .001, (width) x (bridge), *F*(3, 17) = 34.62, *p* < .001, and (height) x (bridge), *F*(3, 17) = 19.73, *p* < .001. These were all qualified by a significant three-way interaction, (width) x (height) x (bridge), *F*(9, 11) = 8.45, *p* = .001, which is graphed in Figures 4 and 5.

2.12 No Bridge

The post hoc analyses indicated that at maximum width (value = 0.75) and no bridge present (see Figure 4), the error score was highest (positive value) at heights of 0.25 (M=0.374, SE=0.356) and 0.50 (M=0.21, SE=0.27) and lowest at height of 0 (M=-1.983, SE=0.227). This suggests that when there are no out-of-screen effects, the users perceived the object as being significantly further than it actually was when the floating window was rectangular and no coverage on the *y-axis*. Also interestingly, when the width was at 0.5 there is a reversal in perceptual error between the conditions where the height was at 0.0 (M=-1.788, SE=0.23) and 0.25 (M=1.724, SE=0.327). This indicates that the users perceived the object as further away than actual without floating borders on height and when a small (0.25) black border is present they immediately perceived the object as closer than actual.

2.13 Bridge

We have similar trends as seen in Figure 5 with the bridge with a couple of interesting exceptions. Notably, the effects at width = 0.75 are in the opposite directions as when the bridge was not visually present. Given that the only difference between these conditions are that the bridge is present or not, this indicates that there is a significant shift in perception when out-of-screen effects are present. A similar shift is seen in width of 0.25 and height of 0.5. When the bridge is visible users are quite accurate (M=0.364, SE=0.248) but when the bridge was not visible they significantly over estimate the distance of the character (M=-2.374, SE=0.260).

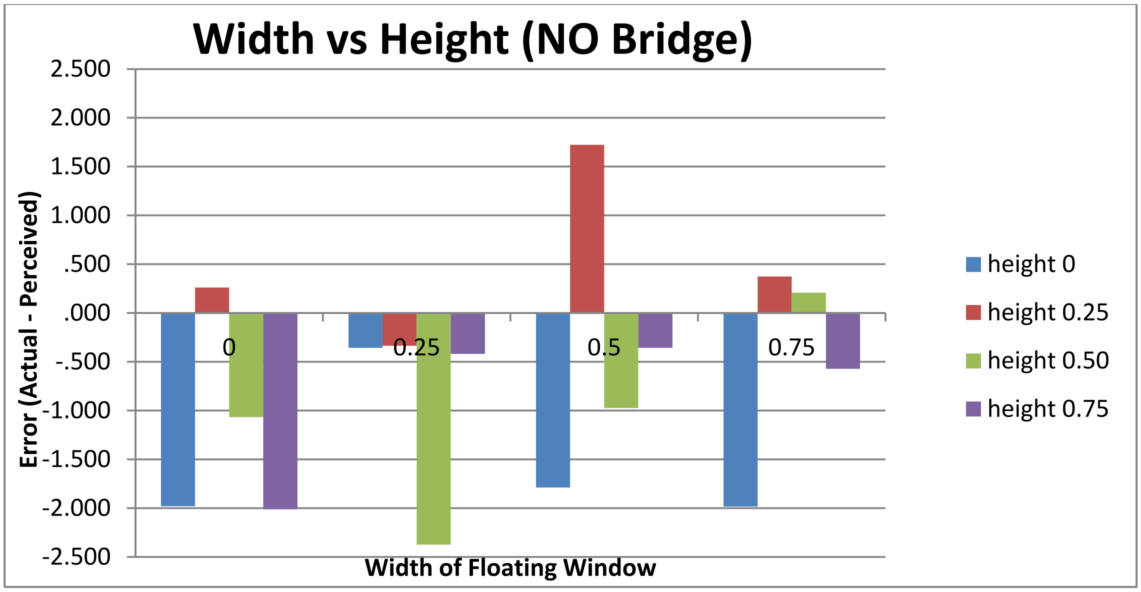


Figure 4. Results of the study showing the effects of the floating window (width) x (height) x (bridge=NO)

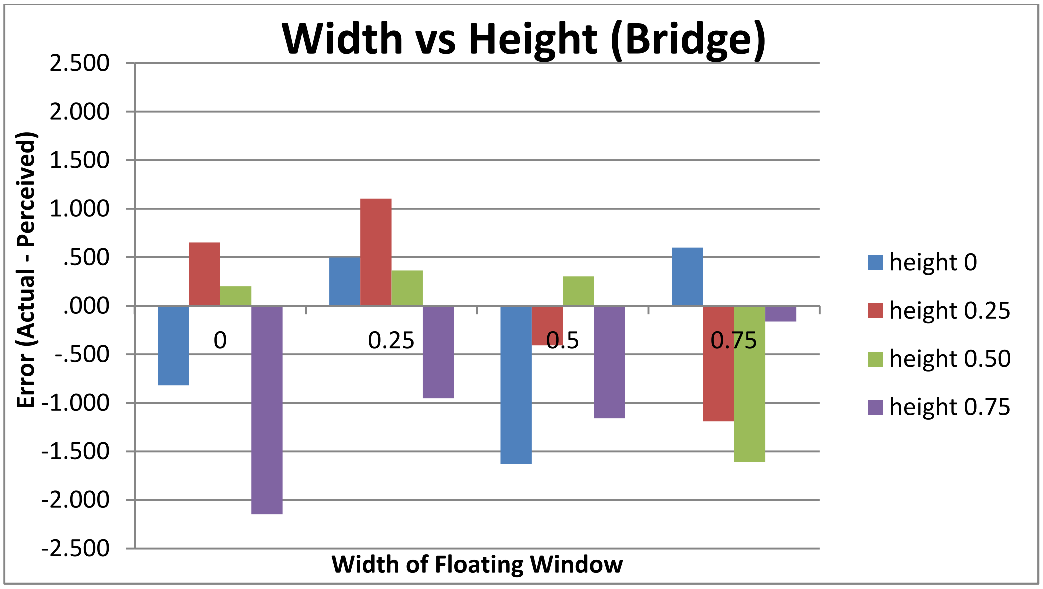


Figure 5. Results of the study showing the effects of the floating window (width) x (height) x (bridge=YES)

2.14 Discussion and Future Work

Stereoscopic 3D has some important potential benefits for games: being able to manipulate objects in a 3-dimensional space can be made much easier with stereoscopy, and distance cues can be more precise than in monoscopic presentation, potentially allowing for more efficient task performance[6] and immersion[7]. Nevertheless, when S3D is a straight conversion from a 2D game, there is little real benefit to the player (although players in one study reported increased enjoyment)[8]. Shortcomings in S3D game development can be overcome in part through an understanding of the ways that we can adjust S3D content in real-time[9]. In this paper, we presented a preliminary study of the effects of shape and size of the floating window technique on users' perception of depth in game environments. The results of the experiment indicate that as expected we can utilize the presence of a floating window to manipulate whether the user perceives objects at distances further or closer than they actually are placed in the virtual world. More importantly, we have quantified these effects based on width and height of a rectangular shaped floating window with and without the presence of out-of-screen effects and have noted that they significantly shift the users' perception. We conjecture that this is since there are objects protruding out of the screen, this provides a virtual depth reference point for judging the distance of the character. We see this as a first step to quantification of these effects. A complete model of how the shape and size of the floating window affects user perception would be an invaluable tool for game designers who are developing stereoscopic 3D content. Further study is required however, our study used only static characters and scenes and thus it would be essential to determine whether these effects and trends hold up in the presence of dynamic objects (animated), dynamic scenes, and dynamic out of screen effects. Also, future studies should investigate the orientation and non-rectangular shapes of the floating window.

ACKNOWLEDGMENTS

We gratefully acknowledge the funding provided for this project by the *Ontario Media Development Corporation* (OMDC), the *Ontario Centres of Excellence* (OCE) through the iGO3D consortium. We also thank the Social Sciences and Humanities Research Council of Canada (SSHRC) for partial funding of this project through the IMMERSE initiative. We also profusely thank Urszula Hogue for her help with the statistical analysis.

REFERENCES

[1] Spottiswoode, Raymond & Nigel, [The Theory of Stereoscopic Transmission], U. of California Press, (1953).

[2] Gardner, B.R., "The Dyanmic Floating Window – a new creative tool for 3D movies," Proc. SPIE 7863, 78631A-78631A-12 (2011).

[3] Zerebecki, C., Stanfield, B., Tawadrous, M., Buckstein, D., Hogue, A., Kapralos, B., "Interactive Floating Windows: a new technique for stereoscopic video games," Proc. SPIE 8288, 82882L-1—82882L-8 (2012).

[4] Mendiburu, [3D Movie Making: Stereoscopic Digital Cinema from Script to Screen], In 3D Movie Making, 2-3. London: Focal Press, (2009).

[5] Cullen B., Galperin D., Collins K., Hogue A., and Kapralos B., "The effects of 5.1 sound presentations on the perception of stereoscopic imagery in video games," Proc. SPIE 8648-41, (2013).

[6] Hubona G. S., Wheeler P. N., Shirah G. W., and Brandt M., "The relative contributions of stereo, lighting, and background scenes in promoting 3D depth visualization," ACM TOCHI, Papers 6(3), 214-242 (1999).

[7] Schild, J., LaViola, J., and Masuch, M. "Understanding User Experience in Stereoscopic 3D Games", Proceedings of the 2012 ACM Annual Conference on Human Factors in Computing Systems (CHI 2012), 89-98, May (2012).

[8] Litwiller, T, & LaViola, J., "Evaluating the benefits of 3d stereo in modern video games," Proc. SIGCHI Conf. on Human Factors in Computing Systems, 2345-2354 (2011).

[9] Zachara M. and Zagal J., "Challenges for Success in Stereo Gaming: A Virtual Boy Case Study," Proc. Intl. Conf. on Advances in Computer Entertainment Technology, 99-106 (2009).

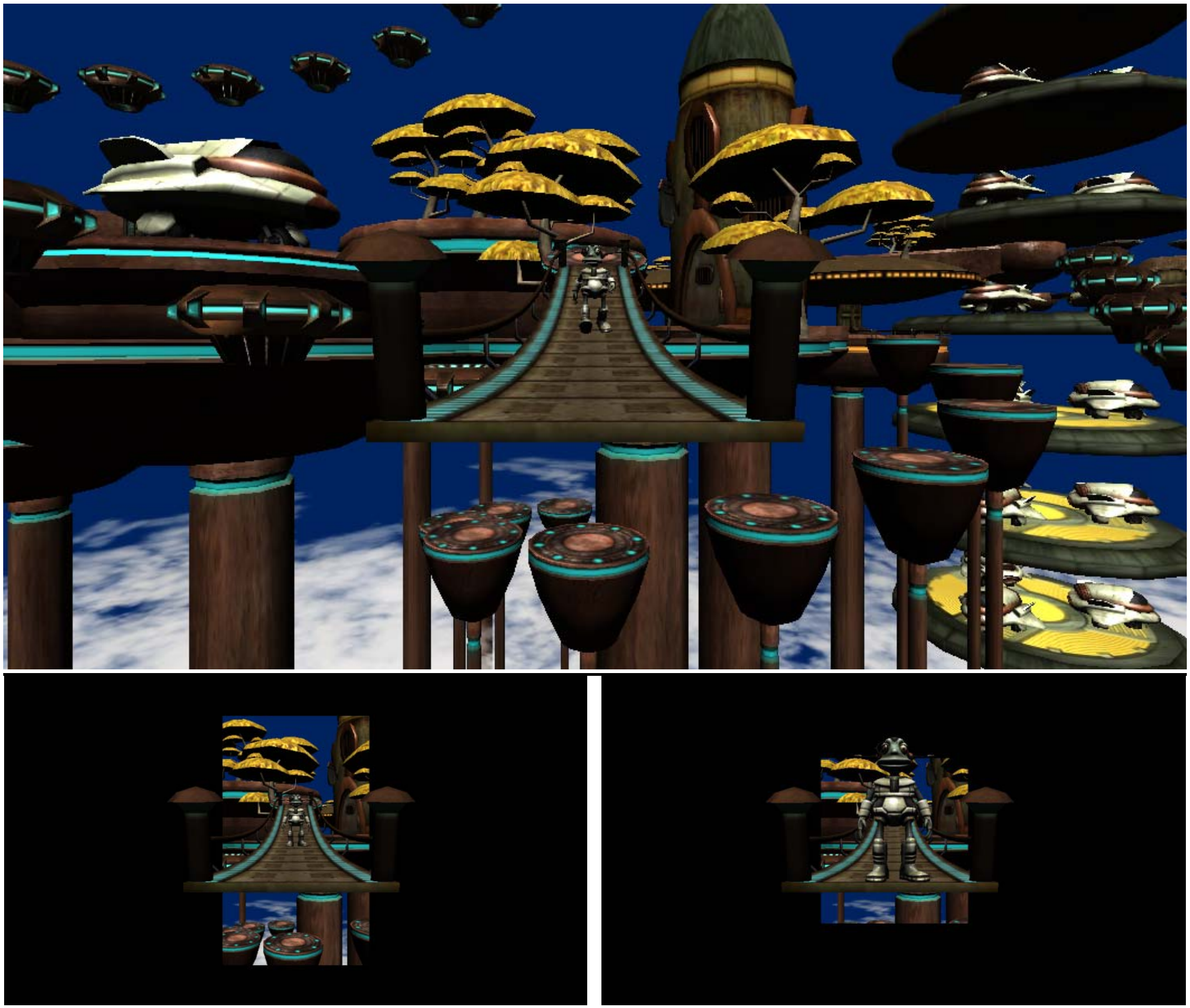


Figure 6: The experimental scene. The floating window mask is created with different dimensions (width and height coverage), and the character is placed in the middle of the scene. The user must observe the character and determine its final position. Top: experimental trial with floating window width (0), height (0), bridge (ON). Bottom left: width (0.75) height (0.25), bridge (ON). Bottom right: width (0.75), height (0.50), bridge (ON).