Mono-Stereoscopic Camera in a Virtual Reality Environment: Case Study in Cybersickness

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***Abstract*— Cybersickness in Virtual Reality (VR) is a serious issue affecting the overall experience. Many research papers have investigated the causes of cybersickness and offered potential solutions for reducing cybersickness. In this paper, we demonstrate a method to reduce cybersickness by using a novel rendering technique in the virtual environment (VE) – Dynamic Mono-Stereoscopic Rendering System (DMSRS). The DMSRS system uses two different cameras to create a hybrid rendering that includes monoscopic and stereoscopic systems. By default, VEs are rendered using stereoscopic or monoscopic rendering exclusively. The results indicate that cybersickness decreased amongst users with little to no VR experience hindered when using the DMSRS.**

Keywords—Cybersickness, Virtual Reality, monoscopic, stereoscopic, user studies.

I. INTRODUCTION

One of the challenges of developing a VR application is creating an experience that will not induce an uncomfortable amount of cybersickness. Cybersickness is a subtype of motion sickness that causes symptoms such as nausea, headaches, fatigue, and vertigo [1]. The symptoms listed may not be as severe when compared to motion sickness a person would get outside of VR [2]. However, these symptoms hamper the usability of VR for some users.

Previous research showed that rendering methods, such as monoscopic or stereoscopic, could impact the cybersickness in VR [3][4]. Monoscopic images convey little sense of depth, and a person traversing through a monoscopic VR system would reduce one's ability to perceive distances of scene elements [5]. Compared to monoscopic images, stereoscopic rendering could provide better depth information, which could increase people's presence in an immersive environment. Most Software Development Kits (SDK), like SteamVR and Oculus SDK, implement the stereoscopic rendering by creating two images side by side on a viewport for both eyes and are either tilted or displaced. When both images are viewed at the same time, the user can then experience the depth in a VE [6]. However, the trade of using stereoscopic rendering is potentially increasing the chances of cybersickness [7].

In this research paper, we explored whether combining stereoscopic rendering and monoscopic rendering for relevant objects could decrease cybersickness. To find the answer to this question, we created a camera system rendering the objects stereoscopically in a set of bounds relative to the center Field of View (FoV) of the camera, while all other objects in the scene would be rendered using monoscopic rendering. The effects of this Dynamic Mono-Stereoscopic Rendering System (DMSRS) will be determined by creating a cybersickness inducing VE and comparing the results of the proposed system with a stereoscopic camera system and monoscopic camera system. The goal is to observe if the DMSRS could decrease users' feeling of cybersickness symptoms without significant reduction in user experience compared with the standard stereoscopic rendering system.

II. BACKGROUND AND RELATED WORK

A. Cybersickness

Cybersickness is a set of symptoms closely related to motion sickness symptoms that can happen during or after a VR session [8]. These symptoms negatively affect users' presence and immersion in a VE. Cybersickness can be measured using the simulator sickness questionnaire (SSQ) [1]. This questionnaire uses a Likert scale to identify symptoms a user might feel after experiencing a VE. The causes of cybersickness are not entirely known yet, and tolerance differs between users [9]. There are theories established that can explain how humans become sick while in VR. One of them is the Poison Theory, an evolutionary theory, which states that the symptoms we feel after a VR session are due to our bodies thinking they have been poisoned [10]. The VE is viewed as a hallucination, similar to the effect that poison has on the body. Therefore, as a self-protection measure, we feel nausea and vomit to get rid of the effects the VE has on our body. The problem with the theory is that it only explains some of the symptoms that cybersickness can cause. So, the most agreed upon theory is the sensory conflict theory [11][12] which states that there is a discontinuity between either visual, positioning movement of the body, somatosensory input or semicircular canal, and otolith input [13]. However, other research has pointed out that all conflicts between sensors are the same and intermodal stimulation cannot be used as a basis to calculate sensory conflict [14]. Regardless, cybersickness remains a major impediment for the domain of VR to overcome.

To address this problem, many solutions have been proposed and tested, such as a virtual nose [20], a warning system with fuzzy control for combating cybersickness [15] and improving the correction of lens distortion [16]. Moreover, reduction in the Field of View (FoV) is known to reduce cybersickness [17]. For instance, Fernanders et al. came up with dynamic FoV modification. They applied rectangular structures, which contained a black opaque

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rectangle with a variable transparency circular hole in the center, which forms a see-through cutout to implement dynamic FoV restriction [18]. Decreasing the FoV, however, may reduce the user's sense of presence [4]. The DMSRS described in this paper further extended this method by creating a mono-stereo hybrid system that would shift objects from stereoscopic to monoscopic or vice versa during runtime. The intention is to reduce the cybersickness while limiting the influence of user presence caused by the reduced FoV.

B. *Our Contributions*

The predominant goal of our research is to observe if our mono-stereoscopic camera system can decrease users' cybersickness symptoms. Our paper made the following novel contributions:

- Designed and Developed DMSRS.
- Conducted a user study to explore the impact of using the DMSRS on the users' symptoms in a VR session.
- The study showed that the mono-stereoscopic camera rendering system can reduce perceived VR sickness.
- Established guidelines for future VE rendering approaches.

In the following sections, the design and implementation of DMSRS will be reviewed, as well as related works. Next, the user study will be explored to determine the effectiveness of our technique compared with the stereoscopic rendering technique. A discussion of the results will then follow. Finally, our conclusions and the direction future works should take will be presented.

III. SYSTEM DESIGN

A cellphone-based VR headset (Merge VR) was used for this project because of its increasing popularity, which has a higher possibility of triggering cybersickness. According to the pilot study in the lab, using a cellphone-based VR headset could potentially result in cybersickness easier than PC based headsets like HTC Vive or the Oculus Rift. Therefore, using a cellphone-based headset might cause the cybersickness quicker. To keep the study more effective, we chose to use a Samsung s9 cellphone and a Merge VR headset to run DMSRS. To implement the algorithm of DMSRS, we designed and developed a two-camera VR viewport and two identical VEs in a Unity scene, one for each eye. Like other VR SDKs, the two-camera VR viewport has left and right cameras for left and right eyes. Thus, in the VR viewport, each camera takes up half of the screen space. However, in DMSRS, each camera is pointing to one of the identical VEs. The black texture in Figure 1 blocks the user's right eye from seeing bits of the left world and vice versa.

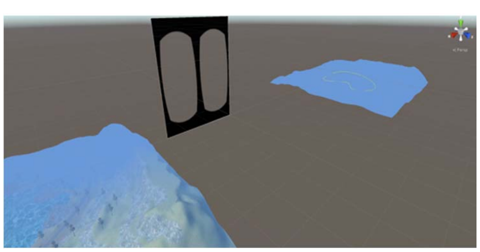

Fig. 1. Two identical worlds

Since no VR SDKs were used, we implemented our own distortion correction based on Merge VR and head motion tracking using the cellphone's gyroscope. A shader was implemented to render the worlds as a convex image to undistort the images. With these steps, the virtual world has basic functioning VR aspects.

Furthermore, we designed and developed a mono-stereo hybrid rendering algorithm that would dynamically switch objects between stereoscopic to monoscopic at runtime. This algorithm only affects the right eye view since just one view must be offset. Every object in the right eye view is tagged as monoscopic by default and have no stereoscopic offset applied to its position.

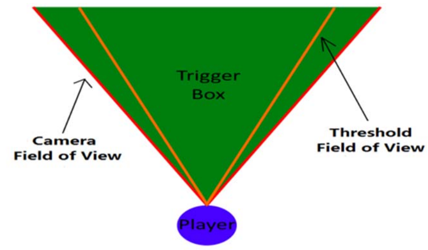

Fig. 2. Camera field of view and threshold field of view

As shown in Figure 2, to switch between monoscopic and stereoscopic rendering for the right camera, we designed a trigger box and two FoVs that were the threshold FoV, which is 30 degrees, and camera FoV, which is 60 degrees. According to [18], we picked the middle value of the FoV to test the algorithm. The far clipping plane of the trigger box extends 65.5 meters in front of the car. When an object touches the trigger box (Green Area), the tag of that object is switched from monoscopic to stereoscopic and added to a list. Simultaneously, the object is marked if it enters the trigger box from the right, left, or center of the camera for calculations later. After that, we want to gradually translate the object's position from monoscopic to stereoscopic using linear interpolation from camera FoV to threshold FoV by -0.22f meters in total. If the object is within the camera FoV, but is not lower than the threshold FoV, such as entered from the far clipping plane, we will calculate a positional offset relative to the camera FoV and threshold FoV. This will smooth the transition from a monoscopic position to a stereoscopic position. If the object is inside the threshold FoV, nothing will be applied to it.

IV. STUDY ENVIRONMENT DESIGN

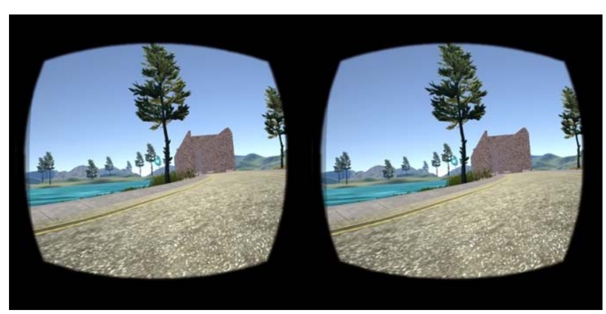

Fig. 3. Virtual environment

To be able to use the DMSRS, a non-static scenario is preferred. Therefore, we designed a Virtual Environment (VE), which includes a loop of track for a self-driving vehicle. The speed of the vehicle is set to 140 kph. However, while it is turning, the speed will be slower caused by the physics engine. The users will be sitting in the self-driving vehicle. There are trees, bushes, small hills, a lake and a bridge placed at different distances in the VE (Fig.3). To help the participants have similar experiences while the vehicle is driving, they were requested to follow the targets on the sides of the track. The 42 targets are placed relatively 30-45 degrees left/right to the front of the vehicle. Similar to the task designed by Allison et al. [19], we placed the targets on the left and right sides alternatively, so the participants are always rotating their head left and right to follow the targets.

V. USER STUDY PRODUCER

A. Hypotheses

Approximately 60-70% of experienced VR users will report some level of cybersickness after their session [21]. This occurs as a result of the stereoscopic rendering technique. However, we know that stereoscopic application tends to improve presence due to the illusion of depth they give the VE [3]. We do not want to lose that benefit with our camera system because that would cause the participants to lose immersion into the virtual world. The main purpose of this study is to see if hybrid monoscopic and stereoscopic rendering in a VE could reduce the amount of cybersickness in a user while maintaining the immersion. The following part lists and justifies the two hypotheses of this study.

Hypothesis 1: Users who use DMSRS would experience less cybersickness than when they use stereoscopic rendering

Hypothesis 2: Users who use the mono camera system will experience less cybersickness than when they use just a stereoscopic rendering.

The test of hypothesis 1 is to support the main contribution of this paper. Hypothesis 2 is an important base of DMSRS. It seems to be a clear conclusion proved by previous research. However, none of the previous studies were conducted with cellphone-based VR. The fact that cellphone-based VR yield to more cybersickness than regular HMD VR may interfere with the benefits of mono camera rendering. Therefore, we feel it necessary to verify hypothesis 2 in the cellphone-based VR.

B. Participants

This research consisted of 19 participants that were recruited through the help of college instructors. The participants were college students ranging in ages from 20-30 years old that had a variety of previous VR experience. Some reported that they had never used VR, while others said they used it moderately. All participants were healthy males and females that reported no prior illness to cybersickness.

C. Study Design

The study was conducted indoors in a closed space. Only the researchers and participants were present during each study. Each study session lasted between 40-50 minutes and included setting up the VR headset, conducting the test, and filling out SSQ afterwards. There are three sessions in the study, with one session being split into three rounds. Each participant completed only one session of the study in one day. In each given session, the participants were required to ride in a waypoint car around a track. In each session, the users conducted the test for three rounds, with each round consisting of three laps, which gave a total of nine laps. After every round, participants rested for three to five minutes and answered the SSQ. If at any point the participant felt extreme discomfort, the test would be stopped, noted and a post SSQ was completed.

1) Study Test: The test was conducted over three days with at least 24 hours between the days to allow the participant to recover from any cybersickness. Over the three days, in each session, the participant took the test with one of the three different camera systems: mono-stereoscopic, stereoscopic, and monoscopic rendering. Participants rode in an autopilot car around the track three times. Each participant was told that their goal is to find red flags in the VE and count the number of flags present. If the flag was successfully tagged, it would change its color to blue. The participants would inform the researcher on the number of flags tagged. The number of flags tagged is not to be analyzed in the study, but merely intended to keep the participant focused in the VE. Then, the participant repeated the test in the same condition two more times. The second and third days had the same test, but with a different camera setting each day. The order of the condition, or the camera setting, was chosen at a counter-balanced order.

2) Data Metric and Post Questionnaire: The data metrics collected from each participant included their post SSQ scores. To get the relative results of a participant's cybersickness, post SSQ were required. The questionnaire consisted of 28 different symptoms a participant might feel after using VR. These symptoms are marked by the participantas as none, slight, moderate, or severe. Each participant was required to answer all questions after each of the three-lap rounds (three such rounds on each day). So, a total of three SSQ (Post1, Post2, Post3) forms were collected each session per person.

VI. RESULT AND DISCUSSION

This section presents results and a discussion of the relevant hypotheses. We applied Wilcoxon signed rank tests where data did not have a normal distribution (ordinal data, such as the SSQ questionnaire) to compare the distinctness of the measurements under disparate conditions. Additionally, we used Bonferroni correction where appropriate.

A. Stereoscopic vs. DMSRS

The study utilized a counterbalancing design, and randomly set conditions. The intention is to reduce the effect of order on experimental results. We compared post questionnaire (SSQ) in all conditions.

In the first part of the study, which is stereoscopic vs. DMSRS, we used the Wilcoxon signed rank test to compare the symptoms of the participants. In the stereoscopic rendering condition, the SSQ after the second round (Post2) indicated that participants' symptoms of drowsiness were significantly higher than those in the mono-stereo rendering ($Z = -2.070$, $p = 0.019$) (1-tailed). By comparing the participants' symptoms after the first round of stereoscopic rendering to that of mono-stereoscopic rendering, we found that in the former, difficulty focusing, difficulty concentrating, and fullness of head were significantly higher than that of the latter ($Z = -2.449$, $p = 0.007$) ($Z = -2.000$, $p = 0.023$) ($Z = -1.732$, $p = 0.042$) (1-tailed) respectively. In other words, the DMSRS helped users experience less cybersickness.

Furthermore, we found that the mean of fatigue (Post1), headache (Post1), faintness (Post2) in the stereoscopic rendering were higher than those in the DMSRS. Although, these results (p) were not significant (Z = -1.342, p = 0.09) (Z = -1.633, p = 0.051) (Z = -1.414, p = 0.078) (1-tailed), given our small sample size, we concluded that these results may still suggest an encouraging trend in support of the first hypothesis.

B. *Stereoscopic vs. Monoscopic*

The second hypothesis is that users using the mono camera system will experience less cybersickness than using the stereoscopic rendering. SSQ scores were compared in stereoscopic and monoscopic renderings since it was directly related to the participants' discomfort.

Symptoms of difficulty concentrating in stereoscopic rendering scores after the first round (Post1) were undoubtedly higher than the condition of monoscopic rendering (Z = -2.000, p = 0.023) (1-tailed). In other words, our study results support this hypothesis.

Meanwhile, in the stereoscopic rendering, participants' symptoms of fatigue (Post2) (Z = -1.508, p = 0.066) (1- tailed), boredom (Post3) (Z = -1.414, p = 0.079) (1-tailed), drowsiness (Post2) (Z = -1.414, p = 0.079) (1-tailed) (Post3) (Z = -1.414, p = 0.079) (1-tailed), headache (Post2) (Z = - 1.414, p = 0.079) (1-tailed), stomach awareness (Post3) (Z = -1.342, p = 0.09) (1-tailed) and vomiting (Post3) (Z = -1.342, p =0.09) (1-tailed) also reflect an increasing trend compared to the monoscopic rendering. From the above data, we can indicate that symptoms of participants' cybersickness tends to be serious.

Besides, taking into account all 19 participants, we observed that the difference in cybersickness SSQ scores were not significant between DMSRS and monoscopic rendering. Therefore, DMSRS indeed worked effectively, it would be valuable in reducing cybersickness.

While SSQ scores can be a good measure of subjective discomfort amongst participants, they are not a good measure if participants terminate the experiment early. If a participant terminates early, their results were excluded from our data. However, all 19 participants in our study successfully completed all the sessions without early termination.

VII. CONCLUSION AND FUTURE WORK

We developed a DMSRS in VE, which extends the technique of decreasing the display FoV [18], and conducted a three-session within-subject user study to explore the effects on the users' symptoms of cybersickness and their experiences in a VE. We combined stereoscopic rendering and monoscopic rendering for relevant objects. Albeit the number of participants in our study was relatively small, our data demonstrated that participants experienced less cybersickness in monoscopic and mono-stereoscopic rendering than in stereoscopic rendering. In other words, the DMSRS improved user experience in the VE.

In the future, we plan to expand the number of participants to investigate if/how the threshold FoV angles, far clipping plane distance, and total offset value would affect cybersickness, as well as the DMSRS's influences in users' presence. We also want to explore how DMSRS could help users adapt to the VE. For instance, we can get an idea of how users are thoroughly experiencing the VE through EEG data collection, where a recording of a participant's brain activity will be taken each study day. We will compare and contrast the alpha, delta, theta and beta points to see what effect each camera has on different brain signals. The ultimate goal is to extend the user's comfort in VE through the usage of the DMSRS.

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