Ramps are Better than Stairs to Reduce Cybersickness in Applications Based on a HMD and a Gamepad

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Abstract

We study ways to reduce cybersickness and improve the user's experience in virtual reality applications that use a HMD and a Gamepad as interaction devices. Our approach consists on a revision of the design space of such tasks in order to identify ways to minimize user's perceived movements. In this paper we concentrate on the task of navigation in realistic scenarios, such as the Tuscany Demo [12]. We performed three user studies in order to identify the most problematic issues in this scenario and the effects of geometry and interaction techniques in the overall experience, in particular in the task of moving up and down stairs. As a result of these studies, we propose the use of invisible ramps on top of stairs, in order to minimize users' perceived movements while moving through stairs and hence reduce users' discomfort.

Keywords: Virtual reality, Interaction design, Simulation environments

Index Terms: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality

1 Introduction

The Oculus Rift [12] is a Head Mounted Display (HMD) that represents a new generation of virtual reality devices directed to the consumer's market, specially built for videogames. Such type of devices are special in several ways: they have received great public attention since their funding stages (i.e. the Oculus' very successful Kickstarter's campaign), they come with very interesting and competitive features (i.e. 90° horizontal FOV, 7 inches screen with 1280x780 pixels), and their prices are very attractive for consumers (i.e. U$ 300). However, they also suffer the same problems of current professional solutions in the field of Virtual Reality Environments (VE), in particular user's feeling of cybersickness.

Cybersickness is usually related to Motion Sickness (MS), where the user's discomfort is caused by the feeling of movement in VE. Its symptoms are similar to the ones of MS, a better studied disorder that some people feel when they move in the real world. However, in the case of cybersickness, we are only interested in disorders caused by the use of VE technology, and how we can improve such technology in order to reduce such symptoms. Cybersickness has been studied for decades, and unfortunately there is no definite solution to this problem. [11]

Although there are several issues that developers should take into consideration in order to improve the experience with the Oculus Rift [14] and there are hardware and low level software improvements in production [13], there are still some issues that can not be easily solved, such as the disparity between visual and vestibular stimuli. Such disparity is caused by the difference between the stimuli received through users' eyes and the stimuli in their inner ears: users see they are moving, but their inner ear tell them they are motionless. Whereas it is possible to add more technology in order to stimulate a user's inner ear, we believe it is also important to consider variations in other important elements of a VE application in order to reduce this disparity.

In this study, we describe VE applications as a combination of the following parts: geometry, rendering, devices, application behaviour, and interaction techniques. We propose a study of the design decisions in all these elements in order to find combinations that reduce cybersickness. We took the Tuscany Demo [12] as an example because this demo's rendering takes into consideration the Oculus' specific requirements for stereo rendering and lens adjustments, however other elements have not been adapted to the new device. For example, the interaction techniques are the ones more commonly used in current videogames, with no special considerations regarding the differences created by the new display. Although there could be elements that should not or could not be changed, it is important to explore the possibilities of reducing cybersickness by changes in all these dimensions.

This paper presents some variations in interaction techniques and geometry for the Tuscany Demo (Figure 1) and the user studies that gives us some conclusions. Our long term goal is to reduce the feeling of cybersickness while keeping the user's experience as rich as possible, in terms of visual appeal and functionality. Though these findings have only been tested on this application and with limited hardware, we believe this method and some of our ideas can improve the experience in many other VE applications with HMDs in general. Even with the limitations of this study, we aim to provide better experiences in applications such as architectural walkthroughs, a very important field within VR.

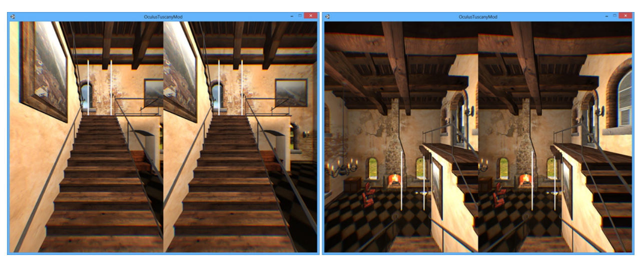

Figure 1: Modification of Oculus Rift Tuscany Demo : Top view (Left) and Bottom view (Right).

2 Related Work

MS usually starts with dizziness, stomach awareness and then it develops to nausea and finally vomit [7]. It is caused by the perception of movement that is sensed by some of the visual, vestibular, and kinestesic systems [23]. There are several theories about why motion sickness is produced. According to the theory of sensory conflict, the nervous system starts an adaptation process that causes MS as a side effect when a subject is exposed to conflicting stimuli [16]. Although it is very well known, this theory has demonstrated low predictability [5]. Postural instability, a more novel theory, states that the sensory conflict is not the cause of MS but instead the mechanisms the body has to keep balance.

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Both MS and cybersickness produce the same types of symptoms but they are not necessarily the same thing. Vestibular stimulation alone can be sufficient to induce MS and it is primarily a visual-vestibular sensory mismatch. Cybersickness can occur with visual stimulation and without vestibular stimulation [11].

Some experiments on cybersickness have been explained by the postural instability theory [21, 17, 6]. According to this theory, cybersickness effects are caused when the human balance mechanism is stimulated in an abnormal way [19]. However, these experiments usually require highly controlled conditions, which are not easy to reproduce in VE and in particular in videogames [22].

Cybersickness has been traditionally studied in terms of vection (i.e. self motion illusion). Sudden changes in trajectory or speed (i.e. vection changes) exacerbates the effects [2]. This is because postural adjustments are induced by the simulated motion, due to perceived visual information and sense of self motion [21].

Subjects using HMDs and trackers are particularly sensible to cybersickness, due to technical limitations in this type of devices, among other reasons. Issues such as high latency, reduced FOV, low resolution, and poor calibration have been mentioned as culprits [11]. Although technologies are always improving, we are interested in finding the best conditions for a particular technology.

Traditional methods to reduce cybersickness include: alternative sensory feedback [10], moving platforms [3, 1] and rest frames [15]. We discard these methods because we considered them too complex, expensive or invasive for the expected kind of users.

Lessons learned from previous studies are also taken into account in our set-up. For example, it has been shown that it is better to sit than stand while playing videogames [18]. It is also known that it is better to take control of your own navigation than being passive [4].

3 Methodology

We performed a preliminary survey to identify key causes of cybersickness in the Tuscany Demo. We picked one of the causes and studied its design space, in order to identify interesting variations. We then performed a user study, gathered some data, and validated our findings with a second study. Details of these steps in our methodology are the following.

3.1 Preliminary Survey

This exploratory study was performed during 3 demos of the Oculus Rift Technology. 22 university students under 30 years old tried this technology with the Tuscany Demo, some with keyboard and some with a gamepad. We mentioned at the beginning that the use of this equipment may produce cybersickness. Subjects started in one of two predefined places (beside the lake or on the house's balcony) and we asked them to go to the other place. We gave some directions about how to use controls to some subjects that require such information. At the end of the task we asked subjects which places or which actions created more discomfort. Some answers were the following: going up and down the stairs, rotating one's head too fast, moving close and far from an object, the apparent movement of the distant mountains, and motionless water in the lake.

We decided to concentrate the following studies on the movement through the stairs, since 20 of the 22 subjects felt discomfort in such a movement during a short period of time. This task also seems a key part of the user's experience and although this movement was rather short in this demo, we changed the application's behaviour and request from users to continually go up and down the stairs for a long period of time, however we asked users to stop when they felt sick and most of them stop in less than two minutes. We limited the duration of the test to a short period of time because we believe that low-end HMD devices like the Oculus Rift are highly susceptible to produce cybersickness effects and is well known that cybersickness is polygenic and polysymptomatic [8]. We also limited our study to a gamepad as input device, since the keyboard created extra and unnecessary discomfort in subjects due to movement limitations.

3.2 Design Space Variations

We concentrated our variations in the interaction techniques and geometry elements, since we wanted to keep the same visual appealing (i.e. rendering), the same functionality (i.e. application behaviour), and the same devices (i.e. HMD and gamepad).

In terms of interaction techniques, we considered variations to the control mapping between the gamepad and the avatar's position and orientation. Although this demo comes with a pretty standard navigation technique, we believed there could be better navigation techniques for this type of environments while subjects are using an Oculus Rift. In terms of geometry, we noticed that the main reason for subjects' discomfort while taking the stairs was caused by the apparent head movement caused by the virtual steps. Although techniques such as *Shake-Your-Head* [20] show advantages of real user's head movements in desktop VE applications, such a movement is still not very popular when using a HMD like the Oculus. Since users with an Oculus and a gamepad are usually sitting and motionless, we proposed to reduce the virtual movement while taking the stairs so we induce less postural instability.

Although we still have to compare the benefits of our proposal against other approaches such as the one in [20] even in other factors such as presence, we believe ours could perform better in terms on cybersickness in VR environments with HMDs, according to the assumptions of the postural instability theory. Techniques such as [20] seem to increase the gap between the virtual and the real posture, but this affirmation requires further studies.

3.3 User Study 1

This study reviews discomfort symptoms between scenarios with 3 different control types and 2 geometries for stairs. The Simulator Sickness Questionnaire (SSQ) [9] was used to measure differences between conditions.

We asked subjects to go up and down the first part of the Tuscany House's stairs. We tried two configurations for stairs, as shown in Figure 2. One set of subjects used the stairs as they come in the demo, and therefore they suffered movements induced by that geometry. The other set of users used a modified geometry: on top of the virtual stairs we put an invisible ramp. Subjects moved on top of the ramp and not the stairs, therefore they did not suffer head movements caused by steps, just movements caused by the change of height induced by the ramp.

All subjects use a Logitech's Gamepad for movement, and in particular the right joystick for movements up and down the stairs. There are 20 steps in these stairs, and the only allowed movement with the gamepad is up and down. Once a subject reaches either end of the stairs, visual feedback goes to dark smoothly and the avatar is positioned for the next task. In this way, we avoid issues related to head and other movements different to going up and down. Three navigational mappings between joystick and avatar's movements were tested, as shown in Figure 3: constant speed after a joystick movement's threshold t, a direct mapping between joystick's movements and speed, and a smooth version of constant speed.

Figure 2: Geometry Conditions: Stairs and Ramp Modes.

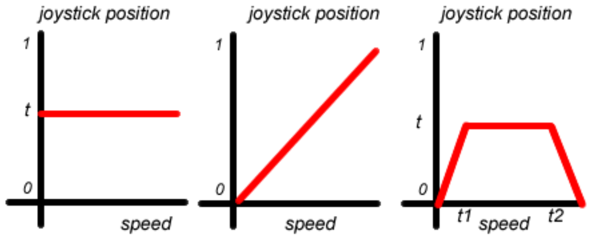

Figure 3: Movement Conditions: Constant Speed, Direct Mapping to Speed, Smoothed Constant Speed.

Our hypothesis are as follows:

- **H1**: The virtual ramp reduces cybersickness, in comparison with the stairs
- **H2**: The smoothed constant speed reduces cybersickness, in comparison to the other speed conditions

A virtual ramp clearly reduces postural instability. In the case of the smoothed constant speed, we believe it reduces abrupt changes in movement, therefore reducing postural instability when speed changes occur. 20 volunteer students from our University were recruited for this study, 14 men and 6 women, with an average age of 22 years old. All reported normal vision and good health conditions at the moment of the experiment. They also reported no previous history on neurological, vestibular, stomach, or intestine diseases. We conducted a within-subjects experiment, in which subjects should go up and down the stairs during 2 minutes, with a pause of 5 minutes between conditions. Before each condition we informed subjects about the changes in geometry, and after each trial subjects should fill the SSQ form. Geometry changes were counter balanced between subjects.

3.3.1 Results and Discussion

We performed an analysis of our factors and their influence in user's cybersickness by means of the SSQ score. A within-subjects, two-ways repeated-measures ANOVA analysis of the data was performed. If we take into consideration geometry no matter the mapping modes we tried, we found significant differences that benefit a ramp geometry instead of just stairs ($p = 0.016$), therefore **H1** holds.

Similarly, we analyzed how geometry affects the SSQ score in each one of the navigational mapping conditions. In the constant speed mode, SSQ scores were significantly better ($p = 0.009$) for a ramp (28.13 ave, 26.13 SD) than for a stair geometry (74.23 ave, 59.57 SD). A similar result was found in the case of the speed mapping ($p = 0.047$) with a better score for a ramp (34.9 ave, 19.82 SD) than for a stair geometry (58.34 ave, 40.47 SD). In the case of the Smoothed Constant Speed mapping we did not find significant results ($p = 0.173$). We believe the reason a virtual ramp is better than stairs is because vection is lower, and therefore postural instability is reduced in this application.

We did not find significant difference between navigational mappings in the general scenario of mapping vs. SSQ score ($p = 0.532$). However there was a tendency in the data that favours speed mapping instead of the other two, and constant mapping instead of smoothed constant mapping. We believe the reason that smoothed speed performs worse than constant speed lies in the speed mapping with no control that subjects should bear during a period of time in the case of smoothed speed, instead of the instantaneous change of speed in the constant speed scenario. In this case, the stimuli of an instantaneous change to constant speed seems more bearable than a period of constant acceleration, although further studies should be done in order to identify the cause of this preference. Because there are no significant differences we can not validate **H2**.

We decided to design an even simpler, between-subjects experiment in order to overcome some limitations that we found in this one. First, some subjects suffered fatigue after some tests, and repeating the SSQ questionnaire could be influenced by the order of conditions. Subjects could also accommodate to subsequent conditions due to their experience. We also believed there is some subject conditioning by explicitly telling them they could feel cybersickness effects, so we decided to use a format closer to a technological demo, in which we do not explicitly announce at the beginning the possibility of cybersickness.

3.4 User Study 2

We used the same application that was used in the Study 1, but we took into account just two conditions for navigational mapping, speed mapping and constant speed, given the poor results of the smoothed constant speed in the previous study. We used a Demo Fair at our University for recruiting subjects. Attendants were offered a sequence of trials with the Oculus Rift, one our modified version of the Tuscany Demo and the other a virtual roller coaster. If attendees volunteer for our study after the Tuscany Demo, we asked them to fill the SSQ questionnaire and then to optionally try the roller coaster. No major warnings were mentioned at the beginning of the first demo, similar to the way the Oculus Rift is presented in Demo Fairs everywhere. In this way, we tried to diminish possible confounding factors such as fatigue between trials and predisposition to cybersickness.

We decided to keep our hypothesis as similar as possible as the ones in the first study:

- **H3**: The virtual ramp reduces cybersickness, in comparison with the stairs
- **H4**: The constant speed mapping reduces cybersickness, in comparison to direct mapping to speed

44 volunteers participated in our experiment, 36 men and 8 women, with an average age of 22. All reported a normal vision condition and good health at the moment of the experiment, with no previous history on neurological,vestibular,stomach,or intestine diseases. We designed a between-subjects experiment, with 2 independent variables with 2 possible values each. Each subject should go up and down the stairs, but in only one combination of geometry and navigational mapping conditions. We just informed subjects about the navigational speed method, so they could know what to expect from the application in this regard. This is different to the way we performed the first test, since in that case we told subjects about the changes in geometry and did not tell the changes in interaction technique, so they had to discover how the gamepad worked. We believe subjects really need to know what to expect about the navigational control, but geometry changes are oblivious to the experience. Subjects filled the SSQ questionnaire after their trial.

3.4.1 Results and Discussion

A one-way ANOVA analysis was performed in the data of this study. When we considered geometry conditions no matter the interaction technique mapping, we found a statistically significant difference ($p = 0.011$) that favours the ramp condition (17.03 ave, 15.87 SD) on top of stairs (27.42 ave, 20.05 SD). Figure 4 shows how geometry affects the SSQ score in both navigational mapping methods. Results show that the ramp condition (17.03 ave, 15.87 SD) is better ($p = 0.025$) than the stair condition (28.42 ave, 22.25 SD), in the case of constant speed. In this way we can confirm **H3**. Results are not statistically significant in the case of the direct mapping to speed ($p = 0.216$), although this data shows a tendency in favour of the ramp scenario.

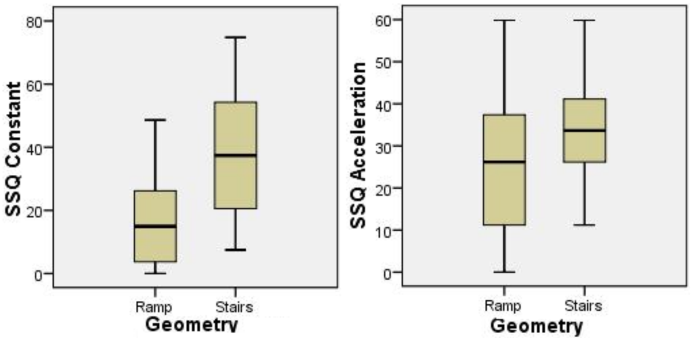

Figure 4: SSQ Scores for Geometry Conditions in Each Navigational Mapping: Constant Speed (Left), Direct Mapping for Speed (Right).

Overall the mapping scheme did not show significant results ($p = 0.498$). It seems that the direct mapping to speed ameliorates effects in stairs, since faster speeds could reduce the movement effects due to steps, but we have to perform more studies on why these contradictory tendencies. Figure 5 shows the effects of navigational mapping on the SSQ score. Although we did not find statistically significant results neither in the stairs ($p = 0.263$) nor the ramp scenarios ($p = 0.304$), it is interesting to notice contradictory tendencies between these two scenarios. Therefore, we can not confirm or deny **H4**.

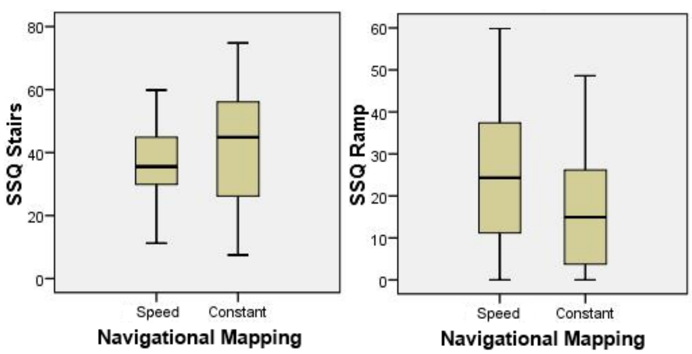

Figure 5: SSQ Scores for Navigational Mapping Conditions in Each Geometry: Stairs (Left) and Ramp (Right).

4 Conclusions and Future Work

This paper presents our exploration of the design space of a VE application in order to find out ways to ameliorate MS symptoms. Our studies show that a more linear surface for movements in the case of stairs could reduce MS effects since it produces less vection. These results can also be explained from the point of view of the postural instability theory, since a ramp induces less postural adjustments than stairs. Although we did not find significant results regarding preferences on interaction techniques, we believe this factor can also influence MS and therefore we explore its influence in other tasks.

As future work we plan to improve the instrumentation of our studies by means of motion capture technologies, in order to measure changes in posture. We also plan to study other problematic tasks for users, in order to identify the best solution in the design space for this demo, which can be applied to other demos for the Oculus Rift.

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