Geometric simplification for reducing optic flow in VR

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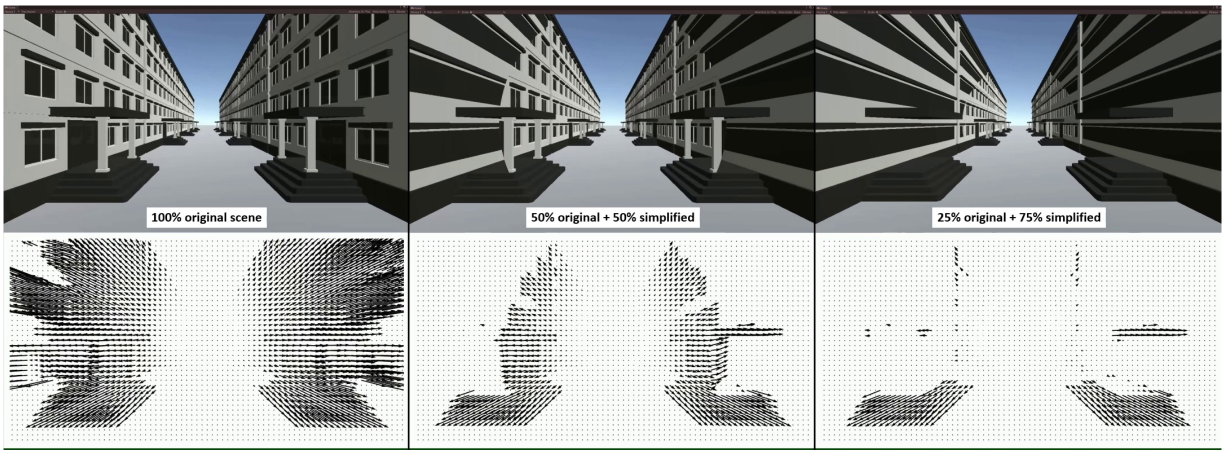

Figure 1: Simplification of the scene (top) for reducing the optic flow in peripheral FOV (bottom).

Abstract

Today virtual reality (VR) technologies became more and more widespread and found strong applications in various domains. However the fear to experience motion sickness is still an important barrier for new VR users. Instead of moving physically, VR users experience virtual locomotion but their vestibular systems do not sense the self-motion that are visually induced by immersive displays. The mismatch in visual and vestibular senses causes sickness. Previous solutions actively reduce user's field-of-view, introduce intruder in the view or alter their navigation. In this paper we propose a passive approach that partially simplify the virtual environment according to user navigation. One manual simplification approach has been proposed and prototyped to simplify the scene seen in the peripheral field of view. The optic flow is analyzed on the rendered images seen by users. The result shows that the simplification reduces the perceived optic flow which is the main cause of the visually induced motion sickness (VIMS). This pilot study confirm the potential efficiency of reducing cybersickness through geometric simplification.

Index Terms: Computing methodologies—Computer graphics—Graphics systems and interfaces—Virtual reality; Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality;

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1 Introduction

Virtual reality (VR) applications are no longer confined to gaming. Cheaper and better VR hardware has encouraged more and more applications in workplaces. On one hand the low cost personal computers have high graphic computing capacity and low cost VR headsets have high performance in rendering and tracking [3]. On the other hand various game engines such as Unity3D, Unreal Engine, etc. allow public unprofessional developers to prototype interesting 3D applications for various domains [2]. Therefore VR technologies have been largely applied in various domains such as engineering, cultural heritage, training, medical services and also entertainment.

Under this context many novice VR users have not yet got used to navigation and perception in virtual environment and they can feel discomfort during their virtual experience due to visually induced motion sickness (VIMS). According to the sensory conflict theory, VIMS is provoked during a VR experience when humans perceive incoherently self-motion through vision and vestibular senses. Instead of moving physically, VR users send commands using devices (e.g., gamepad) to move in virtual worlds. Users can feel visually induced self-motion but they do not feel any movement according to their vestibular systems. This incoherent movement perception can provoke cybersickness among susceptible users which is half of the world population [18].

Two objective measures have been shown to influence VIMS: the optic flow generated from visualized images [11] and the cybersickness dose value (CSDV) [17] generated by navigation. The optic flow is motion of light seen in human eyes when human watch illuminated objects moving. It is represented by a vector field in which the light pattern velocity at each point of the field of view (FOV) is quantified. The VR immersion will let users to absorb completely the generated optic flow. The CSDV is related to the velocity and exposure time during navigation as well as the complexity of the VR scene. Our past studies have shown that both the changes of navigation velocity and scene complexity can affect VIMS significantly [19]. This paper focuses on the simplification of VR scenes to reduce VIMS.

2 Related work

Various VIMS counter-measures in VR can be found in the literature to reduce VIMS through managing sensory conflicting cues. They either enhance the vestibular cues or reducing visual motion cues.

2.1 Physical movement

As explained in the context paragraph, the lack of physical movement appropriate to the VR scene movement is a cause of VIMS. Therefore, the "direct" way to reduce cybersickness is to let users make physical movements. A walking-in-place method has been developed to allow users to physically move their legs [12] but the pseudo walking may not efficiently provoke pertinent self-motion in the vestibular system. Locomotion simulators further allow users to walk as in a real life within a restricted zone during VR experience, e.g. an omnidirectional tread-mill system [10]. However, the natural walk may not be guaranteed due to the latency of the mechanical system. In addition, this kind of solutions can be expensive and not suitable for most users with personal usage.

2.2 Physiological stimulation

Human vestibular system sensation can be altered though galvanic stimulation [14] to feel physical acceleration or balance changes. Therefore sensory conflict between visual and vestibular information can be decreased during VR experience. When providing vibration and electroshock to the legs, users can also feel pseudo physical walking motion [15]. However, these solutions require extra hardware and are intrusive.

2.3 Navigation parameters control

In order to avoid extra hardware, researchers have turned to software control. VR applications can be designed to actively alter user navigation parameters in order to reduce visually induced self-motion and VIMS. The user locomotion acceleration and speed can be adapted [4] or replaced by carefully calibrated automatic navigation [20]. The disadvantage is that users can no longer navigate freely with these counter-measures and the quality of navigation in VR can be reduced.

2.4 Visualization modification

Also on the software level, VR applications can be designed to actively alter user visualization. The insertion of a virtual nose as a static reference has been proposed as a VIMS counter-measure [21]. The static virtual nose can reduce the illusion of self-motion but may have a negative impact for user's immersion.

To reduce the VIMS during VR navigation, a radical approach has been proposed to blur the visual scene during rotating navigation [6]. The blurring effect is easily perceived by users and the consequence is a reduction in immersion.

It has been known that visually induced self-motion perceived by users is mainly induced by visual motion seen in the peripheral FOV [16]. A decrease of the FOV in virtual environment through VR headset can reduce the perceived self-motion [5]. Based on these principles, dynamic reductions in users' FOV has been developed as a VIMS counter-measure [1, 9]. When the user is stationary in the virtual environment, the full FOV is enabled and the entire screen is displaying virtual environment. Whereas during the navigation, FOV is reduced by displaying the frontal view in a limited viewport. Unfortunately, this method occlude the peripheral vision and can decrease the degree of immersion.

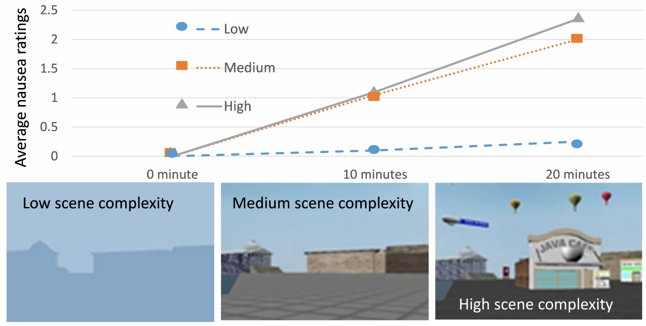

Figure 2: Effects of reducing VR scene complexity on rated nausea.

2.5 Geometric processing of virtual scene

Recently geometric processing of virtual scenes for reducing optic flow appeared in the literature. This kind of method is passive and will not degrade user navigation nor visual perception in the virtual world. For example, the part of the virtual environment seen in the peripheral FOV by users was deformed geometrically along the navigation direction and the visually perceived optic flow has been shown to be significantly reduced [13]. The advantage of this approach is that the degree of immersion is not affected since user FOV is maintained and user navigation control are maintained.

However, even though deformation is temporary, developers of VR systems or users may still have conservative views. In this paper, a less intrusive approach of geometric processing to reduce VIMS is proposed. Instead of deformation, the method simplifies geometrically the virtual environment according to user navigation. Simplification is not new and has been used to improve the performance for rendering [8]. This suggests that the VR application designers are likely to be more receptive to a geometry simplification method that can significantly reduce VIMS. The correlation between the scene complexity and visually induced motion sickness has been proposed in the literature [18, 19]. In this paper, two studies are presented. Study 1 confirms the significant reduction of VIMS by reduction the VR scene complexity. Study 2 proposes the geometric simplification methods and the significant reductions in optic flow vector magnitudes.

3 Study 1 – Effects of reducing VR scene complexity on VIMS

Twenty-four participants were randomly assigned to three 20-minute VR navigation journeys. The navigation paths and the basic VR scenes were the same across the three journeys except the texture mappings of VR objects were manipulated to provide VR scene complexity of low, medium and high levels (fig. 2).

Results indicated that as the VR scene complexity increased from low to medium, rated nausea significantly increased ($p < 0.05$, ANOVA) but there was no significant increases when the scene complexity increased from medium to high. Study 1 suggests that reducing VR scene complexity can reduce VIMS. However, it also indicates that the effects are not linear and there is room for fine manipulation and optimization. Hence, we conducted Study 2.

4 Study 2 - Dynamic scene simplification for reducing optic flow

Since the optic flow in the peripheral FOV is a main cause of VIMS [7, 11, 16], we propose an original approach to reduce peripheral optic flow by simplifying virtual scene dynamically. The idea is to dynamically and temporarily simplifying the geometry of the surrounding virtual scene during navigation so that the relative motion of the scene perceived in the user peripheral vision is reduced. When a user is navigating, the part of environment located in the

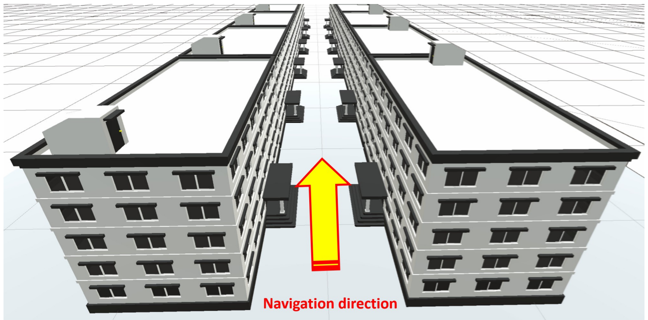

Figure 3: Virtual scene is a street with buildings on two sides.

user peripheral vision will be simplified. In the followings subsections some details are presented: an experimental scene, geometric simplifications applied to the scene and rendered images synthesis.

4.1 Scene creation

For prototyping a proof of concept a virtual scene is created (fig. 3) in order to further experiment the geometric simplification. The scene consists of buildings duplicated on the both sides of the street along which the navigation will be realized.

4.2 Geometric simplification

The geometric simplification was applied on each building manually according to the navigation direction. Following the concept of the CSDV [17, 18], spatial frequency along the directions of navigation were simplified. In figure fig. 4 the simplification of the building is illustrated. On the frontal façade, windows of the same floor are merged into a unique large window. Because the windows of the same floor are aligned with the navigation direction and their relative motion perceived visually by users will cause high self-motion. In addition, the two pillars at the gate are removed. The windows on the lateral side of the building are completely removed since they are less important for the visual fidelity of the building. Such geometric simplification can be automated in future work according to formulation of CSDV.

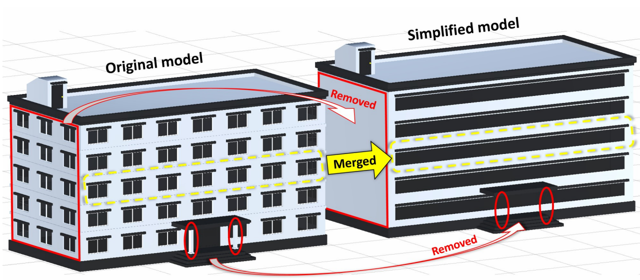

Figure 4: Comparison between original and simplified buildings.

4.3 Synthesis of original and simplified scenes

Figure 5 illustrates the pipeline of image synthesis. Two virtual cameras were used for rendering respectively images of central (original) scene (fig. 5.a) and images of simplified scene (fig. 5.b). The images of original scene are used to generate a circular mask (fig. 5.c) that will finally mask the center of the images of simplified scene (fig. 5.b). The resulted images (fig. 5.d) rendered to users are actually simplified scene images except for the circular center being original scene images. The radius of the circular mask is determined by the angle of frontal field of view of users.

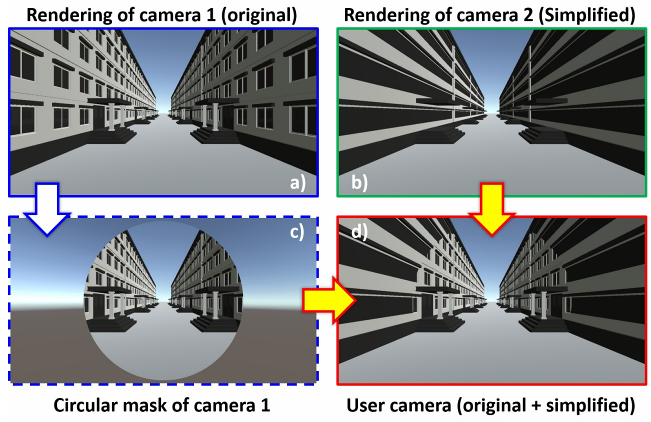

Figure 5: Rendered image synthesis for original and simplified scenes.

4.4 Experimentation and optic flow analysis

The optic flow patterns with and without geometric simplification have been analyzed. Figure 6 illustrates the optic flow motion vectors. Flow vector magnitudes in the peripheral visual field were significantly reduced by half from an average of 10.4 pixels to 4.5 pixels ($p < 0.05$, paired-t tests).

4.5 Discussion

In 2001, the same author reported a predictive metric called "spatial velocity (SV)" for VIMS. SV was defined as the dot product between navigation velocity (V) and the spatial frequency (S) of the VR scene along the same direction of V [18]. This "SV" has been formulated into CSDV which is predictive of VIMS. The SV formula can be integrated with the current geometric simplification method so as to dynamically calculate the best way to simplify the spatial frequency of VR scene for the reduction of VIMS.

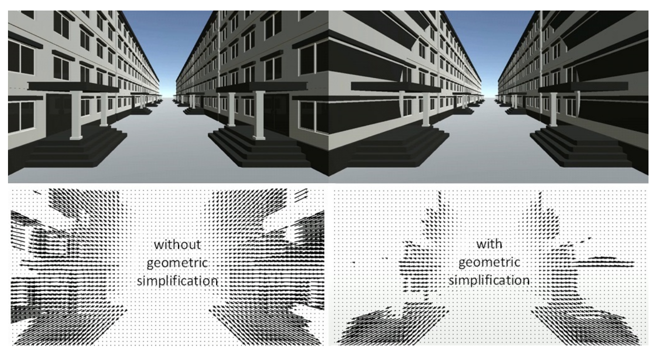

Figure 6: Optic flow analysis on the original (left) and simplified (right) scenes.

5 Conclusion

In this paper, two studies are presented. First, effects of reducing VIMS by reducing VR scene complexity are reported. Second, a geometric simplification method is proposed to reduce optic flow in VR simulation. A VR application has been prototyped to simplify geometrically the virtual scene seen in the peripheral field of view by users. Optic flow has been analyzed on the rendered images on both original and simplified scenes. Geometric simplification can significantly reduce the optic flow seen in the peripheral field of view of user. This investigation confirms the potential effectiveness of the geometric simplification on visually induced self-motion in VR.

Although the current version of the geometric simplification is a proof-of-concept prototype, the method can be fully automated with further development. Future work to integrate CSDV into the geometric simplification model in order to determine the best way to simplify the scene for reducing VIMS is desirable. Due to difference among human individuals, the human perception thresholds will be explored to optimize the simplification levels.

Acknowledgments

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