Geometry deformation for reducing cybersickness in VR

Ruding Lou[1]

[1]LiSPEN, Arts et Metiers, Institut Image, Chalon-sur-Saone, France

Résumé

Virtual reality (VR) technologies became more and more widespread for a couple of years as they got more and more mature. The accessibility to VR highly increased thanks to recent low-cost commercial VR head mounted display systems and easy-to-use development toolkits. One important and well-studied human perception issue is related to motion sickness or cybersickness. In this paper we are dealing with case when users feel a visually induced induced self-motion that are not felt through their vestibular systems. This incoherent movement perception provokes cybersickness to the users.

To tackle this issue, we present in this paper a novel method to reduce cybersickness through reducing visually induced self-motion by processing geometrically the virtual scene while navigating. The first prototype of geometry deformation applied on virtual building appearing in the peripheral vision of user has been implemented and experimented. The feedback from the experiment participants shows that the visually induced self-motion is reduced and the navigation quality and presence level are guaranteed.

Mots clés : geometry processing, mesh deformation, virtual reality, cybersickness

1. Introduction

Virtual reality (VR) technologies became more and more widespread for a couple of years as they got more and more mature. The accessibility to VR highly increased thanks to recent low-cost commercial VR head mounted display (HMD) systems and easy-to-use development toolkits. These technologies found strong applications both in professional activities such as virtual product engineering and in personal activities such as video games.

The last progress in VR technologies does not concern only the performance and realism of computer simulation but also human perception aspects. One important and well-studied human perception issue is related to motion sickness or cybersickness. Since VR HMDs are much more used than ever, cybersickness problem resolution is of primary concern. According to the well-known sensory conflict theory [Rea78], cybersickness is provoked during a VR experience when humans perceive incoherent movements by different physiological sensors : eyes (visual), ears (audio), vestibular system (physical), muscles (spent effort), etc. Usually instead of moving physically, users send commands using devices (e.g., joysticks) to navigate in virtual worlds. Therefore, users can feel very realistic movement through perceived visual information but they do not feel any movement according to their vestibular system.

To tackle this issue, we present in this paper a novel method to reduce cybersickness through an original approach : we propose to reduce visually induced self-motion deforming geometrically the surrounding virtual scene during user navigation. The proposed approach will allow reducing visually induced self-motion and so lower cybersickness. The approach is proposed for the case users can perceive the virtual world solely by vision and they do not get any feedback by other senses (haptic, audio, etc.). In this condition, we suppose that the major cause of the self-motion induced by users is the visually perceived relative movement of objects in the lateral field of view (FOV). Therefore, the proposed approach will reduce the relative movement of objects seen in the lateral FOV of users by deforming geometrically the virtual scene, in order to reduce the perceived navigation self-motion.

The rest of the paper is organized as following : the literature review about different ways to deal with the motion sickness in virtual reality (section 2) ; The general concept of the proposed approach and hypothesis (section 3) ; The development of the first prototype and its pilot study (section 4) ; The conclusion and perspectives of this work (section 5).

2. State of the art

A huge piece of work in the state of the art has been done to reduce cybersickness and they can be categorized into the following approaches.

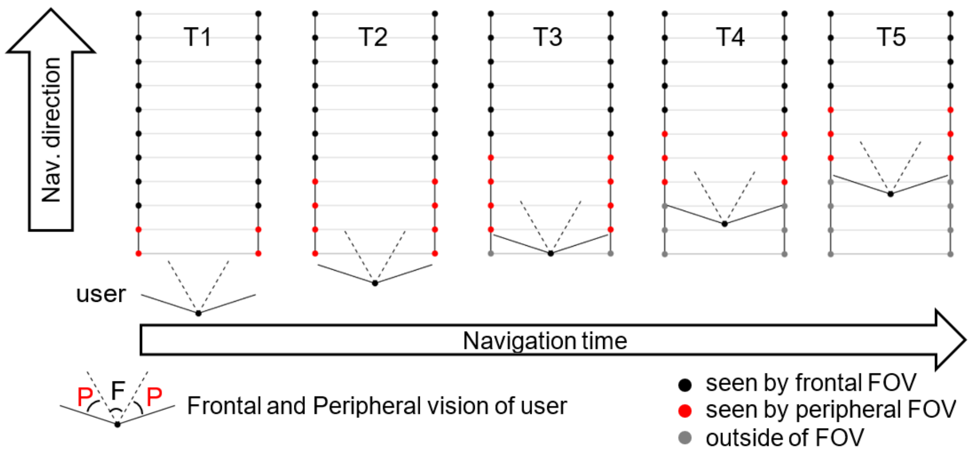

Figure 1 : *Illustration of user navigation in virtual environment and the frontal and peripheral FOV.*

2.1. Augmenting physical movement during VR experience

The reason of having motion sickness explained in the context paragraph consists in the lack of physical movement that can be perceived by the vestibular system. Therefore, The "direct" way to reduce cybersickness is to let users make physical movements according to the navigation mode [WO90]. For example, instead of using joystick to interpret movement for walking virtually in an immersive environment, users can physically move their legs to walk in place, which approximates real walking [WO90] [RSS*02]. Different from walking in place, "omnidirectional treadmill" systems have been proposed to let users adopt a similar gait as in real walking [FCSE13]. These solutions are usually ideal and consistent with the cause of cybersickness but usually they are expensive and not suitable for most public users.

2.2. Physiological enrichment

Other works have been proposed to provide physiological stimuli to users. For example when providing vibration and electroshock to the legs, users can feel pseudo physical walking movements without moving [MAA*05]. It is also possible to achieve walk navigation by using galvanic vestibular stimulation [PPCM15]. The drawbacks of this kind of approach are that users have to wear complementary devices and the physiological stimuli are not fully comfortable for practical daily use.

2.3. VR interaction control

Another way to reduce the sensory conflict is to adjust the navigation parameters. Typically, the navigation acceleration are re-adjusted in order to reduce the difference between the movement perceived by the eyes and the vestibular system [PCM18]. The approach proposed in [Arg14] consists in adapting the navigation speed and trajectory based on the spatial relationship between the user and the environment. But this may reduce the navigation quality since the user's intention on the navigation parameters (speed, navigation & trajectory) is not ensured.

2.4. Peripheral visual field control

Rogers et al. [RRW17] showed that most of the self-motion perceived visually by users is mainly based on the relative movement of the objects that are seen in the peripheral field of view (FOV). Therefore, it is possible to reduce cybersickness by reducing the FOV [BFG17]. 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 the partial FOV is enabled by displaying the frontal view in a limited viewport. The reduction of the FOV removes the lateral vision and only lets users to see what is in front of him/her. The shortcoming of this approach is that it decreases the degree of immersion if the FOV is strongly reduced. Other approach involves adding a blur effect during rotating navigation in order to reduce the induced self-motion [BMMF17]. The blurring effect is easily perceived by users and the consequence is the degree immersion is seriously reduced.

2.5. Position of the proposed approach relative to the state of the art

The approach proposed in this paper deals with the sensation of illusory self-motion that is induced by the visual flow in peripheral vision. The proposed approach will overcome shortcomings present in certain previous works. In compare with the previous work [PCM18] [Arg14] our approach does not modify the navigation intention of the user (speed, acceleration and trajectory). Unlike the approach proposed in [BFG17] our approach will let user the full FOV available during the VR experience. In the contrary with the approach proposed in [BMMF17] all rendered images are clear with our approach.

Our approach consists in reducing the relative movement quantity perceived visually in the lateral FOV. Unlike the methods "VR interaction control", our approach keeps the

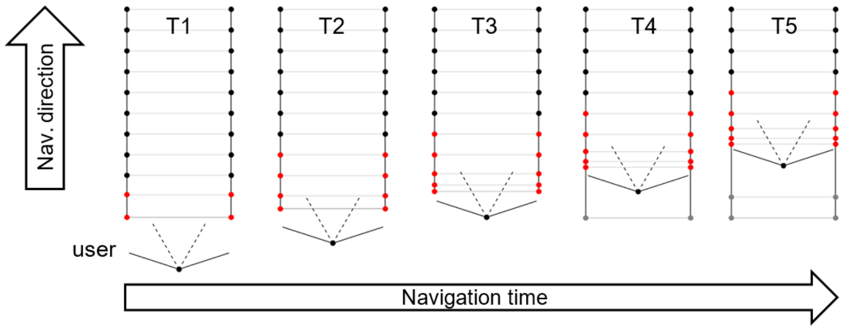

Figure 2 : *Deformation of virtual environment seen in the peripheral FOV.*

user's intention on the navigation parameters in order to ensure navigation quality. Unlike the methods "Peripheral visual field control", the degree of immersion is ensured with our approach by using the entire FOV and keeping clear vision.

3. Proposed approach

During virtual navigation in virtual environment different virtual parts are seen by the user. These seen parts can be categorized into three types : seen in the frontal FOV, seen in the peripheral FOV and outside of FOV. The virtual navigation is illustrated in figure 1. The user navigates in the virtual environment that is modelled by the rectangle surrounded by points. The user moves in the navigation direction and different instances (T1 – T5) are illustrated. The look direction of the user is aligned with the navigation direction and its FOV is represented by the two solid lines. The FOV is then segmented into three fields by two dashed line : left peripheral, frontal and right peripheral FOV. According to the different positions of the user in different instances (T1 - T5), the part of virtual environment seen in the frontal FOV is represented by black points, the one seen in the peripheral FOV is represented by red points and the one outside of the FOV is represented by gray points.

The self-motion induced by user is due to the relative movement of the virtual environment perceived by user vision. According to previous studies [BSW11] [Rie11], the induced self-motion is essentially due to the relative movement of the environment seen in peripheral FOV (represented by red points in figure 1). Therefore, our approach will deform the environment in order to somehow "compress" the geometry visible in the lateral FOV so that it seems moving slower than the frontally viewed part. Figure 2 shows the deformation of the virtual environment especially for the part that are seen in the peripheral FOV. The red points that are seen in the peripheral FOV move in the same direction with the user. The speed of the red points is increased progressively but always smaller than the speed of the user. Once the red points move out of the vision of user they become gray and can be reset to their initial positions.

When user navigates in an environment the various objects are not structured in a regular space which can be easily categorized in a similar way as the black, red and gray points (figure 1). Moreover, the deformation method should be able to deform simultaneously several disconnected meshes. Therefore, the most appropriated deformation method that is anticipated is the cage-based deformation [NS13]. Figure 3 illustrates the cage generation on the navigation environment for the user. The vertices of the generated cage are categorized and colorized (black, red and gray) according to the FOV of the user, in a similar way illustrated in figure 1. In order to deform the virtual environment according to the user navigation direction, the cage (vertices & edges) will be modified in a similar way than the one presented in figure 2

3.1. Hypotheses

Several research hypotheses have been identified along the objectives defined above.

H1 : There is a frontier to separate the frontal and lateral view according to various navigation parameters : navigation direction and speed, user gaze, etc.

H2 : The geometrical deformation of the scene can change the perceived self-motion.

H3 : The reduced perceived self-motion reduces the motion sickness.

H4 : When deforming the scene for the part visible in the lateral FOV the navigation quality and degree of immersion will not be significantly impacted.

3.2. Scientific and technical barriers

The major challenges to prove the hypotheses identified above are analyzed :

B1 : What are the most appropriate subjective and objective evaluation tools for motion sickness ?

B2 : How to compute in real time the frontier between frontal and lateral FOV ?

B3 : How to deform geometrically in real time the scene according to the different linear/angular speed and acceleration of the user's navigation ?

B4 : How to adapt the deformation parameters according to the motion sickness degree ?

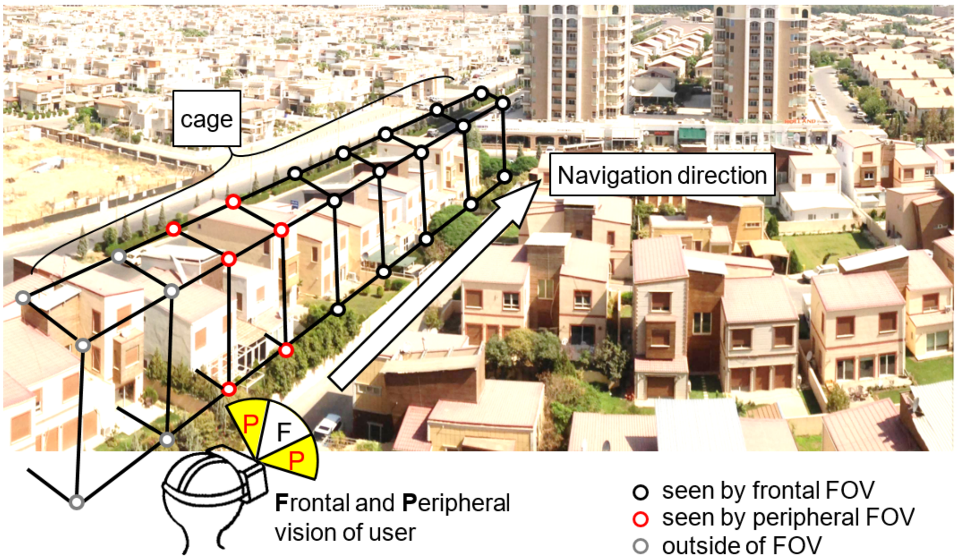

Figure 3 : *Cage generation and segmentation of the navigation environment.*

4. Pilot study

A first prototype of our approach has been designed and implemented [LC19]. A pilot experimentation about this prototype has been conducted . It consists in the case where user navigates in a straight line with constant speed. The virtual objects on the two sides of the navigation path are deformed to reduce the relative movement perceived by the user. A pilot experimentation about this prototype shows that the navigation quality and degree of immersion are not impacted. This pilot study shows that the proposed method is efficient and worthy to investigate.

4.1. Implementation of prototype

The literature is broad regarding mesh deformation but some specific requirements were identified in our case :

- everything in the peripheral FOV should be deformed in a uniform way according to the direction of navigation and the distance to the observer ;
- the deformation should be invariant relative to the mesh tessellation ;
- the algorithm should be able to deform simultaneously several disconnected meshes.

Based on these requirements, the adopted mesh deformation method is the lattice-based deformation method presented by Sederberg and Parry [SP86]. Briefly speaking, starting from multiple meshes, a global bounding box is computed in order to generate lattices of regular sizes. The vertices of the lattices are then defined as control points for the 3-dimensional Bézier solid included in the bounding box. Therefore, when moving these control points, the included Bézier solid is deformed, as well as all the meshes that are inside. Figure 4.a illustrates the virtual environment used in the pilot study. It consists of a street with buildings on its two sides. The user (observer) goes straight through the buildings in a constant speed. The lattices with control points are computed and represented by red points and orange edges. The three pictures (figure 4.a, b and c) show respectively three instances in chronology and the initial position of the observer is shown in the figure 4.a. When the observer navigates the control points are also moved and their displacement will yield the buildings deformation (figure 4.b and c). The detail of the implemented deformation algorithm is presented in [LC19].

Figure 5 shows the first person view of the observer navigating in the between the buildings. The normal buildings are used during the navigation in figure 5.a. The geometrical deformation is applied on the buildings during the navigation in figure 5.b. The buildings seen nearby the user are deformed to reduce the relative movement that can be perceived visually by the user (figure 5.b).

The proposed method has been implemented under Unity3D and displayed in an HTC Vive HMD with the environment shown in figure 4. Navigation in the virtual scene lasts less than 30s. A first experimentation has been realized.

4.2. Experimentation

20 subjects aged from 20 to 50 were asked to voluntarily test our approach and compare two navigation modes (figure 4.a and b). After navigating twice in both modes, each subject were asked to answer a questionnaire containing seven questions, based on the Witmer-Singer presence questionnaire [WS98]. This questionnaire allows to evaluate the navigation quality and degree of immersion during virtual experience. At end the subjects were also asked to compare the perceived navigation speed in the two modes.

According to the experimentation results, the adopted approach does not produce significant difference both in terms of navigation quality and presence level and the self-motion

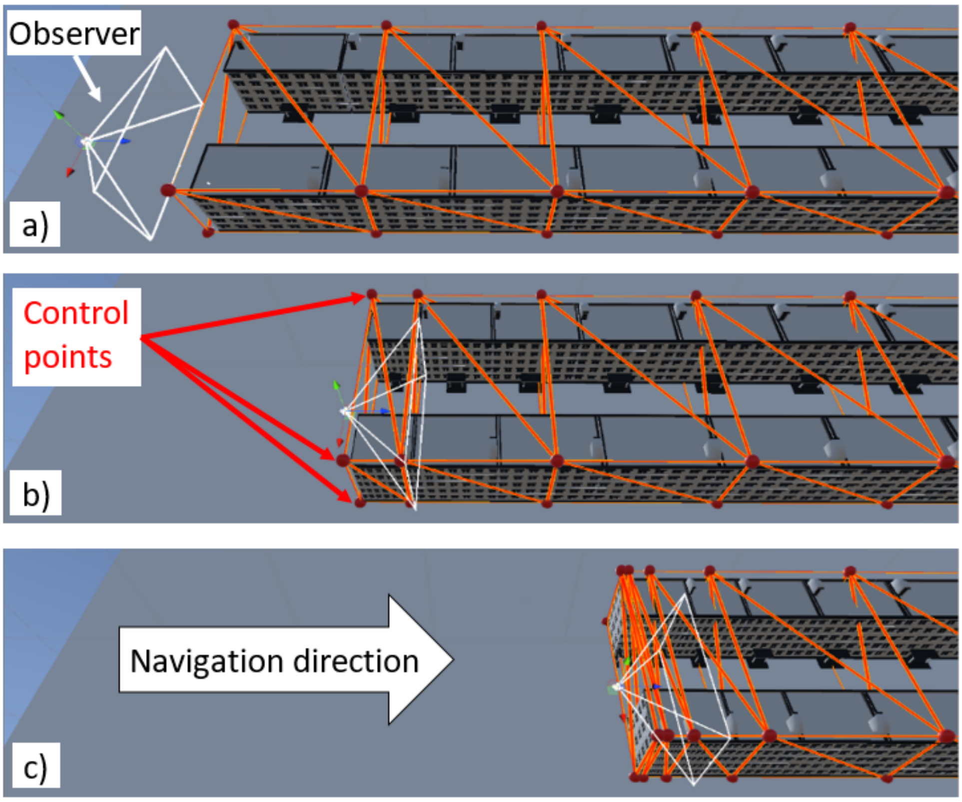

Figure 4 : *Virtual observer navigation through the buildings under geometrical deformation using a lattice-based approach.*

perceived by users were lower in the mode with deformation than the normal scene.

5. Conclusion and perspectives

In this paper an approach using geometry deformation to reduce motion sickness during VR experience is proposed. According to the literature review it is original to use knowledge of geometry modelling in VR motion sickness problem solving.

A first prototype has been implemented and experimented. There are still many research questions to answer and technical problems to solve. For example, user looks around during navigation, the navigation is other than advancing : translation, rotation, etc. The results of the experimentation shows that the visually induced self-motion has been reduced without significant difference about navigation quality nor presence level.

The positive results of this pilot study shows that the proposed approach in this paper is worthy to be more investigated. All the research hypothesis (section 3.1) and scientific & technical barriers (section 3.2) will be addressed in the future work.

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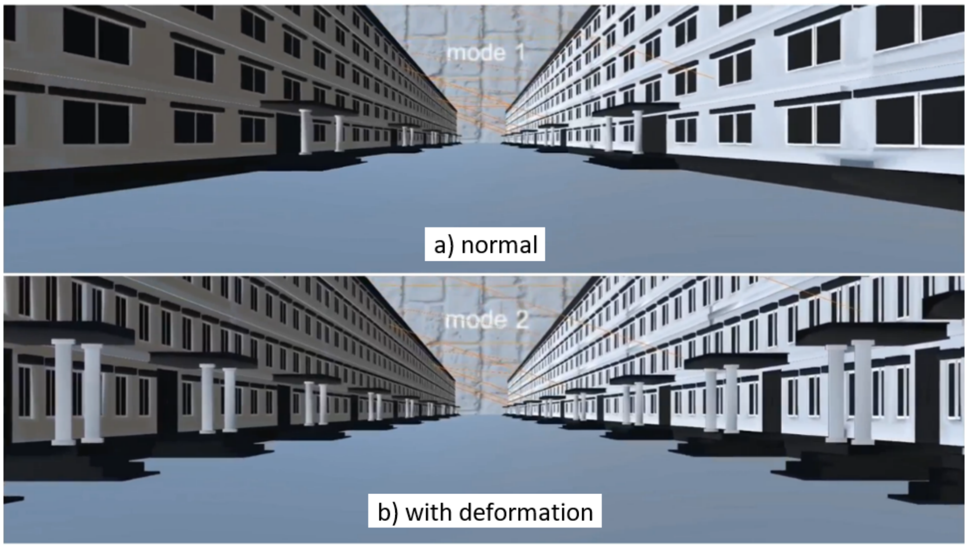

Figure 5 : *Virtual observer navigation through the normal buildings (a) and buidings under geometrical deformation using a lattice-based approach.*

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