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Reducing Cybersickness by Geometry Deformation

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ABSTRACT

One major and well-known issue that occurs during VR experience is the appearance of cybersickness, which refrains users from accepting VR technologies. The induced cybersickness is due to a self-motion feeling that is produced when users see objects moving in the virtual world. To reduce cybersickness several methods have been proposed in the literature, however they do not guarantee immersion and navigation quality. In this paper, a new method to reduce cybersickness is proposed. The geometric deformation of the virtual model displayed in the peripheral field of view allows reducing the self-motion perceived by the user. Pilot test results show that visually induced self-motion is reduced with a guaranteed immersion quality while the user navigation parameters are kept.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality; Computing methodologies—Computer graphics—Shape modeling—Mesh geometry models

1 INTRODUCTION

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

The last progress in VR technologies does not concern only the performance and realism of computer simulation but also human factors aspects. One major human factor issue is related to cybersickness. Since VR HMDs are much more used than ever, cybersickness issue resolution is of primary concern. According to the well-known sensory conflict theory [6], cybersickness is provoked during a VR experience when humans perceive incoherent movements by different physiological sensors: eyes, ears, vestibular system, etc. Usually instead of moving physically, users send commands using devices (e.g., joysticks) to navigate in virtual worlds. Therefore, users can feel realistic movements through perceived visual information but they do not feel any movement according to their vestibular system.

To tackle this issue, we present here a novel method to reduce cybersickness through an original approach: we propose to reduce visually induced self-motion by deforming the surrounding virtual scene while navigating.

2 RELATED WORK

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

The "direct" way is to let users make physical movements according to the navigation mode. For example, to virtually walk in an immersive environment, users can physically move their legs to walk in place, which approximates real walking [5]. Rather than walking in place, "omnidirectional treadmill" systems have been proposed to let users make similar efforts as in real walking [2]. These solutions are usually ideal and consistent with the cause of cybersickness but usually they are expensive and not suitable for most public users.

Other work proposed to provide physiological stimuli to users. For example when providing vibrations to the legs, users can feel pseudo physical walking movements without moving [4]. The drawbacks are that users have to wear complementary devices and the physiological stimuli are not fully comfortable.

Another way is to adjust navigation parameters: the navigation acceleration is continuously re-adjusted depending on the current user physiological state [3]. But this may reduce navigation quality since the user has no full control over the navigation parameters.

Rogers et al. [7] 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, cybersickness can be reduced by reducing the FOV [1]. However it decreases the immersion level if the FOV is strongly reduced.

In this paper, we contribute on past work by proposing an original solution for cybersickness by geometry deformation. Our approach allows reducing visually induced self-motion and so lower cybersickness, by keeping the full FOV and reducing the relative movement quantity perceived visually in the lateral FOV. The perceived navigation speed is thus reduced while ensuring navigation quality by preserving the relative motion perceived in the frontal FOV.

3 GEOMETRY DEFORMATION

Fig. 1 illustrates our approach to deform the geometry of the surrounding virtual objects (here a street bordered by buildings) when an observer moves virtually. The three pictures show the scene at three different moments in chronological order. The parts of the buildings coming into the observer peripheral FOV move also in the same direction of the observer.

3.1 Mesh Deformation Approach

The literature is broad regarding mesh deformation but some specific requirements were identified in our case: (i) everything in the peripheral FOV should be deformed in a uniform way according to the direction of navigation and the distance to the observer; (ii) the deformation should be invariant relative to the mesh tessellation; (iii) disconnected meshes should be deformed simultaneously. Based on these requirements, the adopted mesh deformation method is the lattice-based deformation method proposed by Sederberg and Parry [8]. 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 points, the included Bézier solid is deformed, as well as all the meshes that are inside. The lattices generation for the virtual scene is illustrated in Fig. 1. The red spheres represent control points of the lattices and their displacement will yield the model deformation.

3.2 Navigation-driven VR Environment Deformation

It is necessary to define how navigation will drive the deformation. In fact, in our case, it will consist in moving the lattices control points according to the observer's navigation parameters. Here, considering the virtual scene of Fig. 1, we suppose that the observer

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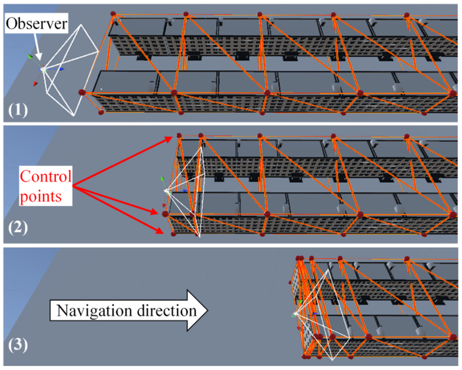

Figure 1: Virtual observer navigation through the buildings under deformation using a lattice-based approach.

navigation velocity ($\mathbf{v_n}$) is constant and his/her position ($\mathbf{p_n}$) is always on the medial axis of the street. By default each lattices control point has a null velocity so that the buildings are not deformed. During navigation, at each frame, they will move and so deform the buildings accordingly. The algorithm used to change the velocity of the control points ($\mathbf{v_c}$) is described in Alg. 1.

Algorithm 1 VR environment deformation

```
$s \leftarrow$ lattice size
for all rendering frames do
    for all control points $c$ with position $\mathbf{p_c}$ and velocity $\mathbf{v_c}$ do
        $\mathbf{d_n} \leftarrow \mathbf{v_n}/||\mathbf{v_n}||$
        $r \leftarrow 1 - ||(\mathbf{p_n} - \mathbf{p_c}) \cdot \mathbf{d_n}||/s$
        if $r > 0$ then
            $\mathbf{v_c} \leftarrow r \cdot \mathbf{v_n}$
        end if
    end for
end for
```

4 EXPERIMENTATION AND RESULTS

The proposed method was implemented under Unity3D and displayed in an HTC Vive HMD with the environment shown in Fig. 1. The virtual street is 300m long and navigation in the scene lasts 20s.

20 subjects (2 females) aged from 20 to 50 ($M = 29.9$, $SD = 11.34$) were asked to voluntarily test our approach and compare two navigation modes. The first mode, named M1, is a normal navigation mode without any deformation of the virtual scene (considered as the reference) and the second mode, named M2, includes the deformation of the virtual scene. In both modes, navigation speed is constant. Half of the subjects were used to VR and the others not.

After navigating twice in both modes, each subject were asked to answer a questionnaire containing seven questions, based on the Witmer-Singer presence questionnaire [9]. For each question, a seven-point Likert scale was used to capture the subjects' responses. The questionnaire is composed of:

- Three questions about navigation quality in the two modes. The scores were summed to give a final score from 1 to 21.
- Three questions about the degree of presence in the two modes. The scores were summed to give a final score from 1 to 21.
- The last question compares the perceived navigation speed between both modes. The score varies from -3 (completely faster in M1) through 0 (equivalent speed) to 3 (completely faster in M2).

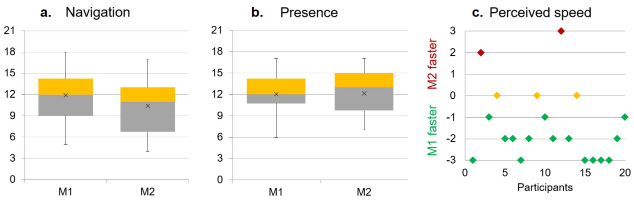

Figure 2: Navigation quality, presence and perceived speed.

A Shapiro-Wilk test showed all the data to be normally distributed. Regarding navigation quality, a t-test showed that there was no significant difference between both modes ($M_{M1} = 11.9$, $SD_{M1} = 3.61$; $M_{M2} = 10.4$, $SD_{M2} = 3.91$), $t(19) = 1.26$, $p = 0.22 > 0.05$ (Fig. 2a.), indicating that navigation quality is not affected by our approach. Regarding presence, a t-test showed that there was no significant difference between both modes ($M_{M1} = 12.05$, $SD_{M1} = 3.23$; $M_{M2} = 12.15$, $SD_{M2} = 3.01$), $t(19) = -0.12$, $p = 0.91 > 0.05$ (Fig. 2b.), indicating that presence is not affected by our approach. Finally, the perceived navigation speed was found to be higher in M1 than in M2 ($M = -1.4$, $SD = 1.70$) (Fig. 2c.), which may indicate that, with our approach and with longer tests, cybersickness could be reduced as visually induced self-motion is reduced.

5 CONCLUSION

In this paper a new approach was proposed to tackle cybersickness in VR by deforming the surrounding environment. The proposed approach does neither limit the FOV in the display system nor modify the navigation parameters. The deformation of the environment allows reducing the perceived navigation speed. A first experimentation showed that our approach does not impact navigation quality nor the presence level.

Future work will include further in-depth tests to assess our approach regarding cybersickness reduction, as well as extending our approach to deform the environment whatever the navigation mode (translation, rotation, fly, etc.) and on more complex situations.

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