# Reducing Cybersickness by Geometry Deformation

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**ABSTRACT**

Since a couple of years, virtual reality (VR) technologies showed to be more and more useful and used in digital activities. One major and well-known issue that occurs during VR experience is the provocation of cybersickness, which refrains users from accepting these 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. The shortcoming of these methods is that the immersion and navigation quality is not guaranteed. 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. First results show that visually induced self-motion is indeed reduced with a guaranteed immersion quality while the user navigation parameters are kept.

**Keywords**: Navigation, Cybersickness, Mesh deformation.

**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 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 [1], 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 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 they can be categorized into the following approaches.

The "direct" way to reduce cybersickness is to let users make physical movements according to the navigation mode [1]. For example, to virtually walk in an immersive environment, users can physically move their legs to walk in place, which approximates real walking [3]. Rather than walking in place, "omnidirectional treadmill" systems have been proposed to let users make similar efforts as in real walking [4]. 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 and electroshocks to the legs, users can feel pseudo physical walking movements without moving [5]. The drawbacks of this kind of approach are that users have to wear complementary devices and the physiological stimuli are not fully comfortable.

Another way to reduce the sensory conflict is to adjust the navigation parameters. Typically, the navigation speed and acceleration are re-adjusted in order to reduce the difference between the movement perceived by the eyes and the vestibular system [6]. But this may reduce the navigation quality since the user intention on the speed is not ensured.

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, it is possible to reduce cybersickness by reducing the FOV [8]. 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.

In this paper, we contribute on past work by proposing, developing and experimenting an original solution to reduce 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

Figure 1 illustrates our approach to deform the geometry of the surrounding objects (here a street bordered by buildings) in the virtual environment when an observer moves virtually. The three pictures show respectively 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

In the literature, many methods exist for mesh deformation but some specific requirements are identified in our case. Indeed, 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. Last, the algorithm should be able to deform simultaneously several disconnected meshes.

The adopted mesh deformation method is the lattice-based deformation method presented by Sederberg and Parry [9]. 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. The lattices generation for the virtual environment (here buildings) is illustrated in Fig. 1. The red spheres represent control points of the lattices and their displacement will yield the buildings deformation.

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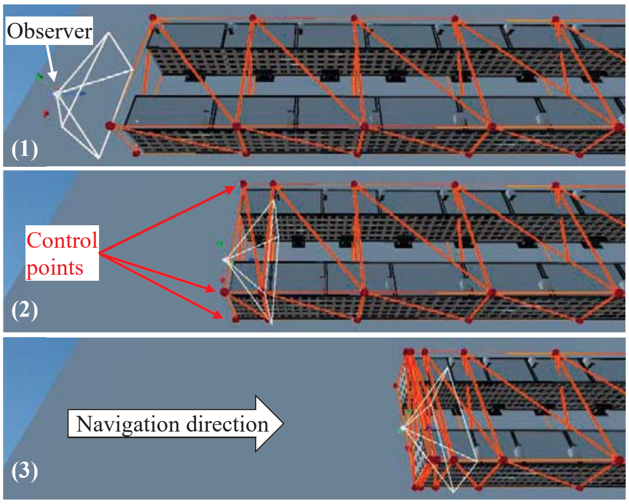


Figure 1: Virtual observer navigation through the buildings under deformation using a lattice-based approach.

### 3.2 Navigation-driven VR Environment Deformation

Once the mesh deformation method is chosen 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.

In this paper, we suppose that the observer navigation velocity $(\boldsymbol{v_n})$ is constant and his/her position $(\boldsymbol{p_n})$ 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 as well to deform the buildings. The overall algorithm used to change the velocity of the control points $(\boldsymbol{v_c})$ is:

$\boldsymbol{s} \leftarrow$ lattice size
foreach rendering frame
  foreach control point $\boldsymbol{c}$ with its position $\boldsymbol{p_c}$ and velocity $\boldsymbol{v_c}$
    $\boldsymbol{d_n} \leftarrow \boldsymbol{v_n} / \|\boldsymbol{v_n}\|$
    $\boldsymbol{r} \leftarrow \boldsymbol{1} - \|(\boldsymbol{p_n} - \boldsymbol{p_c}) \cdot \boldsymbol{d_n}\| / \boldsymbol{s}$
    if $\boldsymbol{r} > \boldsymbol{0}$ then
      $\boldsymbol{v_c} \leftarrow \boldsymbol{r} \cdot \boldsymbol{v_n}$
    end if
  end foreach
end foreach

## 4 Experimentation and Results

The proposed method has been implemented under Unity3D and displayed in an HTC Vive HMD with the environment shown in Fig. 1. Navigation in the virtual scene lasts less than 30s.

20 subjects 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. 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 [10]. For each question, a seven-point Likert scale was used to capture the subjects' responses. The questionnaire is composed of:

- Three questions about the navigation quality in the two modes. The scores of the three questions have been summed to give a final score from 1 to 21.
- Three questions about the degree of presence in the two modes. Again, the scores were summed to give a final score from 1 to 21.
- The last question is to compare the perceived navigation speed in the two modes. The score varies from $-3$ (completely faster in the 1$^{st}$ mode) through 0 (equivalent speed) to 3 (completely faster in the 2$^{nd}$ mode).

A Shapiro-Wilk test showed all the data to be normally distributed. Regarding the 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. 2 left). This shows that the 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. 2 middle). This shows that presence is not affected by our approach. Finally, the perceived navigation speed was found to be higher in the first mode than in the second one (M=-1.4, SD=1.70) (Fig. 2 right), which may suppose that, with our approach and with longer tests, cybersickness could be reduced as visually induced self-motion is reduced.

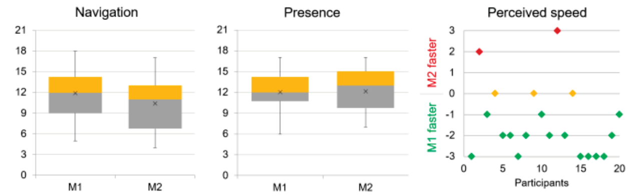


Figure 2: Results for navigation, presence and perceived speed.

## 5 Conclusion

In this paper a new approach was proposed to tackle cybersickness in virtual reality 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 produce significant difference both in terms of navigation quality and presence level.

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

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