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General Framework of Geometric Simplification for Mitigating Cybersickness

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***Abstract*—Virtual reality have advanced rapidly and are spreading in much of the world for huge numbers of application domains. However the cybersickness appears for many VR users and it is still a significant issue preventing them to feel free to use VR technology. In most of VR experience, the immersive display system can provoking much more self-motion perceived by eyes than the one given by vestibular systems. Through the sensory conflict theory, the mismatch in visual and vestibular sense causes sickness. In this paper a general framework for applying geometric simplification on the virtual scene is proposed with the aim of lowering the visually induced self-motion that can be quantified by optic flow analyzed on the rendered images. The synthetized image that includes original scene at central part and simplified scene at peripheral part, are rendered to VR users. The analyzed optic flow on the synthetized images is much less than the one given by the original images.**

***Keywords*—Virtual reality, Geometric simplification, Cybersickness, Optic flow**

I. INTRODUCTION

Virtual reality (VR) technology is spreading rapidly in the worldwide and its applications are no longer reserved to gaming. In many serious domain the VR applications are also called serious game, such as engineering, learning, cultural heritage, training, medical services, etc. In industry engineering, VR completes the numerical engineering process for better taken into account human factor in the product simulation. Learning with VR applications can avoid cost of physical facilities and help the remote training. VR allows human to relive an experience in a cultural place that may not exist anymore in the real life.

In addition to the boom in new application areas, the technical development of VR applications has been expanded thanks to low-cost and mobile VR hardware. VR was historically invented with the CAVE (cave automatic virtual environment) system that takes up space, is very expensive and needs professional maintenance. Recently, with the advent of HMD (head-mounted display), VR began to be used in large numbers in all walks of life for professional use and in every household for personal use [1]. Many researches are interested in the difference in terms of visual perception in the two types of devices [2]. Another reason is the diversity and low cost of 3D application development platforms such as Unity3D, Unreal Engine, etc. allow large development community to prototype and share interesting 3D computer graphics projects for various domains [3].

Under this context many new users are interested in VR applications but they are not used to immersive 3D visualization. One of the most crucial difficulties for them is the cybersickness. Actually they can feel motion sickness during their VR experience due to incoherent perception of the self-motion between the vision and vestibular systems. The authors in [4] present very first so-called “sensory conflict theory” and they clearly defined it by this original sentence from the paper: “motion sickness is a self-inflicted maladaptation phenomenon which occurs at the onset and cessation of conditions of sensory rearrangement when the pattern of inputs from the vestibular systems, other proprioceptors and vision is at variance with the stored patterns derived from recent transactions with the spatial environment”.

In VR the motion sickness is mainly related to the visually induced motion sickness (VIMS) because of the lack of physical motion of VR users. Usually users can express the locomotion intention through VR HMD controllers to navigate in virtual scenes. The opposite motion of the virtual world seen by users make them an illusion of self-motion moving in the virtual world. This phenomena is visually induced self-motion. At the same time their vestibular system does not sense any self-motion, which cause an sensory conflict on the self-motion. Generally speaking, the solutions proposed in the literature for mitigating VIMS is to shorten the gap between the self-motion perceived through vision and vestibular sense. Our proposed approach aims to lower the self-motion illusion due to the visible motion in the rendered images. And we proposed process the rendered images to users.

The optic flow generated from rendered images [5] is directly related to the visually induced self-motion. The idea is to process the rendered images to provoke less optic flow. The optic flow is the visible motion of pixel in digital images and it is used to optimize video compression [6]. Actually the video compression methods minimize the degradation of the image quality where the optic flow intensity is high. The human can deduce self-motion through the extracted light pattern motion from optic flow perceived by the visual system [7]. In VR the optic flow fields can be manipulated to lets human feel different visually induced self-motion[8].

In an immersive display system, users do not see any other objects in the real world so that users do not have any static reference. The illusion of the self-motion provoked by optic flow generated in the displayed images will be dominant. The approach proposed in this paper is to apply smart geometry simplification on the virtual environment for the sake of decreasing the self-motion feeling for users navigating in the virtual environment. The optic flow is analyzed and the virtual scene has been segmented into two categories according to the high and low optic flow generated. The high optic flow part of the virtual environment is simplified according to the user navigation. The advantage of this approach in compare to the previous ones existing in the literature is that, user can have full FOV (field of view), see clear images and free to move in the virtual reality. A general framework including scene segmentation, geometric simplification and image rendering for synthetizing original-simplified scene is proposed in this paper.

II. STATE OF THE ART

In the literature many cybersickness mitigation approaches for VR utilization have been proposed to reduce VIMS through managing sensory conflicting cues. As already stated in the introduction part the ultimate objective is to reduce the sensory conflict of self-motion between vision and vestibular sense. Therefore, the proposed approaches will either increase the sensation of self-motion caused by vestibular system or reduce the one caused by eyes seeing rendered images.

A. Reinforcement of vestibular cues

As said in the introduction section, inadequate physical movement regarding to the VR scene movement is a cause of VIMS. Therefore, the evident solution is to let users to move physically in order to increase the self-motion perceived by the vestibular system. Locomotion simulators are devised to let users to walk physically within a restricted space when experiencing the virtual scene. For example aa tread-mill system [9] is designed for moving in all directions in virtual worlds. 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.

Walking-in-place method has been developed to allow users to physically move their legs [10] but the pseudo walking may not efficiently provoke pertinent self-motion in the vestibular system. Redirected walking in VR has been investigated over the past decade [11] & [12] for allowing user to walk naturally in a limited physical space without any simulator. This approach will let user to feel a conflict between the virtual walking in VR and the physical walking. The conflict is either on the walking distance or walking orientation. A large physical space is required in order to minimize the conflict.

Without any physical movement, human vestibular sense can be rigged by galvanic stimulation [13] to feel fake physical motion. Therefore sensory conflict between visual and vestibular information can be decreased during VR experience. Users can also feel fake physical walking motion approximated by vibration and electroshock can be brought to the legs [14]. However, these solutions require extra hardware and are intrusive.

B. Reduction of visual motion cues

The other kind of approaches based on software level will control the rendered images in order to limit visually induced self-motion and VIMS for users. These approaches can avoid extra hardware (e.g. locomotion simulators), physiological intrusion (e.g. galvanic stimulation) and large working space (e.g. redirected walking).

VR applications can be designed to actively alter user navigation parameters in order to reduce visible scene motion thus to reduce VIMS. The user locomotion acceleration and speed can be adapted [15] or replaced by carefully calibrated automatic navigation [16]. The disadvantage is that users can no longer move freely with these counter-measures and the quality of navigation in VR can be reduced.

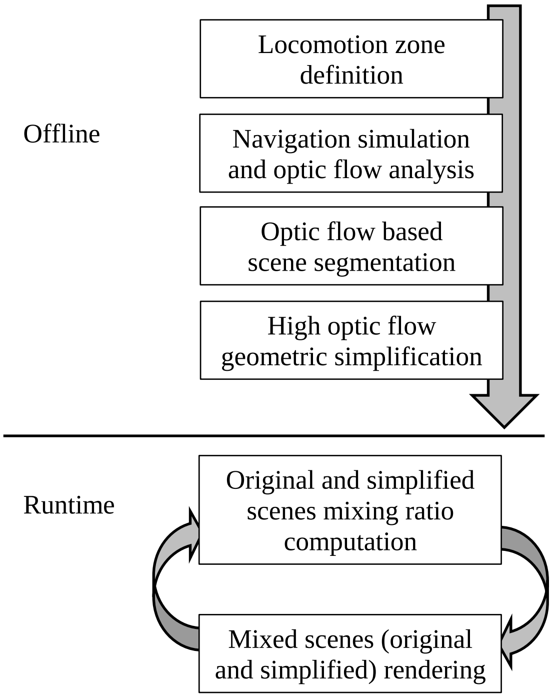

Fig. 1. Framework of gometry simplification for reducing optic flow

Instead of limit user navigation, the user visualization can be also processed on the computer program level for the aim of limiting visible motion in the rendered images. The insertion of a virtual nose as a static reference has been proposed as a cybersickness counter-measure [17]. 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 [18] . The blurring effect is not ignorable by users and this can degrade the quality of immersion.

Always about vision aspect, according to [19] the visually induced self-motion is mainly induced by visual motion seen by users in the peripheral FOV. Therefore, the viewport size of the virtual camera can be reduced for lower the visually perceived self-motion [20]. Based on these principles, dynamic reductions in users' FOV has been developed as a VIMS counter-measure [21] & [22]. If the user does not move in the virtual world, the integral view port is enabled and the virtual world is displayed on the screen integrally. When user starts to move in the virtual world, the viewport size is reduced by enabling partially the central part of the screen to display the frontal view of the user. Unfortunately, this method occlude the peripheral vision and can decrease the degree of immersion.

And last, for avoiding constraints on the user navigation parameters and bad quality of the visual perception in virtual world, it is possible to process geometrically the virtual environment for reducing optic flow. The advantage of geometry processing approach is that the quality of immersive visualization is not affected since on one hand, user FOV is maintained and rendered images are clear, on the other hand user navigation control is maintained. For example, the geometry of the virtual scene seen in the peripheral vision by

Fig. 2. Virtual camera and optic flow analyzed on the captured image

users was deformed along the navigation direction and the visually perceived optic flow has been shown to be significantly reduced [23]. However the scene deformation may affect the one-scale perception of user. The correlation between the scene complexity and VIMS has been proposed in the literatures [24] & [25]. Therefore, another geometry processing approach consists of the geometric simplification of the scene is proposed to reduce significantly the optic flow generated in the rendered images [26]. A case study virtual scene has been created, geometric simplification strategy has been identified and applied manually. The simplified scene is seen by users in the peripheral FOV and the original scene is displayed in the central FOV which is important for user tasks. However the scene simplification strategy has been decided arbitrarily, the windows on the lateral façade of the building are removed but they do not contribute to the optic flow according to the user navigation direction. In addition the approach is not generalized and it is not easy to be applied for other cases.

III. PROPOSED GENERAL FRAMEWORK

In this paper we propose a general framework (Fig. 1) for reducing optic flow by applying geometry simplification on the virtual environment. The framework consists of two parts: offline pre-processing for preparing simplified virtual scene according to analyzed optic flow and runtime computation for rendering the mixture of the original and simplified scene.

A. *Locomotion zone definition*

First, once the virtual environment created, VR designers has to defined the locomotion zone where VR users can move on during navigation. This is similar to the well-known navigation mesh that is useful for helping autonomous agent in pathfinding.

B. *Navigation simulation and optic flow analysis*

Once the navigation zone is defined an autonomous agent will explore the virtual world through previously defined navigation mesh. The agent will simulate the various possible navigation of VR users in the virtual world. All images taken by the camera of the agent will be used to analyze the optic flow. The position and orientation of the agent camera are also stored for each image. Fig. 2.a illustrates an example of virtual camera in the 3D scene and its position and orientation. The image captured by the virtual camera is shown in Fig. 2.b. The dense optic flow is analyzed on the captured images and visualized by HSV (hue, saturation, value) color model (Fig. 2.c.): the hue for the direction and value for the magnitude of optic flow. The black color means that the optic flow is null.

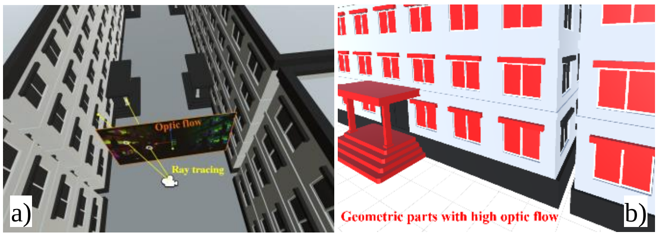

Fig. 4. scene segmentation through optic flow

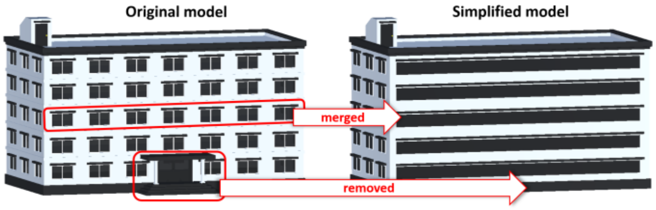

Fig. 3. Geometric simplification on the high optic flow part.

C. *Optic flow based scene segmentation*

In this step the optic flow computed on rendered images are projected onto the 3D geometry of the virtual scene. Therefore, each polygon (i.e. triangle) of the scene 3D mesh will have a scalar value which corresponds to the projected optic flow intensity. Actually during navigation a polygon can be visible during a time interval from its appearance to its disappearance out of the camera FOV, thus different images containing this polygon are used to compute optic flow. In this case the maximal optic flow intensity is assigned to the polygon. Fig. 4.a illustrates the ray tracing technique to project the optic flow image (Fig. 2.c) onto the 3D mesh of the virtual buildings. By giving a proper threshold of the high optic flow intensity the 3D mesh can be segmented and high optic flow part of the 3D mesh can be identified by red in Fig. 4.b.

D. *High optic flow geometric simplification*

In order to reduce the optic flow in the rendered images, the scene is geometrically simplified for removing the parts provoking high optic flow. Simplification is not new and has been used to improve the performance for rendering [26]. The parts less import for visual perception are removed by mesh simplification to lighten the graphics. The mesh idealization approach is also applied to accelerate the FEA in mechanical engineering [26]. Fig. 3 shows one possible geometric simplification for avoiding high optic flow parts of the buildings. Instead of multiple elementary windows for one floor, only one large window rest in the simplified buildings. The windows are merged in an similar direction of the navigation direction (Fig. 2.b), which can reduce the light pattern motion in the rendered images during navigation. The elements for representing the gate are completely removed in the simplified scene since it is not a major part of a building.

E. *Image synthezing of original and simplified scenes*

During the VR experience it is evident that displaying the simplified scene in full screen will provoke minimal optic flow to the users. But the degree of fidelity of the scene is very low. Meanwhile, as already said early in the paper, the visually induced illusion of self-motion for users, is essentially provoked by motion visible in the peripheral vision of the users [19]. Therefore, let user see the original scene in the central FOV and the simplified scene in the peripheral FOV will be a best compromise between low optic flow and high fidelity of the rendered scene.

The ratio between original and simplified scenes is a crucial parameter and it depends on the navigation velocity, optic flow intensity and also personal ability to resist VIMS. The ratio can be optimized dynamically through these criteria during VR program runtime. In this paper we suggest to take into account the angle of the FOV to compute this ratio. As shown in Fig. 5. the full FOV angle is β whereas the FOV angle for the central FOV is α. Therefore the ratio could be computed by:

$$\text{ratio} = \frac{\alpha}{\beta} \tag{1}$$

Technically to synthesize two images, we can generated a circular image from the original scene that will overlap the image from the simplified scene. Game engine such as Unity provides the “Mask” function allowing to develop this image synthesis step.

IV. EXPERIMENTATION

In order to show the efficiency of the geometric simplification on the optic flow patterns mitigating, the comparison between full original scene and partial simplified scene in the peripheral FOV is realized. The optic flow patterns with and without geometric simplification have been analyzed. Fig. 6.a shows 100% original scene and the analyzed optic flow pattern is illustrated in the Fig. 6.c. Whereas the synthetized image of original scene at 50% central FOV with simplified scene at 50% peripheral FOV is shown in Fig. 6.b. The optic flow pattern analyzed on this synthetized image is illustrated in Fig. 6.d. It is easy to see that the optic flow in the peripheral FOV is nearly null thanks to the geometric simplification on the scene.

V. CONCLUSION AND FUTURE WORK

In this paper, a general framework for applying geometric simplification method is proposed to reduce optic flow in VR simulation images rendered to users. Starting from a scene with defined navigation zone, exhausted virtual navigation possibilities can be simulated and optic flow pattern can be analyzed on the rendered images. Therefore, the geometry of the scene could be segmented into two categories: the one provoking high optic flow patterns and the one provoking low flow optic patterns. The geometry is then simplified according to the navigation direction and optic flow orientation. Simplified scene is proposed to be rendered only in the peripheral FOV which is important for the visually induced self-motion and less important for the user task. Experimentation results shows that the geometric simplification applied on the virtual scene can effectively lower even clear the optic flow in rendered images for user’s peripheral FOV.

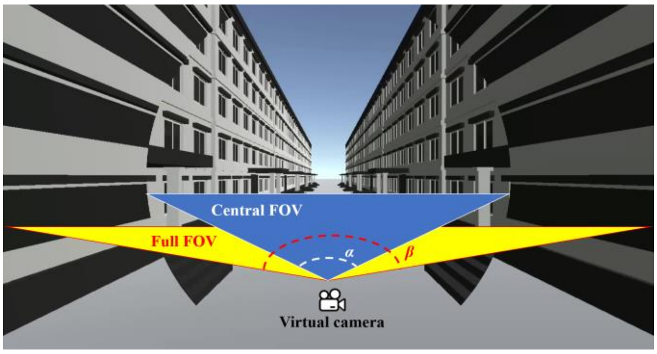

Fig. 5. Mixing ratio between original and simplified scene

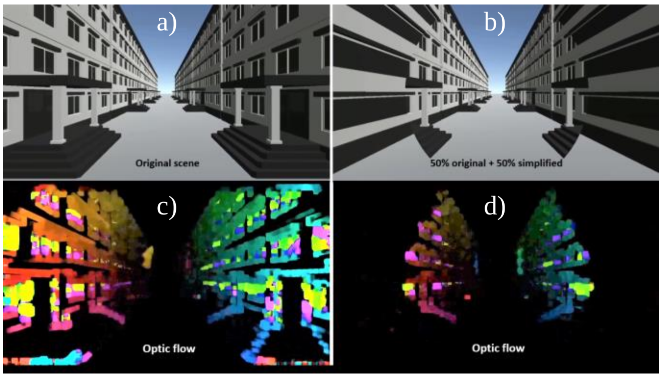

Fig. 6. Comparison of optic flow analysis between original scene and original-simplified scene

In the future the human perception study will be conduct in order to measure the efficiency of the geometric simplification on the cybersickness effect. The automatic geometric simplification according to the optic flow will be designed.

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