New VR Navigation Techniques to Reduce Cybersickness

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Abstract

In nowadays state of the art VR environments, displayed in CAVEs or HMDs, navigation technics may frequently induce cybersickness or VR-Induced Symptoms and Effects (VRISE), drastically limiting the friendly use of VR environments with no navigation limitations. In two distinct experiments, we investigated acceleration VRISE thresholds for longitudinal and rotational motions and compared 3 different VR systems: 2 CAVEs and a HMD (Oculus Rift DK2). We found that VRISE occur more often and more strongly in case of rotational motions and found no major difference between the CAVEs and the HMD.

Based on the obtained thresholds we developed a new "Head Lock" navigation method for rotational motions in a virtual environment in order to generate a "Pseudo AR" mode, keeping fixed visual outside world references. Thanks to a third experiment we have shown that this new metaphor significantly reduces VRISE occurrences and may be a useful base for future natural navigation technics.

Introduction

The recent advent of state of the art virtual reality technology, providing visually realistic and immersive environments using CAVE or HMD, is posing a number of new challenging issues to achieve high quality, though friendly and agreeable VR experience. Although the graphics capabilities of VR tend to be mature, user interaction is a subject of intense research. Interactions are essential to provide the user immersion and sense of presence. One of the most essential task one would like to achieve is navigation, the act of displacement. The quest for realism involves trying to reproduce reality. In the case of displacement, it consists in allowing the user to walk, or to use a navigation device. Paradoxically, this solution which seems simple and natural, requires in practice the use of complex and cumbersome devices, designed to make the user feel that he is moving, while keeping his position in a defined area. Many techniques try to address a major problem of navigation in VR: cyber sickness. Though there are a large number of proposed technics which deal with VRISE (Virtual reality induced symptoms and effects) reduction in specific conditions [8, 13, 14], there is still no sufficiently efficient technic adapted to all navigation situations.
When travelling in a vehicle, passengers can encounter a range of symptoms, from discomfort to nausea through dizziness or vomiting and more [18]. We can refer to it familiarly as vehicle sickness, air sickness, sea sickness or more generally, transportation sickness. Cybersickness and simulator sickness cause the same type of symptoms. There are a few theories that aims to explain cybersickness, among them sensory conflict and ecological theories. The sensory conflict theory is largely studied [10, 12]. It suggests that cybersickness is caused by a mismatch between sensory systems involved in motion perception. Visuo-vestibular conflict is thought to have a strong and frequent impact. The ecological theory [21] states that the simulator sickness is caused by a prolonged period of postural instability during travel. This theory also predicts that postural instability precedes the sickness [24]. Thus some scientific research make use of postural stability measure to quantify cybersickness [8].
In order to better understand the perceptual characteristics of VRISE in actual VR systems, such as Oculus Rift, HTC Vive or PlayStation VR and CAVEs with HD or 4K display systems, we carried out several experiences in various navigation conditions.

Experiment 1

A first experiment has been conducted in Renault's high performance IRIS (Immersive Room and Interactive System) CAVE™, a 5 sided virtual reality room with a combined resolution of 70 M pixels, distributed over sixteen 4K projectors and two 2K projector as well as an additional 3D HD collaborative power wall (see Figure 1). Images of the studied vehicle are displayed in real time thanks to a cluster of 20 HP Z800 computers with 24 Go RAM and 40 nVidia Quadro 6000 graphics boards. The experiment was conducted using Renault's SCANeR Studio © real time driving simulation software [11]. Head tracking was performed with an ART 8-camera infrared tracking system running at 60Hz. A driver station with controlled and measurable seat, steering wheel and driver body position was used for passive driving sessions.

Figure 1. Renault's High Performance CAVE with controlled driver station

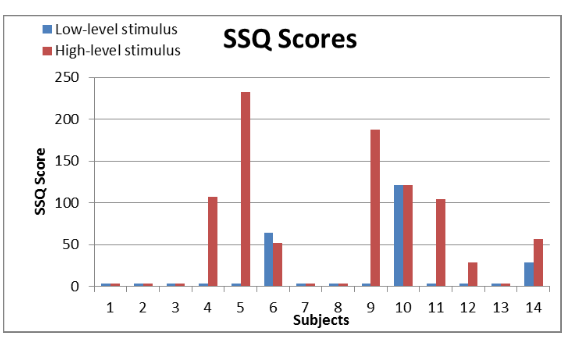
For the planned experiment, low and high level speed and acceleration thresholds were induced, thanks to the experimental driving scenarios, to determine what amplitude of movements is acceptable when driving in a CAVE [14]. Our hypothesis was that the higher the vehicle accelerations, the higher the visuo-vestibular conflict and the more the simulation sickness. In other terms, if the vehicle acceleration is under or close to the vestibular perception threshold, the visuo-vestibular conflict will be not induce or will induce only a weak, thus acceptable VRISE.
Two types of vehicle movements were distinguished in the experiment: translations and rotations. Indeed, physical translational movements and rotational movements are perceived by the different

organs in the vestibular system, the otoliths for linear and the semicircular canals for rotations [2].

Figure 2. Presentation of the curved road used for the second scenario (yaw motion study) of the Experiment 1

Results

28 volunteer subjects participated in the experiment: 14 for longitudinal motion and 14 for rotational motion. Results show that for rotational motion naïve subjects experienced significantly higher SSQ values when the acceleration values were higher (up to 13°/s2) comparatively to low levels (2°/s2) and with the lower level motions they have not experienced significant VRISE (nevertheless still two subjects experienced a slight uneasiness without a disturbing driving effect) and often with zero SSQ values. These naïve subjects seemed to experience an easy ride with the low, about 2°/s2 values, though were uneasy with the higher, 13°/s2 values.
Results also show that the group of experienced subjects had low SSQ values in the two different sessions, independently on the acceleration values and had always zero or very low SSQ values. Thus it would seem that with experienced subjects, such as gamers or VR specialists, these rotational VRISE are low but for naïve subjects low rotational motion levels are required to avoid significant VRISE.
In addition we can also observe that SSQ and postural stability values are not correlated in our experiments. Previous studies have already shown that the relationship between motion sickness and postural stability may vary according to motion characteristics [3], especially in driving situations where even negative correlation may be observed [19], well in accordance with our findings.



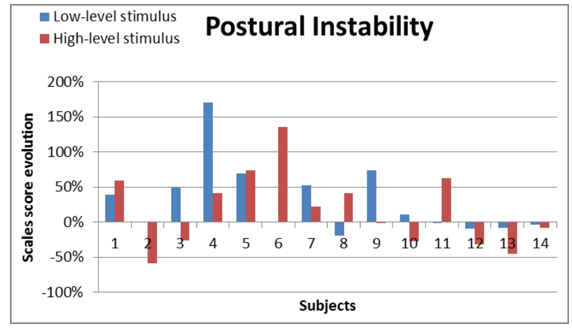


Figure 3. Postural instability evolution and SSQ scores for the two rotational (yaw) motion levels for the Experiment 1

Experiment 2

In a second experiment, the protocol of experiment 1 has been applied to two other display systems: Renault's P3I CAVE and a HMD (Oculus Rift DK2). Renault P3I (Immersive and Intuitive Integration Platform) CAVE, a 4-sided virtual reality room powered by 4 ultra-short throw 1080p video projectors (Panasonic PT-DZ870) in a direct projection setup, with active stereoscopy (Volfoni active 3D glasses) ; and the well-known Oculus Rift DK2 (resolution of 960 x 1080 per eye). While the Oculus rift offers a 110° field of view, the CAVE offers a potentially full field of view. However, the frame design of stereo glasses might partially mask peripheral vision.
Simulation was run in both cases with SCANeR Studio © driving simulation software [11]. We used the same PCs for both systems: HP Z820 Workstations equipped with Intel Xeon CPU E5-2643 v2 processors (3.5 GHz), 32 Gbytes RAM, Nvidia Quadro K6000 graphic cards and Windows 7 (64 bits).
With both systems, participants sat on a real car seat and the sound of the engine was rendered with 2 speakers. They were inside a virtual Renault Scenic cockpit which steering wheel and dashboard were piloted by the simulation scenario.

Results

24 volunteer subjects have been recruited for the experiment: 12 for the longitudinal motion and 12 for the rotational motion. Each participant had to drive 4 times on 4 separate days, corresponding to the 4 different conditions: 2 levels of stimulus x 2 display systems (CAVE or HMD).
Results of our experiments confirm previously reported simulation sickness effects when experimenting strong rotational movement in virtual environments, often observed when navigation using CAVE or HMD systems. These results seem very similar between CAVEs of different characteristics and more surprisingly in comparison with HMDs.

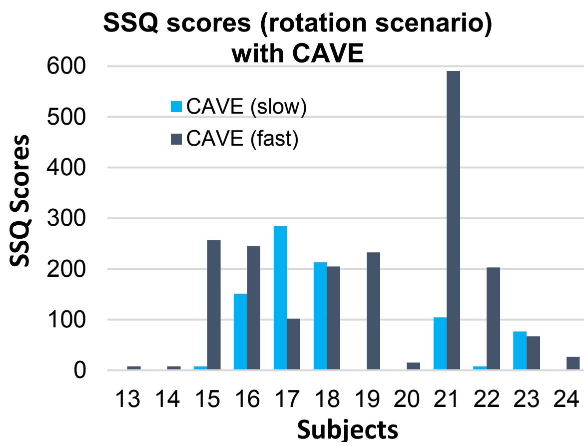


Figure 4. Individual SSQ scores for CAVE display with the two rotational (yaw) motion levels in Experiment 2

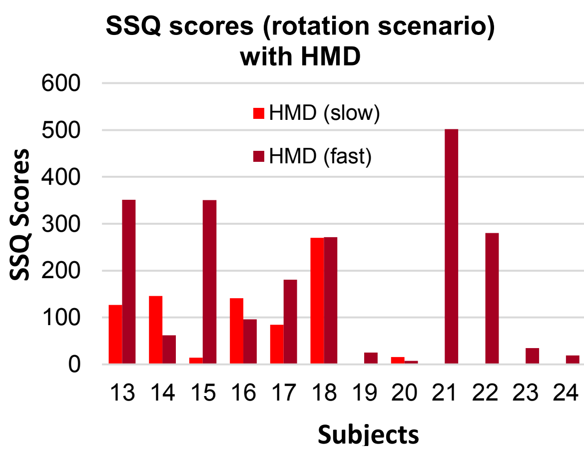


Figure 5. Individual SSQ scores for HMD display with the two rotational (yaw) motion levels in Experiment 2

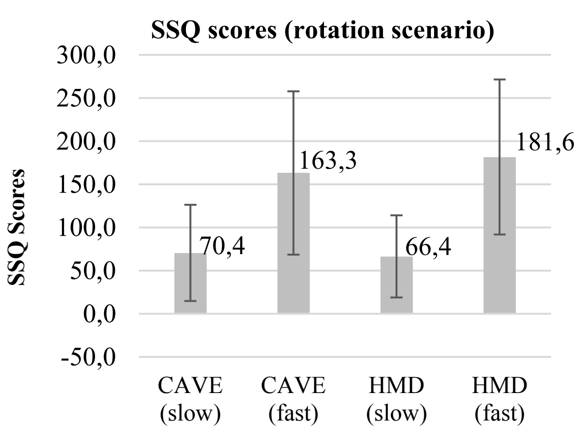


Figure 6. SSQ scores for both displays with the two rotational (yaw) levels: 5.8 °/s and 2 °/s² for the "slow" condition – 19.3 °/s and 13 °/s² for "fast" condition in Experiment 2.

Further work is planned to extend results to other simulation situations, i.e. in interactive driving and nomad device driven situations as well as other virtual environment display characteristics, i.e. other HMDs.

Experiment 3

Head Lock

In order to mitigate the problem of cybersickness that may appear during virtual displacements, we developed *Head Lock,* a locomotion technique that attempts to optimize rotations and which can easily be combined with any other technique of translation movement [9]. We seek to optimize the rotations because it is the part of displacement that most affects the simulator sickness [14]. Figure 7 depicts the different steps of the metaphor. From the normal situation (Figure 7.a), closing one eye insistently will bind the environment to the user's head (Figure 7.b). Then when he/she rotates the head while keeping the eye closed, the 3D scene will accompany (Figure 7.c). During this rotation, the picture seems frozen to the user. Finally, the user simply open his/her eye (Figure 7.d) and can look around normally.

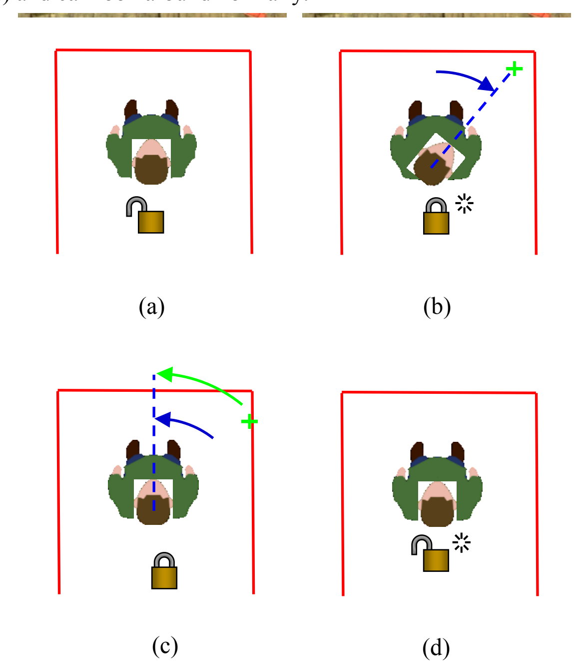


Figure 7. Operating steps of Head Lock

Unlike other methods of rotation, the user does not see the rotation. He is active in performing and no longer passively endure it as when pushing a navigation device, such a joystick. Since the eyelid is directly related to the body part which rotates i.e. the head, we believe that this mechanism provides kinesthetic feedback necessary to improve the sense of presence and to reduce simulator sickness. One can see our technique as an extension of *Grabbing the air* [4] in which the user does not use his hand to catch the air but his eyelid, jaw or eyebrow.

For this technique to work, an immersive display is needed with head-tracking along with an eye blink sensor. Glasses including eye tracking, active stereoscopy along with a marker for head-tracking are ideal but still rare and expensive on the market. It should be noted that the use of a gaze-tracking device would make it possible a particular implementation in which the user no longer bind to the environment to his head but his eyes. He might rotate only with the eyes or combining rotations of the head and eyes.

Pseudo AR Mode

As an alternative solution we added a grid for helping the perception of real sides of the CAVE (Figure 8), in order to generate a pseudo AR mode, where VR rotations are carried out while keeping fixed outside world visual references. We believe that this fixed reference can help the user to understand the rotation he performs [19]. Several studies have suggested that a fixed reference in the user's field of view helped to mitigate the simulator sickness like a cockpit in a flight simulator, a vehicle passenger in a car simulator and even more recently, a virtual nose for the use of a virtual reality headset[25].

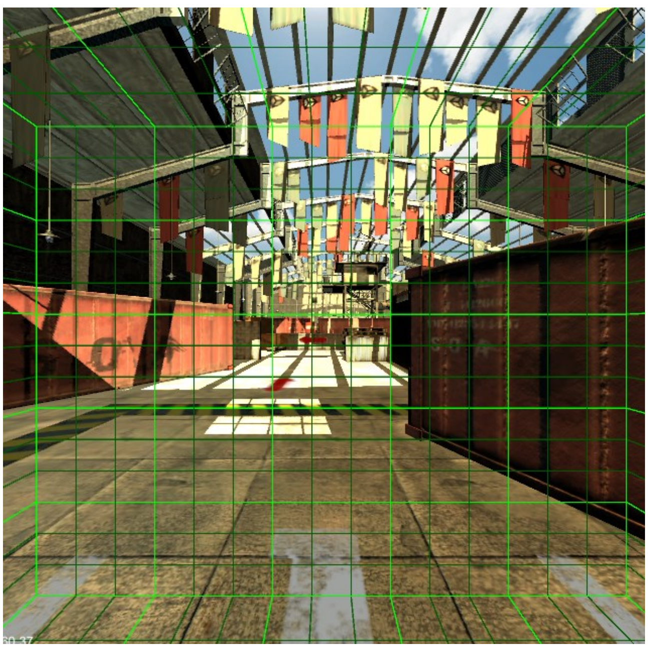


Figure 8. The grid

Evaluation

To evaluate user comfort, cyber-sickness and navigation effectiveness, an evaluation experiment was carried out with 31 participants, measuring postural stability and collecting SSQ values for motion sickness. The aim of this experiment was to benchmark our new navigation technique. We compared it with the classical first person navigation with controller. For the purpose of the experiment, we choose the regular first person navigation technique with joypad for translations of *Head Lock*, also a button was used to trigger the lock for practical reasons.

The experiment was conducted in Renault's development platform P2I (Immersive Integration Platform), a 4-sided CAVE (3 walls and the floor) measuring 3.3 m wide × 3.3 m long × 2.5 m high in a direct projection setup. Each screen uses a mainstream short-range ACER XGA (1024x768) video projector running at 60Hz per eye. An XBox 360 controller was used for the different navigation techniques. A stabilometric platform for measuring postural stability was used to measure the performance of the navigation techniques from a cybersickness perspective. For the purpose of the experiment, a scene was built with free 3D content from the internet. This is a fictive hangar (65 m × 35 m) with realistic distances, sizes. Obstacles were scattered in the scene to define a route, and red arrows were placed on the floor and walls to guide the participant.

Results

The following abbreviations were used for the different modalities:

- J, the controller based first person navigation technique (rotation with a joystick);
- H, the controller based locomotion technique Head Lock (rotation with the head);

We were particularly interested in postural stability as its variation is supposedly correlated to cybersickness [5, 15]. We compared the increase in ratio of our postural stability metric. Post-hoc comparisons were performed using Wilcoxon signed-rank tests with a threshold of 0.05 for significance. On the overall population, H induced less postural instability than J with a highly significant difference ($p = 0.0013 < 0.01$).

In addition to these data, the simulator sickness questionnaire (SSQ) was completed by the subjects before and after the experiment for each modality. The difference in SSQ scores was our indicator to quantify the cybersickness induced by our experiment. On the overall population, H induced less discomfort than J with a highly significant difference ($p = 0.0085 < 0.01$). We observe that those different metric for cybersickness show similar results.

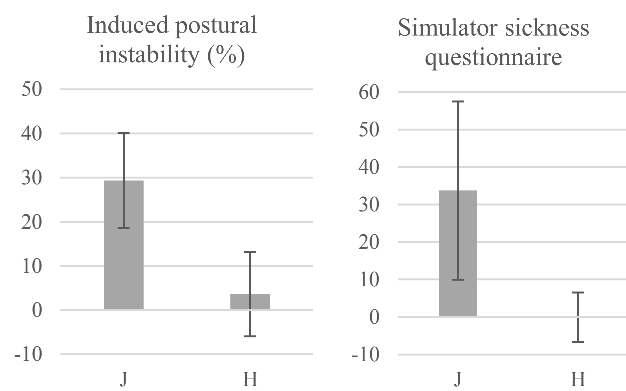


Figure 9. Different metric for cybersickness which show similar results

A presence questionnaire was also completed after each session. We notice very highly significant differences between the two techniques ($p = 0.0000018$). J gets the best sense of presence score. In addition to these data, a feedback questionnaire was completed by subjects after each modality. To the question "How intuitive is the movement?" and on a scale of 1: *Not intuitive* to 7: *Very intuitive* including 4: *Fairly intuitive*, results supports the J modality. J is rated as the most intuitive with a very highly significant difference with H ($p = 0.000018$).

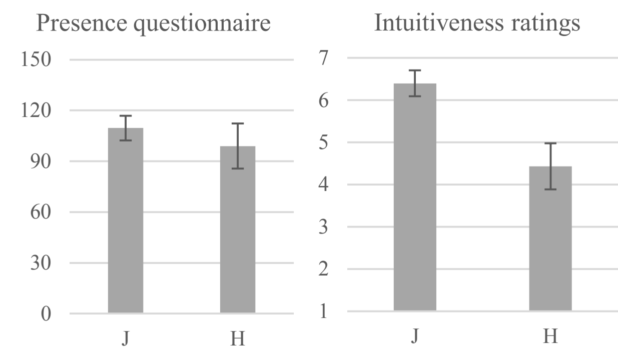


Figure 10. Different metric for cybersickness which show similar results

Discussion

With the advent of state of the art virtual reality technology, navigation in virtual environment without inducing motion sickness is becoming a major challenge. Previous studies and recently proposed technics are already advancing a number of different ways to achieve cybersickness free displacement or at least with the promise of reducing them while navigating in virtual environments, mostly using HMDs. Fernandes et al. propose for example to reduce the *field of view* (FOV) of visualization, reducing the immersion level and thus visuo-vestibular discrepancies [8]. The undesirable drawback is the reduced immersion, due to the reduced FOV and the potential impact on scene fidelity. Loomis and Knapp report for example perceptual differences when comparing virtual and real environments, showing that distance perception is undervalued, meaning objects in virtual environment are perceived to be larger than in real conditions and furthermore the smaller the field of view, the larger the misrepresentation will be [17]. These results are coherent with those observed in the real environment with different fields of view [1], though the issue stays open and in intense discussion concerning the virtual environment [16].

Another way to reduce the immersion level may be to *blur* scene image while navigating. Again, in addition to the reduced immersion level, previous studies show that the overall luminosity and visual scene quality in the observed real world environment may influence distance perception [6, 13].

An efficient way to avoid motion sickness is to avoid continuous displacement while navigating, for example with *teleportation* of the subject. Cloudhead games has proposed such a technics (cinematic or precision blink), completed with some other astuteness (volume blink) for an efficient use of the available space for subject navigation [27]. Another comparable technique is *redirected walking* [26], which allows to modify in real time in a non-perceivable or at least not disturbing way subject navigation in order to stay in the available subject space. Nevertheless, for a number of situations, including driving a car or any other context where a realistic displacement is required all these solutions are not applicable.

Our proposed technic, with a first *Headlock* implementation, is using the role of stable visual reference, used by the observer to avoid motion sickness [22]. Previous tentative were already used to insert in the displayed environment such visual references, but with limited efficiency [25]. If *Headlock* was proved efficient in navigation, it needs to be integrated in a usable intuitive navigation interface. Such a development is under way, integrated in a body/head directed navigation direction, operated by the subject.

Conclusion

In several experiences we could show that if VR induced sickness effects were relatively weak for longitudinal motions, strong rotations (high rotational acceleration) may cause strong cybersickness effects. These effects were found to be similar in CAVE and Head Mounted Displayed environments. To avoid these rotational effects, limiting the everyday use of VR systems, we proposed new navigation techniques as a major step for VRISE reduction. With *Head Lock*, rotational cybersickness effects are dramatically reduced or suppressed as we believe it eliminates optic flow and thus the illusion of self-motion. A grid underlying the edges of the CAVE and playing the role of a fixed reference strongly helps the user to understand the rotation he performs, generating a *Pseudo AR Mode* of displacement.

The presented Headlock technic radically reduces cybersickness, as shown by experimental results. The drawback is that specific actions are needed to perform it, which can be perceived as unnatural. In comparison with previous work, we provided tools to enhance navigation technics for CAVEs, but still HMD compliant. Unlike teleportation based techniques which can reduce VRISE, our metaphors are not disorienting and keep the VR experiment during navigation immersive. Also, unlike walking-based techniques which are effective for cybersickness reduction for short distances, the user may remain static and don't have to readjust his position when he is too close to a wall.

Future works will test the underlying VRISE reduction mechanisms with body/head directed navigation, currently under development.

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Florent Colombet is a research engineer at Renault, VR and Driving Simulation Center. He obtained his PhD in Informatics in 2010 on speed perception rendering in driving simulation. His main research topics are motion sickness and motion rendering in driving simulation and virtual reality. He is also a founder of the Driving Simulation Association.

Paul George obtained his PhD in Informatics in 2016 at Arts et Métiers ParisTech on Immersive interaction for digital project review. He is now working for Renault as a Research Engineer. His research topics are virtual reality and cybersickness.