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COM2018-2514

Motion Sickness in VR Learning Environments

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This paper should be cited as follows:

Lecon, C., (2018). **"Motion Sickness in VR Learning Environments",** Athens: ATINER'S Conference Paper Series, No: **COM2018-2514.**

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URL Conference Papers Series: www.atiner.gr/papers.htm

ISSN: 2241-2891
29/08/2018

Motion Sickness in VR Learning Environments

Carsten Lecon

Abstract

Virtual 3D worlds are not only used for the visualization of complex learning matter, but get increasing importance in learning environments. Students for example act as avatars in an artificially generated world, in which they learn, develop, and present similarly. However, in our 3D lectures some of the learners suffered from motion sickness, an affect that is already known in computer games and similar uses. For example, in our project 'Software Explorer' we use a virtual 3D world for visualizing complex software structures. When working in the 3D room, the students are asked to do some tasks like searching classes or look for the connections between packages. This is done by pointing to items with a 'laser pointer', or by moving through the virtual world. In concluding evaluations, some students felt some indisposition – like the real motion sickness in a car or on a ship; a few students even had to pause acting in the virtual room. In our project 'Kinetosis' (motion sickness) we will examine the causes and the indications of a beginning motion sickness. In order to identify the triggers, we implement appropriate 3D worlds as test settings, for example buildings, computer games, or a virtual rollercoaster. In these settings, different parameters are tested, for example by adjusting frame rate, speed, acceleration, rotation, etc. We then measure resulting effects in the person´s movement (via motion capture, video), eye movement (via eye tracking), body parameters (sweat, temperature, heart rate …), etc. We hope to confirm and extend our hypotheses of how to minimize the user´s motion sickness like behavioural changes of the person (e.g. 'don´t go backwards in a 3D room') or technical changes of the environment (e.g. adapting the frame rate, visual and acoustic diversion, tools for controlled motion like teleport …).

Keywords: Experimental Setting, Kinetosis, Motion Sickness, VR Learning.

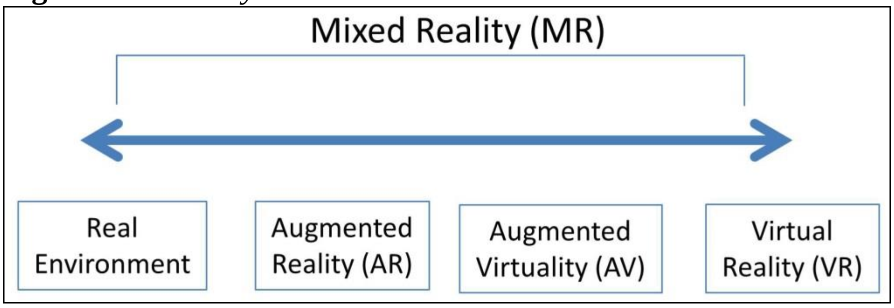
Acknowledgments: Part of the work is funded through the 'HUMUS' Program (2018) of the Federal State of Baden Wuerttemberg (Germany). The author would like to thank Alexandre Matic for the preliminary work (seminar paper, Master´s program), as well as Markus Herkersdorf (TriCAT GmbH), Camil Pogolski, Fabian Deuser, Hannah Schieber, Benjamin Engel, and Lukas Schneider (students) for fruitful discussions and helpful hints.

Introduction

In order to provide training as realistic as possible, the enrichment of the real environment by synthesised additional information is very helpful – and possible, because the hardware, which is necessary for this, is available.

This kind of enrichment is named 'mixed reality'. The level of the artificial assistance can be described by a spectrum ('Virtuality Continuum') like in Figure 1, which is taken from the work of Milgram and Kishono (Milgram and Kishono, 1994), where all combination of the real world with virtual elements are depicted.

Figure 1. *Virtuality Continuum*



We will shortly describe the characteristics of these combinations:

- *Augmented Reality*: Real environment, in which single elements are superposed. One example is information shown on the windscreen of a car, or the completion of the ancient ruin in the display of a smartphone.
- *Augmented Virtuality*: A predominant virtual environment partly enriched with real parts. One example is a virtual world enriched with video streams of real persons. In addition, the tracking of real persons controlling the avatars in the virtual world falls under this label. The so-called 'Mixed Reality' head mounted display –like the 'Lenovo Explorer'[1] – is actually an 'Augmented Virtuality head mounted display: the user sees a virtual world which, an image of the real world can be superposed by cameras.
- *Virtual Reality*: A virtual reality without any real components.

These forms of mixed reality play a more and more important role also in (e-) learning scenarios, for example at our university. However, one problem is the motion sickness, which can affect the learning environment negatively.

The motion sickness, which is the focus in this work, refers mainly to the Virtual Reality (and partly to the Augmented Virtuality).

At this point there are different terms of motion sickness in use (see Previc, 2018; he is talking about visually induced motion sickness, VIMS]:

[1]https://www3.lenovo.com/de/de/lenovo-explorer/

- VIMS in virtual environment: cyber sickness
- VIMS during games: gaming sickness
- VIMS in driving or flight simulators: simulator sickness

In addition, the medical term ‘kinetosis’ well be used in this context. In this paper, we will summarize all kinds of health complaints when acting in a virtual world to ‘motion sicknesses.

In the following we will shortly describe the virtual presence, which is an important aspect of VR environments (See chapter below). In the Methodology chapter we define motion sickness, the causes, symptoms, and counteractions and some implications to our existing VR projects. Our research project for investigation motion sickness is described in the Methology chapter.

Virtual Presence

The test environments for the examination of motion sickness are virtual 3D worlds. Theses worlds can simulate the real world, especially by the own virtual presence, so that the user feels the virtual world as the actual learning or working environment (‘immersion’).

Virtual 3D rooms offer – because of the immersion – a very intensive experience. In Schuemie et al. (2001) there are depicted six explanations of presence: Social richness, realism, transportation, immersion, social actor with medium, medium as social actor.

We could already perceive this effect in several student projects: As an addition to the traditional classroom teaching at our university (in the sense of ‘VR learning’), we use Virtual Reality in several projects. For example:

- ‘Virtual Blended Learning’ (Lecon, and Herkersdorf, 2014): At our university, most of the students are not living at the university town but in surrounding villages. In order to work together – for group work – the students can use the virtual room. The students are represented as avatars; a student´s presence in the (same) room is visible. The students can work from home and can use suitable collaboration tools, for example an interactive whiteboard, a media wall (slides, internet sites …), a remote desktop, visualization and manipulation of 3D objects. One task was the programming of a virtual robot, which should collect (virtual) stones and moves them to a target area. The program code is visible on the media wall, and by click on a button, the robot moves according to the programmed algorithm.
- ‘Software Explorer’ (Oberhauser, and Lecon, 2017): Not only in lectures, but also in companies, the complex of software projects is increasing. For example, Google has about two billion lines of code, which can easily be very confusing. The typical IDEs (Integrated Development Environments) are well suited to write software, but are often not helpful to understand the complex structure of the software – for example by a suitable visualization. The Unified Modelling Language (UML) as a 2D representation comes here to a

limit. In order to address these problems, a 3D approach is proposed; in this way, we have one more dimension to place the parts of the software. Moving through the virtual world is much better when using a head mounted display (concretely HTC Vive, Oculus Rift, and Google Cardboard).

In a VR environment, the user interface differs from the interface in a non-VR application. In our first prototypes of the 'Software Explorer', we used the traditional user interface: (pull down menus, text fields, etc.). However, in the VR mode, this is not adequate, for example, it is very difficult, to point to a specific menu entry with a laser pointer. The fundamental interactions in a VR environment are the navigation of the user in the 3D world and the selection and manipulation of objects. The navigation is done via conventional input devices (mouse, keyboard) or particular input devices for VR: 3D mouse, panning controller, tracking sensors.

The selection and manipulation in the virtual room is more different, because the simple selection on objects by a mouse click is not possible/ impracticable. One alternative in the virtual room is the touching of the objects with specific VR input devices, for example with a 3D cursor as a virtual hand. Alternatively, a selection is done when eyes focus the desired object for some time. Some interactions are possible only in VR, for example to interact directly with objects by 'touching' these with the hands (which are tracked by the VR system). One can use the entire body or only arms, hand and head (when sitting). For example, in a currently developing VR game at our university, the player can use the hand to operate with a crank in order to open a floodgate (Figure 2, left side) or to move a lever (Figure 2, right side).

Figure 2. *VR Interactions in a Computer Game*

In the project 'Software Explorer", the transition from non-VR to VR was well received by the students. However, in evaluation sessions of the project, some students had to interrupt their tasks because of indications of motion sickness (dizziness, headache, slight nausea).

In the 'free locomotion' mode of a VR computer game (student´s project), some students noticed motion sickness, especially when the frame rate was slower than recommended. Even the integration of black pictures (see below, subchapter Counteractions) was rather irritating. Instead, the students would rather have the possibility to teleport to certain places inside the computer game.

Apart from these virtual applications (Software Explorer, VR computer games), simulations of the real life should be taken into account. For example, motion sickness can arise at autonomous driving: While the car is driving autonomously, passengers in the car are often sitting sideways or backwards, which can cause travel sickness (= motion sickness). This concerns in particular persons, which usually are sitting behind the steering wheel always. This could be a serious problem for the provider of autonomous cars, because now the driver is confronted with this unfamiliar effect (travel sickness). The developer of autonomous cars has to take these effects into account.

We will try to simulate such negative effects of motion sickness in a virtual environment. Our goal is:

- We will create simulations as realistic as possible. If possible, we replicate the selected tests in real environments.
- We will detect (first) indications of a beginning motion sickness by measuring appropriate parameters of the test person (see subchapter Apparatus).
- We try to find out ways to minimize the motion sickness (based on existing and new approaches; see chapter Motion Sickness: Causes, Symptoms, and Counteractions).

In general, virtual 3D worlds are very good for testing and evaluation of motion sickness, because they can – in contrast to real environments – be arbitrarily configured, for example by constructing the 'optimal' environment and masking out distracting things, or by successively modifying the level of details. The movement of a person can be affected by adjusting speed, acceleration, rotation, field of vision, etc.

In the following, we will show the causes of motion sickness (chapter Motion Sickness: Causes, Symptoms, and Counteractions) and existing possibilities to minimize motion sickness. In the Methology Chapter we will point out our test environment and the hypothesis, which will we be proved or disproved by our experiments.

Motion Sickness: Causes, Symptoms, and Counteractions

Causes of Motion Sickness

The causes of the occurrence of motion sickness are not yet fully understood. However, there exist several explanation attempts. Mostly, the explanation of motion sickness is due to the major organs of the vestibular system: semi-circular canals and otoliths. In general, the discrepancy between perceived locomotion and physical steadiness can cause sickness (Hettinger and Riccio, 1992). The vestibular organ is responsible for the sense of balance. Both he macula organs (macula saccule and macula utriculi) in the inner ear are orthogonal. Is the body idle (is not moving), the macula saccule is vertical, and the macula utriculi is horizontal. These organs notify the linear acceleration. The inner ear uses three semi-circular canals (lat. *Ductus semicirularis*) for the notifying of the angular acceleration. Depending on the movement, one canal will be stimulated.

More specifically, typical theories to explain motion sickness can be found in the meta-study of Previc (Previc, 2018):

- *Sensory conflict theory*: This is the most widely held theory. It posits that a variety of sensory conflicts create nausea and other symptoms (see subchapter Symptoms of Motion Sickness). The most important conflict is the Coriolis (cross-coupling) effect that occurs after a head tilt during sustained rotation. For example, this effect can occur, if there exits an insufficient accordance between the visual information of the vision system and information of movement of the (simulator) platform.
- *Postural instability*: Conditions of postural instability are especially nauseogenic (Ricco and Stoffregen, 1991). The motion sickness is not caused by a sensor conflict, but by a long lasting instability of the posture control. An abrupt or heavy changing of the environment, so that the posture control will be lost, can cause the effect. For example, this occurs if a person slips on the ice; or the above (example at sensory conflict theory) situation occurs.
- *Subjective verticular mismatch*: This theory argues that only conflicts that lead to a misperception of the vertical relative to previous experience create motion sickness.
- *Poison theory*: Unusual movements of the head indicate that a poison had been ingested and, therefore, are designed to induce the vomiting in response to some vestibular lesions affect toxins. However, the effects of such lesions were selective for mainly centrally acting substances (e.g., nicotine, dopamine) that may interact with vestibular responses centrally [Money and Lackner, Cheung, 1996).

Beside these theories, there exists the *Velocity storage theory* (Laurens and Angelaki, 2011), and the *Otolith asymmetry theory* (Baumgarten and Thumler, 1997).

Symptoms of Motion Sickness

Llorach, Evans, and Blat describe several factors in VR and simulator environments, which can be a trigger for VR sickness (Llorach et al., 2014). The factors are extensive duration, field of vision (FOV), interpupillary distance, position tracking error, refresh rate, lag, and scene complexity. Neukum and Grattenthaler divide these factors into three categories (Neukum and Grattenthaler, 2006):

- *Individual factors*: Personal information like age, gender, experience with simulations/VR environments, etc.
- *Simulator factors*: Calibration, field of vision, content of the scenario, frame rate, flickering of objects, brightness, screen resolution, and many others.
- *Task factors*: degree of control mechanism, head-movements, height above ground, kind of movement, and many others.

Counteractions

We will classify the methods to minimize motion sickness according to the categories of the above subchapter.

Individual Factors

In general, the occurrence of motion sickness decreases with increasing VR experience. This means, one can accustom to acting in a virtual world – to a certain extent. It is important to stop immediately a VR session, if one feels indisposition. Even the user manual of the HTC Vive says: 'Stop using Vive if you experience discomfort.'

Instead of moving through the virtual world, teleportation possibilities should be available.

The person should be in a healthy condition. Fatigue or diseases increase the possibility of a motion sickness. Children under 13 years should not use VR applications – at best with parental control. Interestingly, it had been suggested that motion sickness decrease with a growing age (Reason and Brand, 1975). And children under up to two years feel no motion sickness (apart from the fact, that they should not use VR anyway).

Simulator Factors

In order to avoid motion sickness, an adequate frame rate is important. A frame rate of 45 Hz for each eye is recommended. For example, HTC Vive, as well Oculus Rift use at least 90 Hz (for both eyes) for the rendering. This can only be achieved, if the computer hardware is equipped accordingly, regarding in particular the processor, the graphic card and the main memory. The minimum requirement for the processor is an Intel Core i5-4690K, a graphic card at a minimum NVIDIA GeForce GTX 970 or AMD Radeon RX480 or similar should be used. The capacity of the main memory should be at least 8 GB (DDR3). An upgrade of the processor, graphic card (for example a second one) and main memory leads to a better frame rate (especially if the movement in the VR world is very complex).

It should not be forgotten that the software can influence the rendering of the virtual world. One potential bottleneck is the update method, with is called very often (in order to archive the recommended frame rate of 90 Hz), even if this method contains complex algorithms. At worst, so called frame drops result –with in turn increases the risk of motion sickness.

Flickering is a trigger of motion sickness. Low hardware equipment or a missing Anti-Aliasing can cause flickering: If the user is moving, objects are flickering – the so called 'staircase effect'. In many graphic tools and game engines, the Anti-Aliasing effect can be set.

Subtle particle system effects like rain, snow, falling leaves, etc. seem to reduce motion sickness. Also peripheral visual effects have been successfully used (Buhler et al., 2018).

If the pupil distance is too low or too large, both the pictures, which are generated from the VR glasses, are not matched, so that a blurred overall picture appears. Most of the head mounted displays allow the adjustment of the individual pupil distance.

If the latency is too low, motion sickness can result (see also Waltemate et al., 2016). This applies to the movements of the user, for example head movement, controller movement or moving of an avatar in the virtual environment. The latency should be less than 20 milliseconds. Actually, this is achieved by the HTV Vive (less than 11 milliseconds) and the Oculus Rift (about 13 milliseconds), slightly slowler is the Playstation VR (18 milliseconds). In this case, too, the efficiency of the code plays a significant role.

<u>Task Factors</u>

Task factors relate to solving problems (duration, kind of movement under VR).

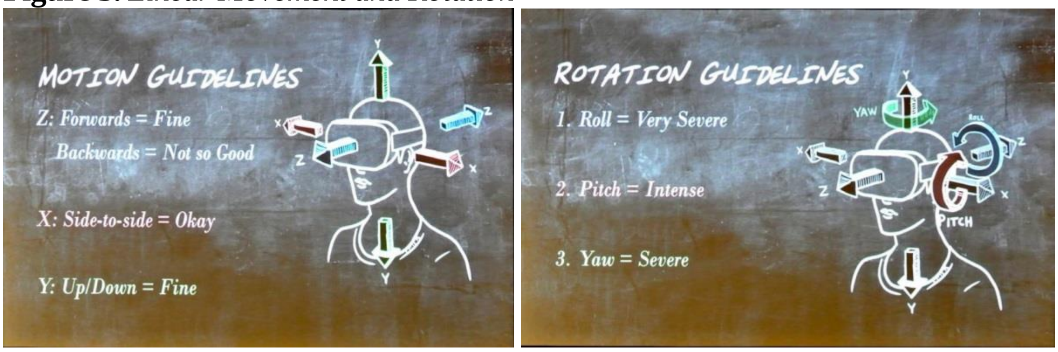
Especially, if a user is unexperienced with regard to VR applications, she or he should take several breaks – initially every 30 to 45 minutes. The duration of a break depends on obvious indications of motion sickness; if symptoms are recognizable, the break should be longer. Of course, on the occurrence of symptoms of motion sickness during a session, the session has to stop immediately; otherwise, it is possible, that the illness will stay for a long time (and leading to negative memories of the experience with VR).

Acting in a virtual world can be done while sitting or standing. If the movement in the virtual world is intensive (roller coaster as an example), a sitting position is of advantage. If the movement in the virtual world is restricted to a stationary room, real walking (in the real room) is possible. At the beginning, one should start with VR experiences without movements. In the game ‘I Expect You To Die’ (Schell Games; Patton, 2018) all interaction takes place in a sitting position. Not the player is moving to the object, the objects move to the player.

Slow user movements upwards or downwards are not critical. However, movements to the sides or backwards are critical. On acceleration – independent of the direction –, the body reacts very sensitive.

Rotations are critical. Due to minimize motion sickness, sometimes black pictures are integrated in a rotation animation, similar to a teleportation. Sometimes, this effect is combined with a rotation, where the viewing direction is successively changed in different degree adjustments, for example 0°, 15°, 30°, 45°, etc. In Figure 3, the different expressions of optional motion sickness for linear (left side) and rotation (right side) movements are illustrated.

Figure 3. *Linear Movement and Rotation*[2]



[2]Source: https://www.heise.de/newsticker/meldung/VR-Brille-Oculus-Rift-Hilfe-gegen-die-Simulator krankheit-3157108.html?hg=1&hgi=0&hgf=false.

Alternative Possibilities

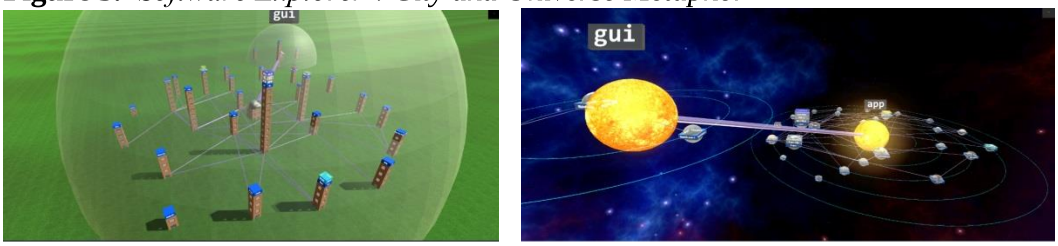
For the ‘normal’ travel sickness there exist some established methods, which can be transferred to the (potentially) motion sickness in VR. Ginger can be taken purely, as a drink (Ginger Ale) or drop (maximal 2 to 4 gram per day).

Another way is the use of an acupressure wristband.

Implications for the Project ‘Software Explorer’

In our project ‘Software Explorer’ (see above), we use two 3D metaphors for the visualization of complex software structures: a city and a universe model (see Figure 3).

Figure 3. *‘Software Explorer’: City and Universe Metaphor*



We have performed evaluations with our students. They had to do some tasks (searching for the biggest class, connections …). The appearance of both metaphors – city and universe – is offered in different order. The students could move in a certain section in the real room. The exploration in the virtual world could be done by going within the bounds (these are visible in the VR world and correspond to the bounds in the real world), by moving the head and by using the controller.

In general, the feedback was very positive. Some results are:

- The universe metaphor was more interesting (‘cool’), but the orientation in the city metaphor was better – apparently due to the visible ground.
- Few students mentioned dizziness, mild headache, very few students had mild nausea.

Based on the above findings and the evaluation, the following appropriate measures result:

- Improvement of the Anti-Aliasing by the implementation of appropriate shaders[3].
- Fundamental revision of the update method (see above); complex routines are only called when necessary.

[3]*Shaders* are hard or software modules, which implement certain rendering effects at the 3D computer graphic.

- The virtual world itself should not move in horizontal direction automatically; only the explicit movement of the head of the person does the horizontal movement.

Methodology

In order to examine the characteristics of motion sickness and working out (further) counteractive measures, we install an experimental laboratory.

We hope that the results of the experiments are transferable to real life, for example when sitting in a (autonomous) car. The advantages of tests in a virtual environment are manifold: The persons are in a ‘benign’ environment, even mistakes lead not to physical damage (except of motion sickness…); the parameters of the virtual environment can arbitrarily adapted, including spatial environment, sound and movement parameters like speed, acceleration, rotation, etc. as well.

As the VR environment, we will use:

- VR computer game (developed within the scope of an ongoing student´s project).
- Minimalistic VR environment, in which some potential trigger of motion sickness can be activated/ deactivated, an adjustment of some parameters (speed/ acceleration of animations, frame rate, level of detail, skyline vs. no skyline, ground, …)
- Roller coaster (purchased), and similar VR sceneries

Even if the motion sickness in VR environment cannot be avoided completely, the advantages of VR often predominate: VR environments offer a massive additional value for working, learning and playing. S. Mammen. A. von Knote, and S. Edenhofer (Mammen et al., 2016) postulate that a certain amount of motion sickness is tolerable.

Hypothesis

In our experiments, we will examine (confirm or disprove) several hypothesis, for example:

- One can accustom oneself to acting in VR – with a reduction of motion sickness.
- Visual distraction minimizes the occurrence of motion sickness (videos, etc.).
- Auditory distraction minimizes the occurrence of motion sickness
    - Music (which kind of music: classical, rock, self-chosen music, etc.)
    - Noises
    - Spoken audio (audio book, …)
- Doing a specific task (private/ job matter) is a distraction which minimizes motion sickness.

- A stable reference point minimizes motion sickness. An actual example is the using of a 'Nasum Virtualis' (Whittinghall et al., 2015). Here it is propagated, that this will minimize motion sickness. Alternatively, in the above-mentioned VR game 'I Expect You To Die' (Patton, 2018) a cigarette and the brim of a hat are blended at s stable position to give orientation.
- There exists a difference between gender (male/female) and the age (younger/older than 50 years) regarding the incidence of motion sickness: The younger and the female persons are more prone to motion sickness.
- Subtle particle effects (snow, rain, etc. – see above) reduce motion sickness.
- The more a virtual 3D world is (clearly) artificial the likelier is the probability of feeling no (or less) motion sickness. The user identifies the virtual world as a simulation explicitly. However, the realism suffers, which excludes the simulation of real scenarios – like driving a car. On the other hand, in some serious games, lower level of details do does not matter.
- Traditional methods to minimize travel sickness (ginger, acupressure wristband) work also in VR.

Apparatus

In order to take into account as many as possible measurement values, we use a number of sensors/ sensor data, for example:

- Eye tracking: We will integrate an eye tracking apparatus inside the head mounted display. The viewing direction does not need to correspond to the orientation of the head mounted display.
- Video recording of the person´s in order to observe accompanying or conspicuous movements. These data have to be interpreted manually. In addition, we are currently thinking about using our motion capture system to interpret the movements of a person (semi-) automatically via a specific algorithm. In preliminary student works, the motion capture data was pre-processed, so that a simpler tracking and interpreting of the movements are possible.
- Bio parameters, for example the observation of body data (visible sweating, unsteady position, pulse rate, temperature, …)
- Test persons are encouraged to articulate their actual impressions and state of health.

Proceeded analysis could consist of recognizing force feedback and using a force plate. However, this apparatus is not yet available.

Evaluation

An intensive evaluation will be done. Mainly, we will recruit test persons from customers of our cooperation partner (which partly have taken part in VR trainings already) and from students of our university. Beside others, we will examine the occurrence of *SSQ* symptoms (SSQ: Simulator Sickness Questionnaire, (Kennedy et al., 1993), for example nausea, stomach (feel different), general malaise, eructation, sweating, increased salivation, stressed eyes, blurred vision, difficulty to see clearly, head pressure, tiredness, concentration difficulty, headache, dizziness (eyes open/ closed), balance problems. Also the proposals for the questionnaire *MSQ* (Motion Sickness Questionnaire, (Kennedy and Graybiel, 1965) will be considered.

Current Status

Currently, we have some VR applications –'Software Explorer' (see above), VR computer games, rollercoasters (purchased) – designed for HTC Vive and Oculus Rift. In the context of seminar work, theoretical foundations of motion sickness (causes and preliminary counteractions) were worked out. Currently we are looking for an eye tracking system for a head mounted display. The motion capture system is ready for operation. The developing of a customizable VR environment is also in progress. Additionally, our partner company will be able to provide a large group of persons for the evaluations. In the context of current student´s projects the preparation of experiments with eye tracking is running. In addition, the programming of a simple VR application will be built in order to easily and quickly test some VR effects.

Conclusions

More and more, virtual 3D worlds play an important role especially in engineering, training/learning (for example serious games) and computer games. Because of the decreasing costs of head mounted display, a total immersion is now available also in the consumer area. However, the danger of kinetosis in the virtual (motion sickness) room is often ignored. In our experiments, we will offer instruments to test existing 3D applications as well as giving hints to avoid typical trigger for motion sickness. It is planned to build an adaptable environment to examine most of our hypotheses. Based on existing VR projects, we have already found some pitfalls (regarding potential motion sickness), these results we will extend.

In addition two student's works (four persons) have currently the focus on motion sickness:

- Construction of an adaptable VR world, so that as many hypotheses as possible can be determined. For this, many configurations will be made possible (frame rate, kind of interaction, level of detail, field of view, and much more).
- Investigation of actual research on motion sickness. Evaluation of VR environments via eye tracking (integrated in a head mounted display), and eventually the use of motion capture.

Finally, a set of best practices and methods will result – at the best.

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