Motion Sickness Reduction for 6-DoF-Navigation in a Virtual Solar System

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Master Thesis

Hochschule Hannover
Faculty IV – Business and Computer Science
Course of Studies M. Sc. Applied Computer Sciences

February 18, 2021

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Declaration of Authorship

I hereby declare that this thesis, and the work presented in it are my own and has been generated by me as the result of my own original research. I confirm that:

1. Where I have consulted the published work of others, this is always clearly attributed.
2. Where I have quoted from the work of others, the source is always given. Except for such quotations, this thesis is entirely my own work.
3. I have acknowledged all main sources of help.
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Contents

1 Background and Related Work

While Virtual Reality technology has gained more and more traction over the recent years, 30% to 80% of users encounter some form of sickness symptoms during their exposure to virtual environments [1]. Additionally, these sickness symptoms can have lasting effects after the exposure as well [2]. The high number of affected users has led to cybersickness being one of, if not the biggest roadblock to a more widespread adoption of Virtual Reality Devices.

According to LaViola [2] the symptoms of exposure to virtual environments include:

- Eye strain
- Headache
- Pallor
- Sweating
- Dryness of mouth
- Fullness of stomach
- Disorientation
- Vertigo
- Nausea
- Vomiting.

Vertigo, in the case of VR-sickness particularly benign paroxysmal positional vertigo (BPPV), is a condition where the individual experiences a false sense of motion, or spinning, and objects or surroundings appear to swirl or move [3].

Several studies also found that severity of symptoms increases with longer exposure times to virtual environments [4, 5, 6]. However, some studies show that users can adapt, and overall sickness reduces with repeated exposure [7].

Throughout the study of these symptoms, several terms have been used to compound these sickness symptoms that appear to be similar to the symptoms of motion sickness. Initially, the term Simulator Sickness was used to describe motion sickness encountered during exposure to flight simulators [8]. The term originated from the assessment of military flight simulators [9]. While Simulator Sickness is still used in recent publications, the terms Cybersickness or VR Sickness are generally used to differentiate, and closer examine the side effects of virtual environments from simulator sickness [8, 10]. The term VR Sickness specifically is used in discussions and studies about sickness symptoms involving head-mounted displays (HMD) [11, 12]. This terminology is often used interchangeably across literature. The terms Cybersickness and VR Sickness will be used in this study, as Stanney, Kennedy, and Drexler [13] argue that, while sickness from virtual environments shares many of the symptoms also experienced during simulator sickness or motion sickness, the sickness profiles are different.

	Simulator sickness	**Sea sickness**	**Space sickness**	**Cybersickness**
Highest rating	Oculomotor	Nauseagenic	Nauseagenic	Disorientation
Middle rating	Nauseagenic	Oculomotor	Disorientation	Nauseagenic
Lowest rating	Disorientation	Disorientation	Oculomotor	Oculomotor

Table 1.1: Related conditions symptom profiles according to Rebenitsch and Owen [1].

According to Rebenitsch and Owen [1] cybersickness and other sickness symptoms similar to motion sickness are polysymptomatic (many symptoms) and polygenic (different manifestation for individuals) and therefore complex to understand and describe. To make the sickness and its symptoms easier to survey and examine, Kennedy et al. [9] categorize the symptoms listed above into three categories:

- Nauseagenic symptoms (dryness of mouth, fullness of stomach, nausea, etc.)
- Oculomotor sypmtoms (eye strain, headache, etc.)
- Disorientation symptoms (vertigo, dizziness, etc.)

The main arguments for the distinction between simulator sickness and cybersickness are that during cybersickness, disorientation symptoms rank highest and oculomotor symptoms rank lowest, while simulator sickness and traditional motion sickness usually have the inverted profile, where disorientation symptoms rank lowest [13].

Cybersickness can also occur without stimulation to the vestibular system, purely through visual cues, unlike motion and simulator sickness, where stimulation of the vestibular system is needed, but not visual stimulation [2]. Additionally, Stanney et al. [13] determined that cybersickness can be up to three times more severe than simulator sickness. Saredakis et al. [8] also note significantly higher average Simulator Sickness Questionnaire scores, although both mention, the scores and questionnaire were established with a focus on military flight simulators used by military personnel. While recently, the Simulator Sickness Questionnaire has been adopted to measure cybersickness in virtual environments, which might be the reason for the higher average scores [8].

1.1 Common causes of cybersickness

Over the recent years there have been several theories trying to explain the sickness symptoms experienced during extended exposure to virtual environments, especially since the commercialisation of head-mounded virtual reality devices. The most common Theories are the sensory conflict theory and the postural instability theory. Additionally, there are some theories that try to explain why sickness symptoms occur in virtual environments like the rest frame theory, and the vergence accommodation conflict theory.

1.1.1 Sensory conflict theory

The generally most accepted, and widespread theory is based on a sensory mismatch either between sensory systems of the body, or between sensory input and expectation given the perceived environment. Most commonly, a sensory conflict due to vection (the illusion of self movement while stationary) is argued to be the main cause of cybersickness [14, 15]. Although, other studies like Palmisano, Mursic, and Kim [16] suggest, that vection is neither the sole, nor primary source of sensory conflict. Sensory conflicts like vection can also occur outside virtual environments, for example when a person is in a stationary vehicle while an adjacent vehicle begins to move [2].

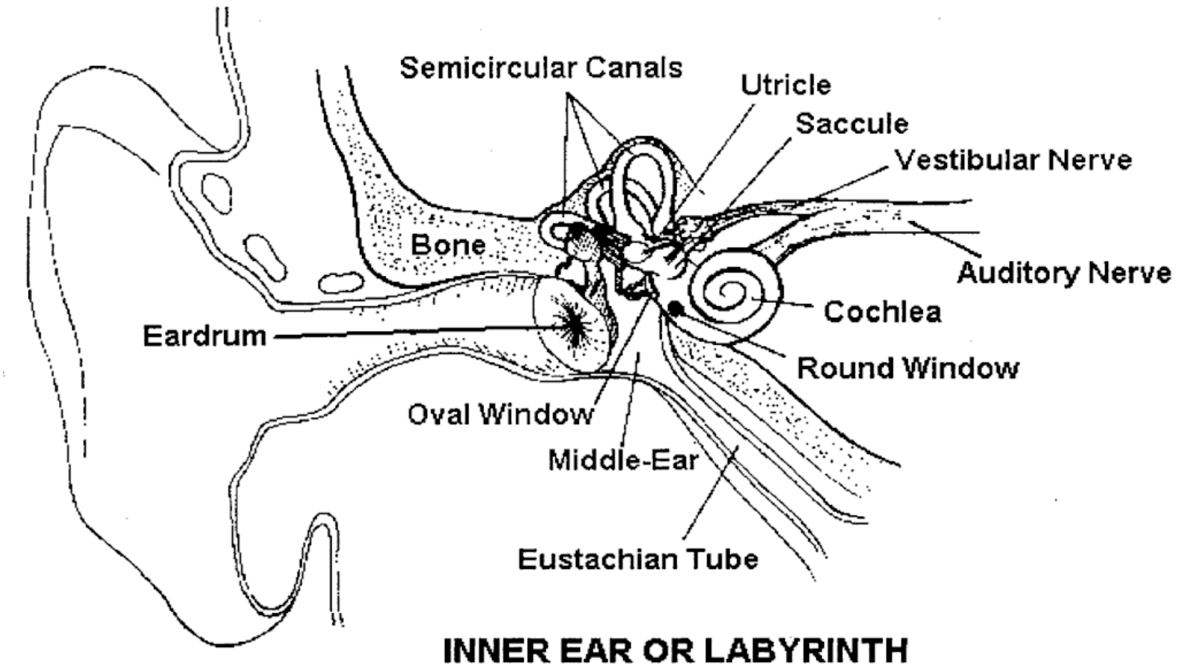

Figure 1.1: The components of the vestibular system [2].

Important for the sensory conflict theory are visual perception and the vestibular system, shown in Figure 1.1. The vestibular system consist of the Semicircular Canals to sense angular momentum, and the Utricle and Saccule to sense linear momentum. Together, the system functions to compensate for movement, stabilize vision, maintain head posture, and maintain balance [17]. In virtual environments, the sensory mismatch is usually between the visual system receiving optical flow patterns characteristic of self motion, while the vestibular system does not perceive these changes in motion. This sensory conflict lies at the root of simulator sickness and was identified early on, when Barrett and Thornton [18] noticed that subjects showed simulator sickness symptoms caused by conflict between the visual presentation of motion and the lack of corresponding vestibular sensation in their fixed-base simulators. Barrett and Thornton also noticed, that subjects only showed sickness symptoms when the simulator was in a perspective similar to driving a car, but showed no symptoms when viewing the car from outside, similar to driving a remote controlled car, as well as passengers showing more severe symptoms than drivers, indicating that involvement in motion is a factor in the occurrence of simulator sickness [19, 18].

The sensory conflict theory is the most popular theory to explain cybersickness, because it has a steadily growing amount of studies supporting it, and the theory is intuitive to understand [1, 19]. However, the theory has been criticised by several studies, because sensory conflict theory only states that sickness is preceded by a sensory conflict, but is unable to predict when cybersickness will occur, or how severe sickness symptoms will be [2, 1, 20].

1.1.2 Postural instability theory

Another theory for cybersickness symptoms is the postural instability theory proposed by Riccio and Stoffregen [21]. They found that motion sickness is preceded by periods of postural instability, where small uncontrolled movements and changes in the subjects centre of gravity occur, and the subject's ability to maintain postural stability is hindered [21, 22]. Stoffregen and Smart [23] translated the theory into three predictions:

- Experiences of motion sickness are always preceded by increases in postural instability.
- Experiences of motion sickness persist until postural stability is restored.
- People who are more naturally unstable are more likely to become motion sick during provocative simulation.

These predictions have been solidified and are supported by numerous studies on visually induced motion sickness [22]. Chardonnet, Mirzaei, and Merienne [24], as well as other studies propose to use the changes in range, variance, and frequency of the subject's centre of gravity as a measurement of postural sway. Based on the accessibility of devices to measure individual's centre of gravity, those measurements have found increasing popularity in studies to objectively measure subject's postural stability and indicate the potential onset of cybersickness symptoms [25]. A comparison between the

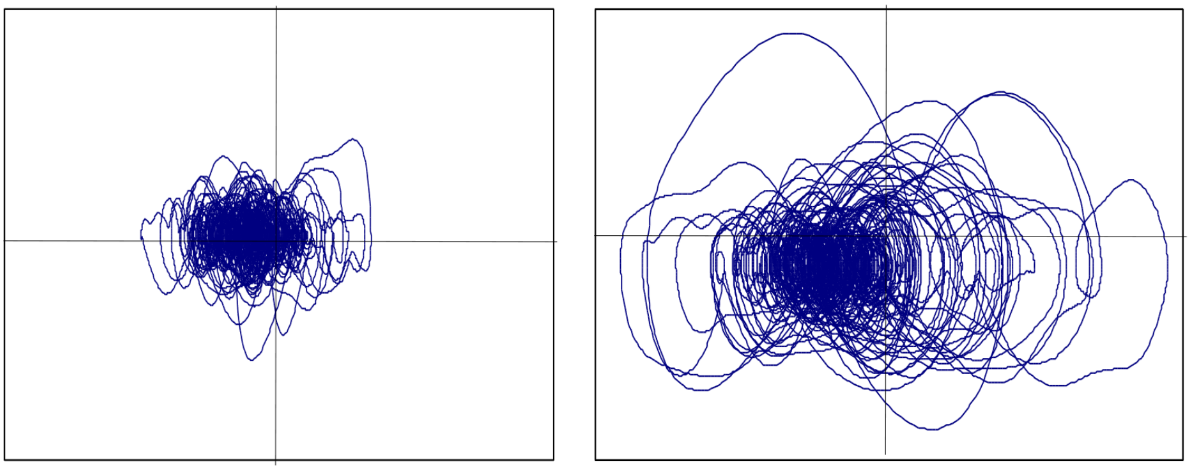

Figure 1.2: Comparison of phase portraits (position (in cm) vs. velocity (in cm/s)) for well (left) and sick (right) subjects in a dataset measuring postural stability [26].

natural postural sway of a subject compared to the postural sway when experiencing motion sickness is shown in Figure 1.2. The recent study by Lim et al. [25] successfully used postural stability measurements to train an algorithm to predict VR content's potential to induce cybersickness, as shown in Figure 1.3, based on the postural instability theory.

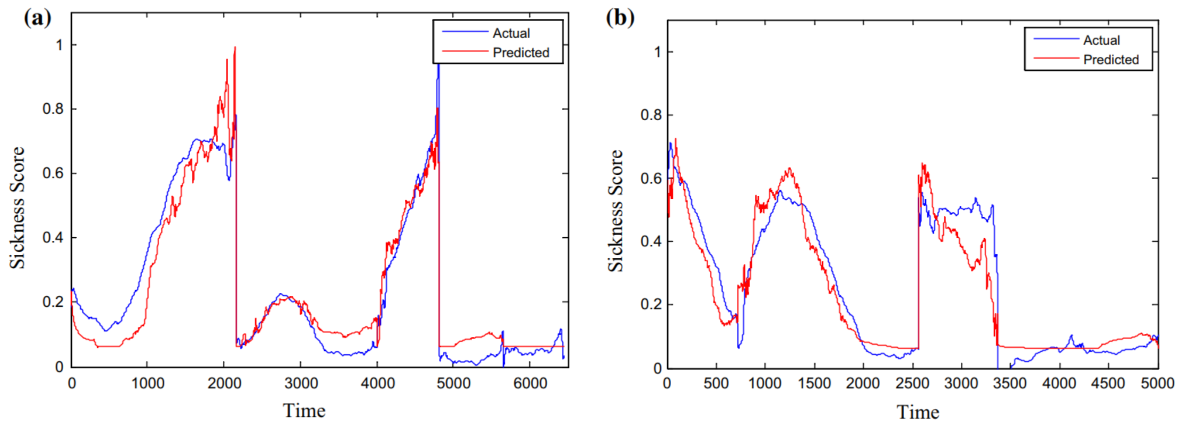

Figure 1.3: Actual sickness (blue) and predicted sickness (red) of (a) training and (b) testing set produced by the prediction algorithm by Lim et al. [25].

1.1.3 Other theories

Rest frame theory

Similar to sensory conflict theory, the rest frame theory argues that a mismatch in sensed gravitation and perceived up-direction is the cause for sickness symptoms [1]. The rest frame theory also shows

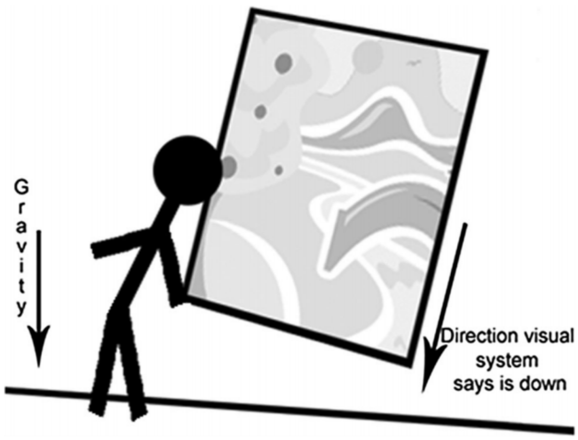

Figure 1.4: Example of sensory mismatch according to rest frame theory [1].

similarities to the postural instability theory, as the discrepancy between perceived up-direction and gravity leads to postural instability and following sickness symptoms [1]. An example of this sensory mismatch, and resulting postural instability is shown in Figure 1.4. The theory also supports the postural instability theory in situations where postural control is lessened, such as in seated positions where the individual's posture is stabilized. Several studies like Chang et al. [27], and Duh, Parker, and Furness [28] found, that superimposing some form of static frame of reference into the virtual environment significantly improves postural stability and reduces cybersickness symptoms.

Vergence-accommodation conflict theory

Another theory to explain cybersickness symptoms, especially oculomotor symptoms, is the vergence-accommodation conflict theory. Vergence is the simultaneous lateral movement of the eyes

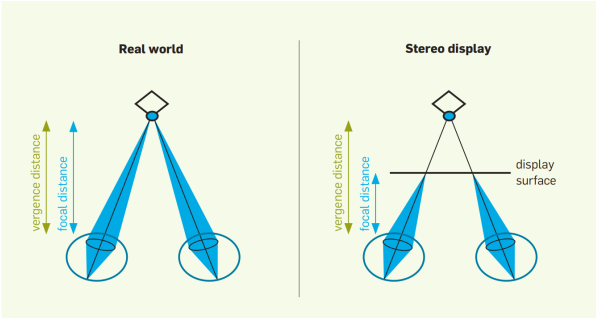

Figure 1.5: Difference between vergence and accomodation distance in the real world (left) and stereoscopic displays (right) [29].

when an individual's visual system is adjusting to objects at different distances [30]. Accommodation is the process of adjusting both eye's focal lengths, focusing on the perceived object [1]. In virtual environments, especially in head-mounted displays, images are presented at a fixed screen depth. This leads to conflict with real life expectations, as vergence and accommodation do not occur naturally at different distances like in stereoscopic displays [8], as shown in Figure 1.5. Kim, Kane, and Banks [30] noted that content with high levels of stimulation usually contain more changes in stimulus distance, and therefore variance of stimulus distance, and level of visual stimulation both increase visual discomfort and eye strain.

A Appendix

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A.1 Appendix Sections

The enumeration for the appendix is different.

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