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

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Declaration of Authorship

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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.
4. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Hannover, February 17, 2021
Location and Date Signature

Contents

1 Background and Related Work **1**
1.1 Common causes of cybersickness . . . 2
1.1.1 Sensory conflict theory . . . 3
1.1.2 Postural instability theory . . . 4
1.1.3 Other theories . . . 5

2 Chapter 1 **7**
2.1 Some Section . . . 7
2.2 Lists . . . 7
2.3 Images . . . 8
2.3.1 Simple Image . . . 8
2.3.2 Image Comparison . . . 8
2.4 Citations and References . . . 8

3 Chapter 2 **9**
3.1 Formulas . . . 9
3.2 Units in Equations . . . 9
3.3 Code Blocks . . . 9
3.3.1 Simple Code Block . . . 9
3.3.2 Imported Code Block from File . . . 9
3.3.3 Inline Code . . . 10
3.4 Tables . . . 10

A Appendix **11**
A.1 Appendix Sections . . . 11

Bibliography **12**

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 exposure to virtual reality environments [1]. Additionally, these sickness symptoms not only occur during the exposure to virtual environments, but can have lasting effects and affect users 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, and originated from the assessment of military flight simulators [8, 9]. While Simulator Sickness is still used in recent publications, the terms Cybersickness or VR Sickness are generally used to differentiate from simulator sickness and closer examine the side effects resulting from the use of virtual environments [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 often 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].

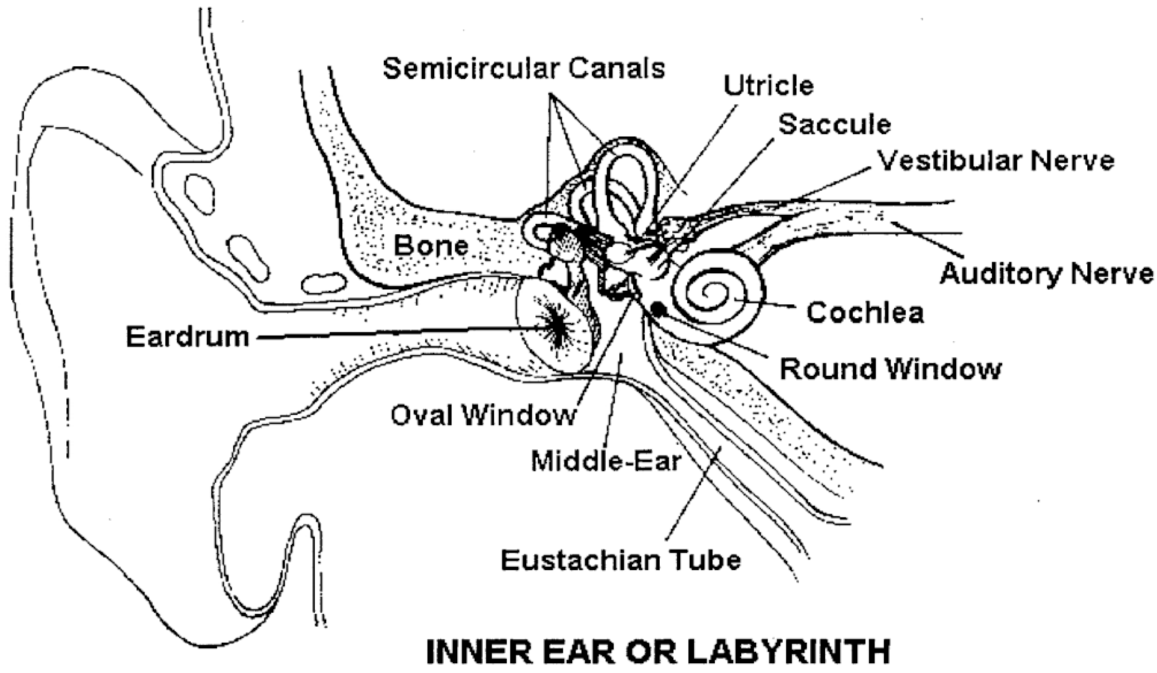

Figure 1.1: The components of the vestibular system [2].

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, as Barrett and Thornton [18] when they noticed that subjects showed symptoms of simulator sickness 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 [19].

The sensory conflict theory is the most popular theory to explain cybersickness, because it has a lot of studies to back it up, and 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 the theory 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 postural stability of subjects and indicate the potential onset of cybersickness symptoms [25]. A comparison between the

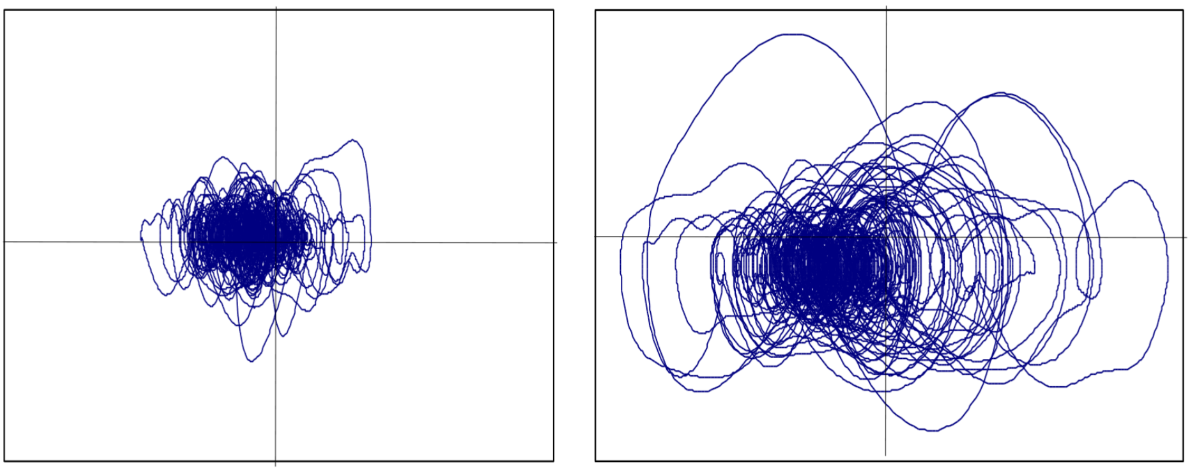

Figure 1.2: Comparison of phase portraits (position (in cm) vs. velocity (in cm/s)) for well (left) and sick (right) subjects in a dataset measuring postural stability [26].

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.

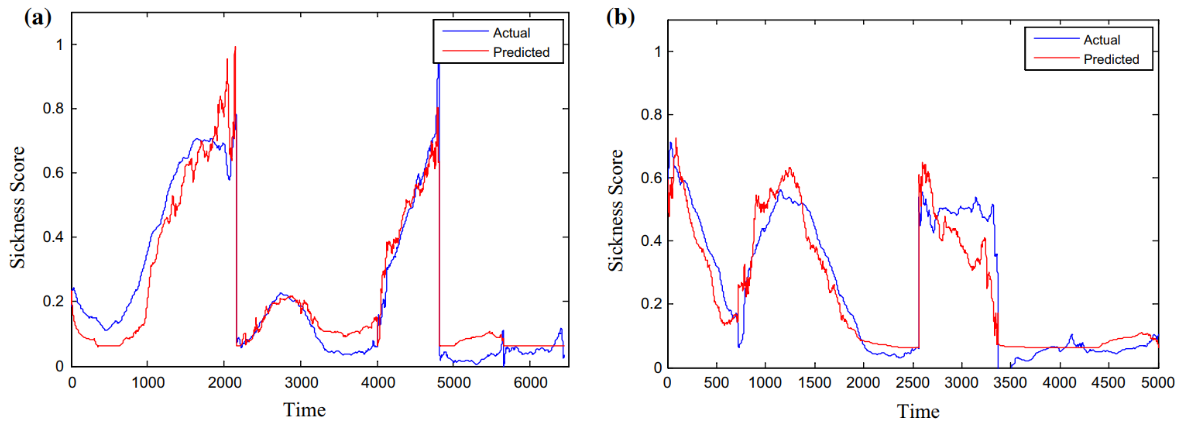

Figure 1.3: Actual sickness (blue) and predicted sickness (red) of (a) training and (b) testing set produced by the prediction algorithm by Lim et al. [25].

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].

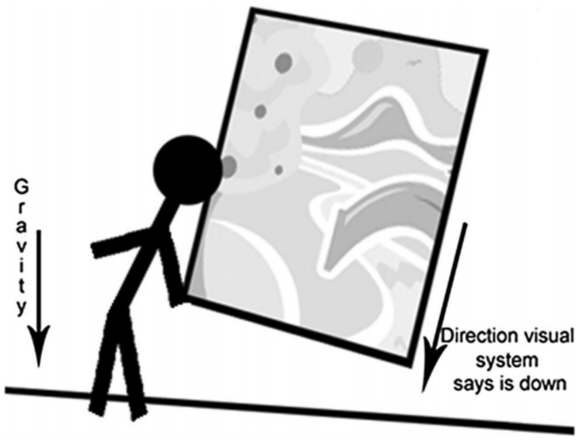

Figure 1.4: Example of sensory mismatch according to rest frame theory [1].

2 Chapter 1

This is a template you can use for your thesis. In the following some examples will be given how to use the template features.

2.1 Some Section

This is a section with some text.

2.2 Lists

This is a list:

- First item
- Second item
- Third item

2.3 Images

2.3.1 Simple Image

This is an image:

Figure 2.1: This is the image caption. The image is from Limberger et al. [27].

2.3.2 Image Comparison

Figure 2.2: Here you can see two images next to another for comparison.

2.4 Citations and References

This is a citation: Limberger et al. [27].

This is a reference to the Appendix A.

This is a reference to an image 2.1.

Here are some more citations for example purposes at the end of the paper:

- Inproceedings [28]
- Article [29]
- Website [30]
- Tech Report [31]
- Master Thesis [32]
- Book [33]

3 Chapter 2

3.1 Formulas

This is a text that describes a formula. This formula is for calculating the brightness of light for a single point that is illuminated by the sun and partially occluded by a moon. This is done by taking the solid angle of the Sun Ω_{sun} subtracting the solid angle of the occluding moon Ω_{occ} and normalize the result. To the right we have a table that describes all the symbols that appear on this page, so people can much more easily see what symbol has which meaning without having to reread the text everytime they want to use the formula.

Symbols	
I	relative brightness
Ω_{sun}	solid angle of the sun
Ω_{occ}	solid angle of intersection

$$I = \frac{\Omega_{sun} - \Omega_{occ}}{\Omega_{sun}}. \tag{3.1}$$

3.2 Units in Equations

$$\frac{6371\,\mathrm{km} * 149\,600\,000\,\mathrm{km}}{695\,510\,\mathrm{km} - 6371\,\mathrm{km}} = 1\,383\,000\,\mathrm{km}. \tag{3.2}$$

3.3 Code Blocks

This templated uses minted for formatting code. It is required to install the python package Pygments. You can do this with the following command: pip install Pygments

3.3.1 Simple Code Block

Here we can see a code block. The second argument specifies the language for text highlighting.

```
// Get the intensity of the eclipse caused by the occluding body for our fragment.
float eclipseLight = calcEclipse(occludingBody, fragPos);

// Get the color of the fragment from the bodies texture.
outputColor = texture(/*...*/);

// Reduce the brightness of the fragment according to the intensity of the eclipse.
outputColor = outputColor * eclipseLight;
```

3.3.2 Imported Code Block from File

The following line imports code from a text file. The first argument is the language for highlighting purposes.

```
// Get the intensity of the eclipse caused by the occluding body for our fragment.
float eclipseLight = calcEclipse(occludingBody, fragPos);

// Get the color of the fragment from the bodies texture.
outputColor = texture(/*...*/);

// Reduce the brightness of the fragment according to the intensity of the eclipse.
outputColor = outputColor * eclipseLight;
```

3.3.3 Inline Code

This is inlined code: `float calcEclipse(vec4 occludingBody, vec3 fragmentPosition)`, where the first argument is the language.

3.4 Tables

This is a table:

Body	**Semi-major Axis**	**Observer Placement**	**Max. Abs. Error**
Mercury	0.39 AU	surface	0.0008
		500,000km	0.0000
Venus	0.72 AU	surface	0.0004
		500,000km	0.0000
Earth	1.00 AU	surface	0.0003
		Moon	0.0000
Mars	1.52 AU	surface	0.0002
		Phobos	0.0000
		Deimos	0.0000
Jupiter	5.20 AU	surface	0.0000
		Io	0.0000
		Callisto	0.0000

Table 3.1: This is the table caption.

A Appendix

This is the appendix. You can put all the stuff you like here.

A.1 Appendix Sections

The enumeration for the appendix is different.

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