Project Proposal: Reducing Simulator Sickness in Virtual Reality with the use of Haptic Feedback

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CCS CONCEPTS

• **Computing methodologies** → **Virtual reality**; • **Hardware** → *Haptic devices*.

KEYWORDS

simulator sickness, virtual reality

1 PROJECT DESCRIPTION

Virtual Reality (VR) has undergone a burst in popularity in recent years with the advent of consumer grade VR headsets like the Oculus Rift and HTC Vive [1]. However an ever present problem with VR environments is simulator sickness. Simulator sickness is similar to motion sickness though its symptoms, which include eye-strain, headache, blurred vision, and nausea, are less severe [8]. Vection, which is experienced when the eyes sense motion that is not corroborated by other organs, is a main cause of simulator sickness and is experienced by approximately 30% of subjects [12]. We posit that allowing other organs to corroborate the motion sensed by the eyes will reduce vection and thus reduce simulator sickness. By providing haptic feedback, as opposed to traditional visual feedback, we allow this corroboration by organs other than the eye.

Reducing simulator sickness in virtual environments is important due to the effects it has on users, which leads to lower levels of immersion and an overall unpleasant experience. If the VR industry wants to grow further, simulator sickness is one of the major issues it needs to tackle.

Current methods of reducing simulator sickness which are well-researched and revolve around the use of locomotion techniques that produce the least amount of vection. Design guidelines published by Kennedy et al. [5] and Porcino et al. [11] stress that short lengths of acceleration, short lengths of usage, decreased field of view, and high frame rates are key to reducing simulator sickness.

One major issue with solving our problem is that simulator sickness is polygenic and polysymptomatic (meaning it has multiple causes and symptoms) [6], so it affects people differently. This has implications for how we measure simulator sickness and great care must be taken when designing our experiment.

We will be using the Simulator Sickness Questionnaire (SSQ) developed by Kennedy et al. [7] to measure simulator sickness. An issue with only using the SSQ is that it is a subjective measure. However, there is research linking heart rate, eye blinking rate, and respiratory sinus arrhythmia to simulator sickness [9].

We propose two solutions: a tether device which provides haptic feedback and a stepper machine which provides the user with the feeling of walking. These two solutions will be compared to the current best practice software solution. These three methods can be summarized as follows:

(1) The tether device will be attached to the back of the user, and once the user walks past a certain point the tether will pull back on the user providing a sense of inertia.
(2) The stepper machine makes use of a generic sports stepper on which the user will walk in place. This walking motion is translated into motion within the virtual environment.
(3) The current best practice software solution is controller based motion, where the user will use the controller provided with the headset to move forward in the virtual environment.

2 PROBLEM STATEMENT

The primary goal of this project is to design and implement two systems both with the aim of reducing simulator sickness when compared to the current software best practices. These systems are a tether device, which provides haptic feedback to the user as they walk, and a stepper machine on which the user will walk-in-place. The main research questions for this project are:

(1) By how much does a walking-in-place implementation using a sports stepper machine, interfaced with a VR headset, reduce simulator sickness when compared to the current software best practice solution?
(2) By how much does a real-walking implementation, using a tether device attached to the user's back, reduce simulator sickness when compared to the current software best practice solution?

3 PROCEDURES AND METHODS

This section will discuss the process a participant will go through during the experiment and will explain the components required for the study. There are three components to solving this problem: the hardware, the virtual environment, and the measurement methodology.

3.1 The Experiment Process

Once a potential participant has answered our pre-screening survey (discussed in Section 4) and is eligible to participate, they will be given a date and time to attend our study. On arrival they will sign an informed consent form. Afterwards the process they will follow is:

(1) The Biopac Systems® measurement devices will be attached to them. This done first so that they become comfortable with the devices.
(2) They will be given the VR headset and the basic controls will be explained to them.

(3) Once they put on the headset and indicate that they are comfortable, they will play through a short and simple VR game developed by Steam for acclimatising to VR. We will also begin recording physiological measurements to record a baseline measurement.
(4) Afterwards they will make use one of our three methods of locomotion, chosen at random.
(5) Once they are complete with the virtual environment, they will take an SSQ, the Biopac devices will be removed, and they will rest for 5-10 minutes.
(6) Steps 4 and 5 are repeated until they have completed all three methods.
(7) We will then ask them for any feedback and then they may leave.

It should be noted that the length that the user will spend in the virtual environment during a single run is not yet finalized. We need to strike a balance between preventing boredom and inciting some simulator sickness. Our current potential range of duration is from 3 minutes to 10 minutes. A final duration will be decided during our prototype development stage.

3.2 Hardware components

3.2.1 VR Headset. Considering our experiment revolves around reducing simulator sickness in VR, we unsurprisingly require a VR headset. We plan to use an HTC Vive given its popularity within the development community and its included tracking devices which will help track the users movements.

3.2.2 Stepper Machine. Since no VR-ready stepper machine exists on the market, one will have to be built. We have two potential designs. The first one attaches the HTC tracker directly to the sports stepper, one on each step, which makes interfacing with the headset easy. Since it would be difficult to directly attach the tracker to the steps, a platform would first be attached underneath. The tracker would then be placed on the platform. An example of this can be seen in Figure 1. The trackers will then send their position to the computer which allows us to update the users position. A potential problem with this design is that attaching the platform and tracker to the stepper might make using it more difficult due to the added weight.

The second design is to detect the movement of the stepper ourselves with a microcontroller. The components required for this are: a generic sports stepper, a microcontroller (e.g. Arduino or Raspberry Pi), and a potentiometer. The potentiometer, connected to the microcontroller, will be attached to the stepper in such a way that when pressure is applied downwards the potentiometer rotates increasing the voltage sent to the microcontroller. When the microcontroller senses this, it sends a signal to the computer, via USB, to move the player forward. Figure 2 shows the relationship between these components. A potential problem with this design is that interfacing between Unity and the microcontroller might prove to be difficult, and that attaching the potentiometer to the stepper might also be troublesome.

A decision as to which design to use will be made within the first week of our initial prototype phase (see Appendix B for the Gantt chart).

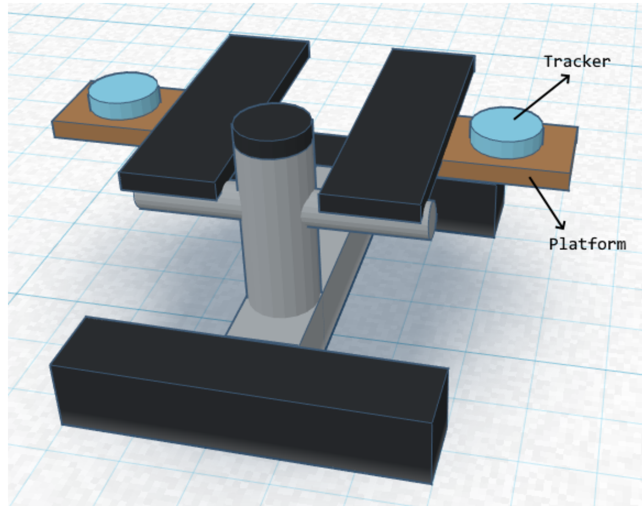

Figure 1: Potential design one: Stepper with HTC Tracker

3.2.3 Tether device. We will make use of a tether that is attached to the the participants waist at one end and to a weight, via a pulley on the wall, at another. This will allow the participant to move freely within the available space. Once they reach the boundary of their available space they will be held back by the tether and move further in the environment by tilting their body forward. This will provide haptic feedback to the participant when they move in the virtual world. This will also need to be built from scratch. A draft design is shown in Figure 3. The HTC Vive sensor will be attached to the weight and based off of the vertical position of the sensor we can deduce the position of the participant.

3.3 The Virtual Environment

We will develop a custom virtual environment in Unity for our users to use during the experiment. The environment will consist of a straight path through a forest through which they will walk. We chose this environment as a straight path fits with the mono-directional movement we're using, and the forest prevents the user from attempting to move in any other direction.

Having the user walk down a straight path for the duration of the experiment will become monotonous, especially given that they will be repeating this process three times. To avoid this we will have to implement some sort of interactive elements into the

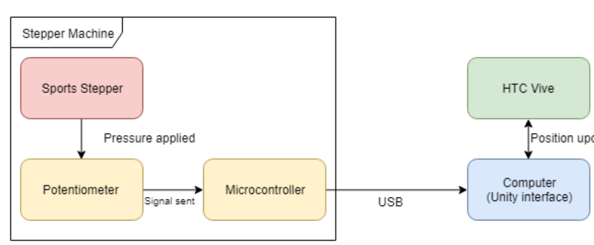

Figure 2: Potential design two: The relationship between the components of the stepper machine.

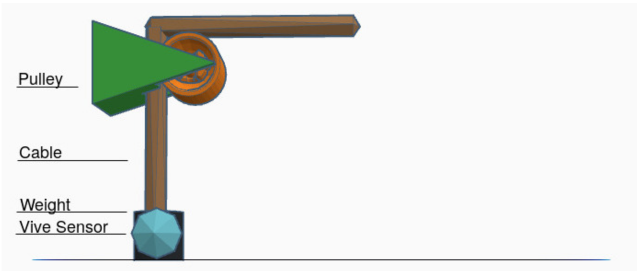

Figure 3: A CAD draft design of the tether.

environment. We currently have three solutions, one of which will be selected upon further investigation.

3.3.1 Following Companion Solution. This solution entails following an animated animal (most likely a dog) through the forest environment. The animal will run away from the user when the user gets too close and stop when the user is too far away. This will continue for the duration of the experiment. Following encourages running which is undesirable as we are interested in testing for simulator sickness at walking speed. This solution will most likely cause frustration and become monotonous as a user will never catch the animal and he/she will need to repeat this same task three times (once for each method of locomotion). However, this solution is also the most likely to produce constant motion because the user is encouraged to keep moving in order to catch the animal. This constant motion increases the likelihood of simulator sickness occurring.

3.3.2 Obstacle Removal Solution. This solution solves the monotony of walking by introducing obstacles along the path. These obstacles will not be difficult to pass as they serve as a method of distracting the user. Users will remove obstacles by simply clicking a button on their controller. The obstacles will then disappear and the user can continue walking. Obstacles can be randomized along the path to ensure that each individual walk feels unique and interesting. However, the time in which the user is not moving should be kept to a minimum (in order to induce motion sickness the user must be moving). This is particularly challenging with obstacles as users are required to stop in order to clear it in the first place. A proposed solution to this problem is to make the obstacles easy to remove, by simply clicking a button, and make them disappear quickly so that a user can continue walking shortly after the obstacle is removed.

3.3.3 Environment Solution. This solution forgoes the idea of only using a forest environment and instead adds an two additional walkable environments. These additional environments follow the same restrictions as the forest environment. They will be the same size and contain only a straight walkable path. They will only differ in locale (e.g. a bridge, a city street). For each method of locomotion, an environment will be randomly selected (with no possible duplicates per user eg: a user who experienced the forest for one method of locomotion will not experience the forest for the other methods of locomotion). This reduces the likelihood of our results being affected by a specific environment. Upon completion of an experimental run, users will be asked to give their thoughts on each environment. This is not intended to measure anything but rather keep the user's attention away from the motion sickness aspect of this experiment. These environments will have no interactive elements and are intended to just be experienced. This solution requires that significant amounts of work be put into developing three environments that are consistent in style but different enough to be noticeable.

3.4 Measurement Methodology

3.4.1 Subjective Measures. We will give participants the Simulator Sickness Questionnaire (SSQ) developed by Kennedy et al. [7] to measure simulator sickness. Kennedy's et al. paper is a highly cited paper and is the most common way to measure simulator sickness. It makes participants rate the severity of 16 symptoms on a 3-point Lickert scale. Symptoms are divided into nausea, oculomotor, and disorientation. Using the rating given by the participant and predefined weights, a final simulator sickness score is determined.

3.4.2 Objective Measures. With the help of the psychology department we will be measuring heart rate, skin conductance, and respiratory rate. This is done by placing electrodes on the subjects connecting it to a small wireless transmitter. The subject will still have full range of motion due to the size of the transmitter. All of these components form part of the Biopac Systems® measurement pack which the psychology department will provide us with.

4 ETHICAL, PROFESSIONAL AND LEGAL ISSUES

Participants will be subject to a virtual environment which is designed in some part to induce simulator sickness and thus ethical issues have been identified during the experiment stage. The following procedures will need to be put in place to combat these issues:

- As we are testing with human subjects, most of which will be students, we will need access permission from Student Affairs and ethical clearance from the Science Faculty Ethics Committee. This involves submitting a form online which will be reviewed by the committee, and will either grant us permission or ask for revisions.
- We will eliminate part of our potential candidates by pre-screening. These include participants who have epilepsy, severe depression, or those who suffer from drug abuse and alcoholism. The pre-screening will prevent these individuals from participating in the experiment.
- We will obtain informed consent from all participants. When advertising the study, a full explanation of what they will undergo will be included, and when they arrive for the experiment they will again be told of what they might experience. Only once they give consent do we move further with the experiment.
- As some of our participants will be female and this experiment requires attaching measurement devices to the participants body, we will recruit a female assistant to help us with female participants to ensure everyone is comfortable.

We believe that the potential benefits of our study will help the field of Virtual Reality and these benefits outweigh the possible short-term effects of simulator sickness participants may experience.

It should also be noted that advice on experiment design is being provided to us by the psychology department.

5 RELATED WORK

5.1 Modes of locomotion

In their review, Boletsis [1] describes a typology of movement under which there are four types of motion: real walking, walking-in-place, controller based methods, and teleportation. They found that real walking was the most immersive though it is expensive and inconvenient. Walking-in-place is described as the next best thing [3]. Controller based methods are the most common in VR applications as they have simple implementations and are familiar to users.

Usoh et al. [13] carried out an experiment investigating whether participants experience a higher sense of presence when using walking-in-place (virtual walking) than when they use hand-held controllers to 'fly' in a virtual environment, this was compared to real walking as a third condition. Their findings were that presence is highest for real walking, then virtual walking, and lastly flying.

Implementations of a stepper machine in research are sparse but the best examples are by Bozgeyikli et al. [2] and Matthies et al. [10]. Bozgeyikli et al. used an optical tracker and reflective markers to track the movement of the stepper, which then moved the user in the virtual environment. They found that it provided a similar experience to traditional walking-in-place methods. Matthies et al. used a microcontroller and potentiometer to interface with the VR environment, though they did not use a traditional VR headset but rather a CAVE implementation. Users reported better immersion but they did not find a statistically significant difference.

5.2 Experiment Design

Because of the different side effects and causes of simulator sickness, more than one variable must be utilized to quantify sickness. This, together with the fact that the experience of ailment in VR fluctuates significantly from individual to individual makes it hard to gauge sickness. The most widely recognized methods for estimation is to utilize the SSQ developed by Kennedy et al. [7]. This is a subjective measure and relies upon the individuals capacity to report on their feeling of sickness. Postural stability tests are sometimes used as a more objective means of measurement. Furthermore, Kim et al. [9] and Harm [4] have observed that the following changes occur as sickness is experienced:

- Increased Heart rate
- Blink rate
- Electroencephalography (electrical activity of the brain)
- Stomachache
- Pallor
- Cold sweating

6 ANTICIPATED OUTCOMES

6.1 System

The system hardware component of the system will be made up of the stepper device, the tether device, the HTC Vive HMD as well as its sensors and controllers. The software component will include the interfacing between the various input devices and the virtual environment in which the participant will find themselves in and engage with. The virtual environment will consist of a forest path that the participant will navigate through and along the way they will be faced with a subset of 5 small puzzles or challenges. These challenges will be a random subset of a larger pool of challenges. This is in light of Young's et al. finding that thinking about getting sick or experiencing negative symptoms gives the participant a predisposition to these negative symptoms [14]. In order to prevent this we give the participant something small and menial to occupy their mind.

6.2 Impact of project

This experiment will provide valuable insights into the effectiveness of haptic feedback as a way to address simulator sickness. Our study will allow us to better understand the issue of simulator sickness by showing how participants respond to each of the modes of locomotion. We will then be able to accept or reject the hypothesis that providing haptic feedback in the form of a force being applied, or in the form of simulated walking, will reduce the amount of simulator sickness experienced.

6.3 Key success factors

For our project to be considered a success we should meet the following criteria:

- The simulator sickness rating obtained from the SSQ should be lower for the tether system or the stepper machine when compared to the current best practice.
- The physiological measures we use to measure simulator sickness should point towards lower simulator sickness (e.g. lower heart rate, lower respiratory rate).
- Users should not report that the tether device or stepper machine are difficult to use.

7 PROJECT PLAN

7.1 Risks

Table 1 in Appendix A is a risk matrix which highlights the various risk factors, shows how probable and severe they are, and discusses how to mitigate and manage them.

7.2 Timeline

Appendix B is a Gantt chart showing the timeline of our project up until our reflection paper. An interesting aspect of the Gantt chart is the time we allocated to experimenting. What should be able to be done in 1 week has been allocated 3 weeks due to equipment scarcity. The psychology department only has 1 Biopac measurement pack. This pack needs to be shared between 3 groups simultaneously, and some Master's psychology studies will also require it in August.

7.3 Resources Required

We will use an HTC Vive as our headset and the tracker that comes with it. For the stepper machine the components required depend on the implementation we move forward with. Regardless, we require a generic sports stepper. Should we choose to use the HTC tracker, we will not require any more resources apart from some solid flat material for the platform, like a plank or solid piece of plastic. For the microcontroller implementation we will need a microcontroller, some wires, and a potentiometer. The tether implementation requires a harness, rope, pulley, mat, and some weights. We also need the Biopac components which are used for physiological measures. This will be provided by the Psychology department.

We will use Unity for development. AcqKnowledge, a program that provides an interactive way to view and manipulate data from the Biopac components, will be used when looking at physiological measurements of the participants.

7.4 Deliverables

The deliverables for this project are:

- Project plan
- Proposal presentation
- Prototype tether device
- Prototype stepper device
- Virtual environment
- Quantitative analysis of experiment results
- Project paper
- Project poster
- Project webpage
- Reflection paper

7.5 Milestones

The first major milestone is the development of a working prototype of the stepper machine, a working prototype of the tether device, and the virtual environment which interfaces with the stepper and tether. A user should be able to move through our environment with the standard Vive controller, stepper or tether. The due date for this is by the 19th of July. The second major milestone is the end of our experiment phase, which will be by the 9th of August. Afterwards it's the final draft, due the 16th of August, and lastly the final submission on the 26th of August.

7.6 Work Allocation

This section discusses the various individual components that each member is in charge of developing.

Mikhail Amod will lead the research and development of the stepper machine. This involves obtaining the necessary components and building it, as well as developing an interface for communication between the stepper and the VR headset.

Jethro Möller will focus on developing the tether device. He will also develop an interface for communication between the tether and the VR headset.

Brandon Gower-Winter will develop the virtual environment. This encompasses setting up the interface between the headset and Unity, acquiring assets (which will be assisted by Mikhail and Jethro), and developing the movement and interaction controls.

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A RISKS AND MANAGEMENT

Table 1: Risk Matrix.

Risk Factor	Probability*	Impact*	Management	Mitigation
Unable to implement stepping machine	4	10	Remove stepper from experiment	Start research early, develop and test using an agile approach.
Unable to measure tension in tether	4	9	Find alternative way of using tension	Find components and methods necessary early.
Scope creep	6	7	Feature freeze, stick to original scope plan	Have a well defined scope which shows exactly what we need to develop, and by when.
Too few participants	5	10	Ask fellow Honours students to participate.	Advertise the study early, make use of UCT's advertising facilities
Psychology department unable to provide measurement devices	4	9	Only use subjective measures (e.g. SSQ).	Meet regularly with the psychology department and have an agreed upon time to use the equipment.

***On a scale from 1 to 10, with 10 being the highest.**

B GANTT CHART

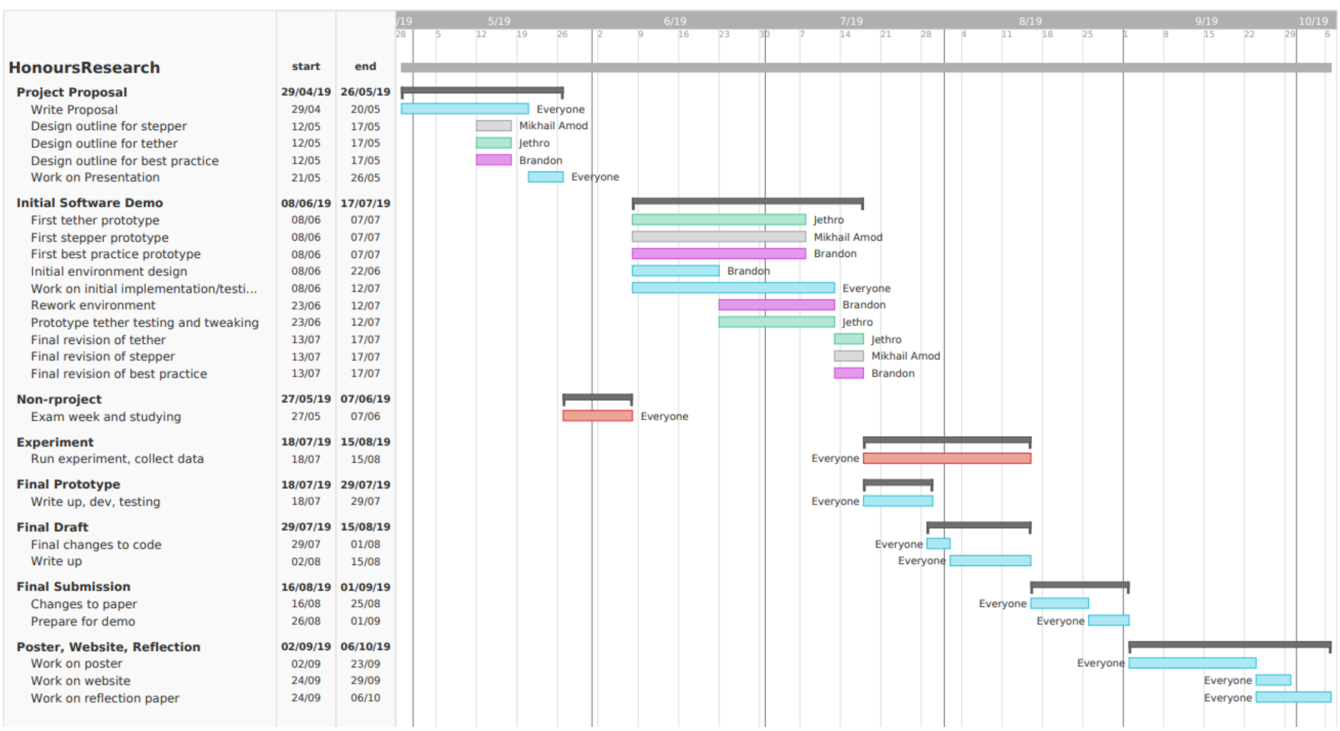

Figure 4: Gantt chart