Scaled Haptic Props for VR - Project Proposal

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1 INTRODUCTION

VR has been reaching more and more homes in the past few years. Devices such as the Oculus Rift and HTC Vive have made VR more accessible and affordable. This has sparked an increase in the development of VR games and experiences. One aspect often overlooked is the design of the controllers and the feedback received by a user's sense of touch, called the haptic feedback, they provide.

Currently a user interacting with a heavy, light, big or small object in virtual reality has an identical haptic experience. There are obvious differences between the virtual object and the controller in their hand. We believe an important part of achieving true immersion in VR is believable haptic feedback. There has been some research into the creation of devices that provide a sense of weight, texture and resistance, but not many successful products that have made it into the mainstream VR market. Haptic props are proven to create a greater sense of immersion for the user. This also has the added effect of better performance by the user, since they feel more comfortable within the virtual world and are able to approach challenges in a natural way. The continued advancement in the development of haptic devices will improve the quality of virtual reality environments. Our goal is to create two different props that provide haptic feedback that leads to a greater user immersion and performance.

2 RELATED WORKS

Haptic feedback research predates VR in the field of Dynamic Touch, first described by Gibson[10] in 1966. It refers to the ability of people to perceive the weight and height of an object just by holding it, even if the object is not visible[5, 17, 21]. It was found by Kingma et al.[13] that the further a handheld object's centre of mass is from the user's wrist the heavier and longer the object is perceived to be. This is extremely useful in the design of VR props since a small prop can be perceived to be a different shape/weight by manipulating the placement of its centre of gravity.

The effectiveness of weighted props in VR was shown by Fujinawa et al.[9] who were able to map the mass properties of an object to its perceived shape. They created props half the size of the objects they were meant to be representing but which were still perceived as normal sized. Weighted props provide what is known as passive kinesthetic feedback. The other form of passive feedback is passive tactile, which refers to the sensation of shape and texture provided by an object[3, 11]. White[23] showed that in a baseball game using a tracked bat handle, which provided realistic tactile feedback, led to a significant increase in game immersion over standard VR controllers. The addition of weights to provide kinesthetic feedback resulted in an significant improvement in hit/miss ratios and average distance per hit. When the batting experience was made more realistic by including a haptic prop, the user experienced greater immersion and performed better.

Apart from passive feedback there is also active feedback which is split into active tactile and active force-reflecting. Active tactile is a response meant to emulate an impact without actually restricting movement, usually in the form of a rumble response. Rumble responses have been used historically in video games to indicate specific interactions (taking damage, colliding with an object, etc.) but have also helped build narrative and immersion[24]. It is a form of feedback that can be easily implemented alongside other feedback methods and exists in VR controllers such as the HTC Vive. Force-reflection provides actual resistance to movement, often through the use of an exoskeleton device which is fitted onto the user. These devices are usually highly technical, experimental and expensive, putting them out of the reach of almost all consumers. Active Force-reflection, especially from a user mounted device, is largely beyond the scope of this paper but there are numerous interesting implementations of the concept[1, 4, 8, 18]

One of the problems with passive haptics is that a controller/prop can only have one shape, so can only represent one thing. The object also can only exist in one place at a time so they cannot be interacted with in different places without moving the prop. Haptic retargeting[3, 6, 14] and haptic reconfiguration[2, 7, 22] are two strategies that aim to combat this. Retargeting aims to subtly warp the game world in order to trick the user into interacting with a specific object or part of an object in the belief that it is a new object or in a different place. Reconfiguration changes the real world environment as the user cannot see it. The placement of objects is manipulated in order to provide a dynamic experience with only a few props. Both these strategies have limited applications and requires complex hardware and/or software to implement.

A new area of study concerns passive props that are able to change their shape in the user's hands. These provide what is known as dynamic passive haptic feedback (DPHF)[25].

Dynamic props use simple motors to alter the shape and weight properties of an object. This can make the object feel heavier or longer in the users hands[19, 25] or even cause additional resistance to be felt by creating additional drag[15, 26].

3 PROBLEM STATEMENT

While haptic props are shown to benefit virtual reality experiences [3, 14, 23, 25, 26], there still is not a clear consensus on the best way to implement them. We plan to develop two different props which will each aim to answer difference questions. The two props developed will be a quarterstaff by Riyaadh Abrahams and a dynamic sword by Liam Byren.

Staff Prop

Since controllers are small handheld objects, they cannot realistically simulate large long props such as long poles or a quarterstaff. Although it would increase realism, it is not practical to use a full-sized quarterstaff prop as swinging one in an enclosed space while wearing a VR headset is dangerous. So even though it would not be technically difficult to implement, it is not a solution to the problem. One possible solution is to use a haptic shape illusion which states "It has been suggested that the perceived shape can be modeled using the limited mass properties of wielded objects"[9]. This way you can have a smaller prop while still making it feel large. This is achieved by adding weights in the correct location. Another problem we run into is the simulation of collisions. When you hit something in real life, the force of the impact is transferred through the object into our hands. We can feel the impact. This is a much harder sensation to simulate inside a virtual environment. One of the solutions is the use of vibration DC motors. So, each time a collision of the prop is detected, we could fire off a motor response to help simulate a force. This is also known as active haptics. This has already been done in previous projects. What will make this project unique is the use of multiple DC motors for a more detailed forces. The combination of the 2 motors could be used to have variation in the force based on the VR environment. One of the research questions we want to answer is: **"Does the combination of active and passive haptic feedback improve immersion in virtual environments"**. We will be designing a staff prop fitted with vibration devices to help test this. We would like to know how much of an impact the vibration has on the user experience.

Sword Prop

In virtual reality when swinging a long object, such as a sword, the user needs to be able to predict the reach of the held object. Currently with standard controllers the user has no haptic feedback to help estimate the length of the held object and is forced to rely on virtual visual clues alone. If the user is required to hit an object coming towards them they may have a hard time predicting when it comes into range, a task which is mostly trivial in the real world. This inability to predict an object's reach could lead to frustration and decrease immersion and enjoyment. Additionally, there is a disconnect between the object they are holding and the shape of the controller, which further decreases immersion. We want to determine whether a haptic prop that is able to shift its centre of gravity to match that of the virtual object would help solve this problem. Ultimately what we want to know is, **does the addition of a dynamic haptic sword prop add to player immersion and performance ability.**

4 PROCEDURES AND METHODS

VR Hardware and Development Platforms

Both props will be designed to be used with a HTC VIVE Headset and make use of VIVE's Trackers, which can attach to any object and allow it to be tracked by the HTC base stations. The game world will be created using Unity. Additional custom prop parts will be 3D printed using a Creality Ender 3 printer and parts will be designed using Blender and Cura.

Testing

Since the experiment aims to increase immersion and user performance we would have liked to be able to do comprehensive user testing. Unfortunately due to the threat of COVID-19 that is no longer a safe and viable option. We have decided to focus instead on heuristic and performance evaluation since that does not require many participants and can be done safely. Heuristic evaluation involves having 4-6 trained evaluators[16] who test the overall usability of a system. These evaluators identify usability issues and rate them according to their severity. We will use the evaluation designed by Sutcliffe and Gault[20] since it was specifically designed for evaluating the usability of virtual reality applications. The evaluation additionally has a heuristic for haptic feedback so is well suited for our experiments. If it becomes safe to do so and the threat of COVID-19 subsides we would like to also include some user testing. This testing will include participants playing in a virtual environment with standard controllers and our haptic props. After each test they will be given the Game Experience Questionnaire (GEQ) developed by Ijsselsteijn et al.[12] which will allow us to compare the effectiveness of our props.

The performance of each prop can also be evaluated based on its performance. The response time of the props need to be as fast as possible in order to be as realistic as possible. For the quarterstaff prop, we can record the latency between a collision happening in the game world and the appropriate rumble response happening. For the sword prop, we can record how long the prop takes to begin to shift and how long it takes for transformations to take place. These performance indicators can be used to access the quality of the designed props.

Quarterstafff Development

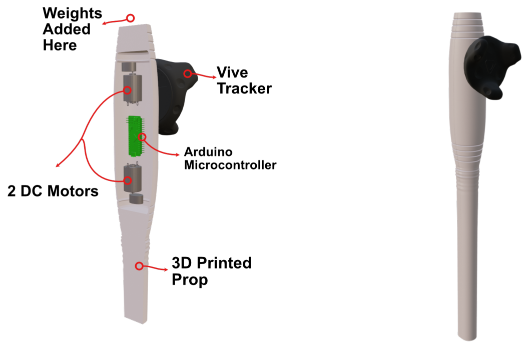

Figure 1: Quarterstaff design

The quarterstaff prop has been designed in such a way that it can contain the electronics parts needed. It has a handle which expands and contains a hollow area which can fit the motors, micro-controller, and battery. The VIVE tracker will be mounted on the side. This is to improve tracking and prevent it from being blocked when holding it at a certain angle. After the design is complete, it will need to be built. The body of the prop will be modelled and 3D printed. 3D printing is preferred over other methods since the design can be customized for our specific needs. We can hollow out the areas we need, and once the electronics parts are finalized, we can include compartments for them. After the 3D printing process, the model can be refined. In addition to 3D printing, we will use a piece of wood for the handle. This would give a realistic texture to the quarterstaff.

Once the base of the prop is complete, the electronics will need to be connected. It was decided that 2 DC Motors would be used, this would help provide variation in the force feedback. The motor that fires will depend on the position of impact of the staff in the virtual environment. The motors will be controlled using an Arduino Micro. This is the initial choice since there are many resources which will help with development. The Arduino will receive input from the VIVE tracker's pogo pin, since it reduces complexity of connecting Bluetooth or WiFi, and will have slightly improved latency. The final step is to add the weights to the top of the prop. This will help in providing the scaled haptic illusion. This process will need to be adjusted and improved.

Quarterstafff Test Environment

Once the prop is complete, a game will be developed to test it in. We have chosen to go with a sci-fi themed environment. A virtual staff will be modeled to represent the physical prop. This staff will be used to destroy enemies. Since the motors in the prop will not have enough force to provide actual resistance, the enemies chosen will be ghostly/ethereal in appearance. It is more believable if the quarterstaff completely passes through a projection or ghost as opposed to a physical enemy. The haptic motors in the prop will help in providing the vibrational feedback to improve the effect. All of the graphics will be paired with sound effects and animations. A multi-sensory experience which contains visual, audio, and haptic feedback all in sync should provide a realistic experience.

Quarterstafff Testing Methods

During the heuristic evaluation the chosen evaluators will play the game three times. During the 1st play through there will be no weights and no vibration enabled. During the second play through, there will be weights attached and a single motor will be active. During the final test, Both motors will be active for variations in force feedback. We would like to collect quantitative and qualitative data. The quantitative data will be average accuracy or completion time. The qualitative data will be gathered with the heuristic evaluation using the methods laid out by Sutcliffe Gault[20].

Sword Development

The dynamic sword prop, which we have decided to call *Swifty* consists of a tactile sword handle with a weight that is able to move, shifting the prop's centre of mass. In order to do this, a stepper motor will move a weight up and down a pulley belt similar to the system used in ShapeSense[15]. The stepper motor will receive commands via an Arduino microcontroller which communicates with Unity via a shared WiFi connection. As the weight moves up and down it will also expand and compress a camera bellows, an accordion like pleated material[1]. This bellows will cover the main mechanism protecting it and making the prop more visually appealing. More importantly the bellows should add additional air resistance which adds to a feeling of weight when swung. Hopefully this has similar effects to those seen with Drag:On[26]. Figure 2 shows a rough sketch of *Switfy* planned setup. Many haptic props contain vibrational motors meant to provide a rumble response as a form of active feedback, we have decided not to include these into *Swifty*. This reduces the overall scope of the project and allows us to focus on testing the effect of the weight shifting and air

[1]https://static.bhphoto.com/images/images2500x2500/1488891924_391031.jpg

resistance. Additionally White[23] showed that there was no significant difference in game experience and performance between a weighted prop and a weighted prop with a rumble response so the additionally benefit to *Shifty* would likely be minimal.

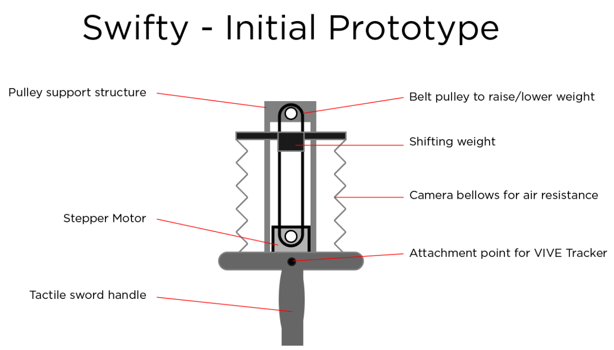

Figure 2: *Swifty* initial prototype sketch

Sword Test Environment

In order for users to interact with the prop and gauge it effectively, a small game will be created in virtual reality using Unity. The virtual scene will consist of a fictitious scene designed to match the aesthetic suitable for a sword. The user will be placed in a centre of a medieval training ground holding either a long or short sword, which is mapped to the position of the prop. During a test objects will be flung towards the user and they will have to swing their sword accurately in order to hit them. A visual and sound effect will be used to indicate whether the object was hit or not. Objects will move at different speeds and trajectories and will also come from different angles. Users will need to be able to correctly judge when the object comes into range of their sword.

Sword Testing Method

In order to test *Swifty* a heuristic evaluation will be done in 3 separate tests, the testing will occur in a random order for each evaluator. The test will always be a game will consists of two halves. In the first half they will attempt to hit incoming targets with a short sword. In the second half the user will switch to a larger longer sword and repeat the same task.

- Test A - The evaluator will use a standard HTC Vive Controller
- Test B - The evaluator will use *Swifty* but the prop will stay the same size throughout the test.
- Test C - The evaluator will use *Swifty* and the prop will move the centre of mass when the evaluator switches from the short to the long sword.

After each test the evaluator will complete a heuristic evaluation using the evaluation method laid out by Sutcliffe Gault[20].

5 ETHICAL ISSUES

There are a few ethical issues that we need to take note of during the course of the project. Most of this will deal with heuristic evaluation. One of the main issues we have will be VR Sickness. Due to the nature of VR, it is possible that some of the evaluators may feel nauseous during the experiment. The evaluators will able be familiar with VR experiences so will be aware of this possibility however we still remind them of the possibility and give them the option to stop the evaluation at any time.

Another ethical issue stems from the threat of COVID-19 pandemic. While we have greatly reduced the number of people required for this experiment we understand that having multiple users wear the same headset can cause a spread of the virus. We will take all the required measures to reduce the risk:

- We will require all users to wear a mask during the experiment. We will also wear masks.
- We will keep 2m space between the us and the participant.
- Only 1 participant will be allowed in the room at a time.
- All devices and surfaces will be wiped down and sanitized after each experiment.

6 ANTICIPATED OUTCOMES

Quarterstafff Anticipated Outcomes

One of the anticipated outcomes is the increased immersion when using active haptics as compared to passive haptics on its own. This makes sense as there will be more feedback during interaction with the virtual environment. There might be some users who do not enjoy the haptic feedback and we would need to get the correct amount of force. We also believe that two motors will provide more realism than a single motor. This is because we can better simulate impacts on different areas of the staff. Another anticipated outcome is we believe the weights will have a major role in improving realism as well as accuracy. It will feel like a longer object than it actually is which would help in moving it around.

Sword Anticipated Outcomes

The results of haptic prop testing shows that the addition of kinesthetic feedback does lead to an increase in immersion so Test B and Test C should outperform Test A, which used a standard controller. The passive prop version of *Swifty* should outperform a standard controller in the short sword segments, however, since both the passive prop and the controller are not mapped for a longer heavy sword, there should be a smaller gap in user performance. Ideally the dynamic version should outperform Test B and Test C on both performance and immersion. If the dynamic prop performs significantly better in both halves of the game than a standard controller, then we can judge the experiment as a success. It would show the effectiveness of dynamic props over both passive props and non-haptic devices and provide a solution that combines both weights and air resistance.

7 PROJECT PLAN

Risks

(1) Unable to complete heuristic evaluation or user testing due to campus being shut down.
(2) No access to VR hardware due to limited amount of devices and limited access.
(3) Limited experience with 3D printing and electronics might cause delays with haptic prop development.
(4) Lack of productivity due to power outages, working from home and other COVID-19 complications.
(5) Scope creep. Try to do too much in the limited time.
(6) Inability to create adequate virtual environment
(7) VR sickness for participants during heuristic evaluation.
(8) Delays caused by unforeseen ethical issues.
The Risk Matrix and Risk Management Plan can be found below in Figure 4 and Table 1

Resources required

We will need various equipment and parts in each stage of the project:

- A high performance PC and stable internet connection will be needed for research and development.
- A 3D printer and filament will be used for printing of 3D props.
- An assortment of electronic parts will be needed for the development of haptic feedback. This will include a micro-controller, WiFi module, and other electronic parts.
- An HTC VIVE Pro and VIVE Tracker is required for the development and testing of VR environment.
- We will need VIVE coverings to keep things hygienic during user testing. We will also need surface cleaner and masks to comply with COVID-19 measures.

Deliverables

These are the project deliverables:

(1) Literature Review
(2) Project Proposal
(3) Ethics Application
(4) 3D Prop
(5) Unity Game / Virtual environment Code
(6) Heuristic Evaluation Results
(7) Final Complete Draft
(8) Final Report Page

Milestones

These are the project milestones:

(1) Research Stage. At this milestone we should have a good understanding of the current research in this field. We should know the various methods of haptic prop design and techniques. Completed by 4 June.
(2) Prop Development. At this milestone we will have completed both the electronics and prop construction. The prop will be able to communicate with Unity. Completed by 16 July.
(3) Game development. At this milestone we will have have completed the construction of the testing environment within Unity. It should be a highly polished product which is as realistic as possible. Completed by 16 August.
(4) Completed Heuristic Evaluations. At this point we should have results that are useful and we can begin the analysis. Completed by 24 August.
(5) Final Hand in. This is the final milestone as the project would be complete by handing in the final report. Completed by 21 September.

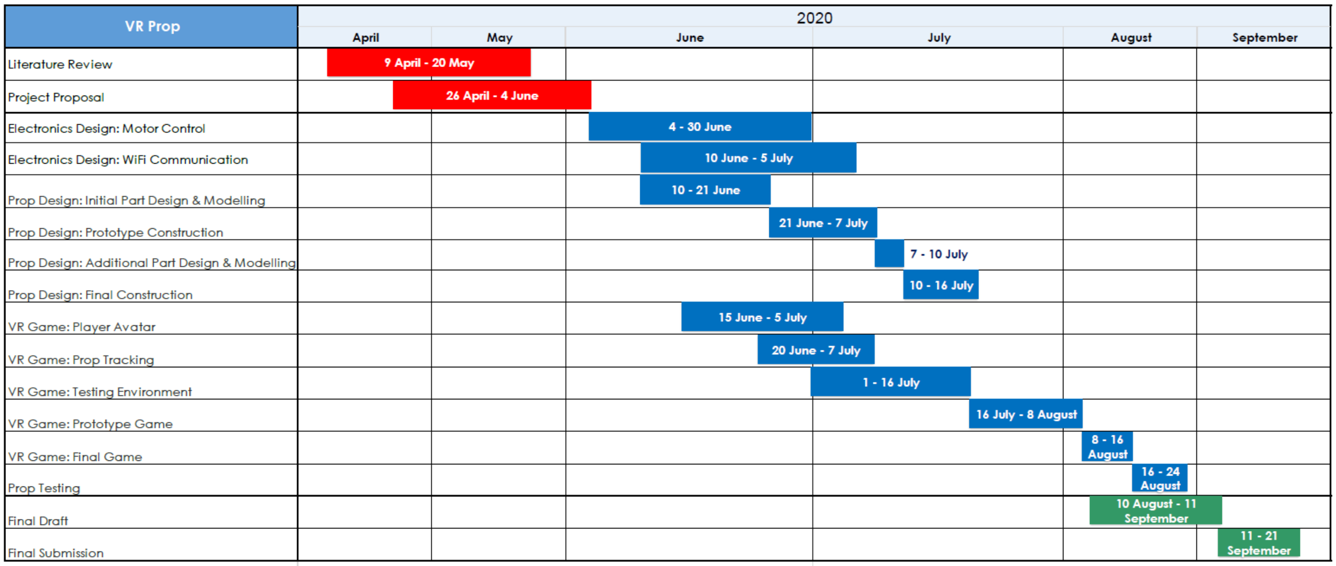

Figure 3: Project Timeline.

Table 1: Risk Management Plan

Number	Description	Probability	Impact	Category	Cause	Owner	Mitigation	Contingency
1	Unable to complete heuristic evaluation or user testing due to campus being shut down	Probable	Major	Resources	COVID-19	Liam	Reduce number of required evaluators and move away from user testing	Wait until pandemic subsides before testing, possibly only in 2021
2	No access to VR hardware due to limited amount of devices and limted access	Probable	Moderate	Resources	Covid-19	Riyaadh	Acquire headsets for home use and share headsets if needed.	Purchase additional headsets
3	Limited experience with 3D printing and electronics might cause delays with haptic prop development.	Possible	Minor	Resources	Lack of experience	Liam	Practice skills in advanced, speak with previous students and purchase simple robotic starter kits.	Reduce device complexity to increase chance of completion
4	Lack of productivity due to power outages, working from home and other COVID-19 complications.	Possible	Moderate	Resources	Eskom and COVID-19	Liam	Enforce good work schedules and stay medically and physically healthy.	Purchase UPS devices or find alternative work environment
5	Scope creep. Try to do too much in the limited time.	Improbable	Minor	Time Management	Inefficient Time Management	Riyaadh	Define strict requirements and deadlines.	Shorten scope to finish on time
6	Inability to create adequate virtual environment	Possible	Major	Time Management	Lack of Experience	Liam	Define strict deadlines and obtain additional learning material	Reduce complexity of virtual world
7	VR sickness for participants during user testing	Improbable	Moderate	Technical	Bad implementation of virtual environment	Riyaadh	Take all VR practices to reduce the risk of VR Sickness	Stop any testing immediately after noticing any VR Sickness
8	Delays caused by unforeseen ethical issues.	Improbable	Minor	Planning	Incorrect Research on ethical issues	Riyaadh	Submit ethics application early to allow for feedback.	Make all changes requested as soon as possible

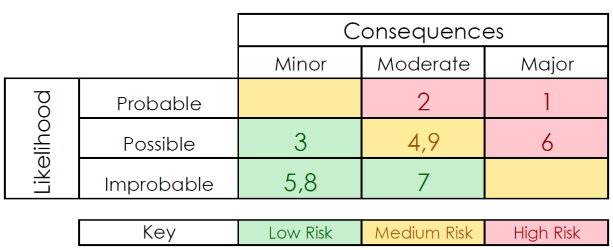

Figure 4: Risk Matrix.

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