Vive & Rope-Based Gameplay Mechanics

Nicholas J. Dorbin and Christopher Forseth

***Executive Summary*—Locomotion in Virtual Reality can be expanded upon by experimenting with new gameplay mechanics, like ropes. A vast majority of games utilize teleportation to navigate their environments, as it is easy to implement and produces minimal motion sickness. By experimenting with new locomotion methods, game developers will have more options available to them when designing their product.**

The Methodology of this thesis involves developing a gameplay mechanic involving ropes that is polished and produces minimal motion sickness. Variations of this mechanic will be developed and tested to discover what combination of factors produces the best results.

Index Terms— HTC Vive, Vive, Virtual Reality, Locomotion

I. INTRODUCTION

Gameplay mechanics for Virtual Reality games using the HTC Vive are a new and unexplored territory for game developers. With its high-fidelity motion tracking controllers, the HTC Vive opens up many new possibilities for methods in which players can interact with the virtual world. However, a majority of the games on the current market are using similar methods of locomotion to navigate their environment. The common methods of locomotion are teleporting, touch pad movement, dash teleportation, and delayed teleportation. Most methods of locomotion that are not a form of teleporting are prone to induce motion sickness in players.

The primary goal of this Mastery thesis is to create a pulling-based form of locomotion that is both fun and induces little to no motion sickness. This mechanic aims to provide an alternative to teleportation, rather than to replace teleportation as a locomotion mechanic. The artifact will contain several levels that demonstrate pulling and rope-based methods of navigation, while testing various differences to identify what aids in the reduction of motion sickness. The expected result is a working prototype that demonstrates a locomotion mechanic that is enjoyable and produces minimal motion sickness.

II. RESEARCH REVIEW

For this thesis topic, articles pertaining to aspects of Virtual Reality (VR) that induce motion sickness are considered. Similar articles that discuss gameplay mechanisms that work or do not work inform the development of this thesis. Vive games that use locomotion methods that are alternatives to teleportation are deconstructed and analyzed for their strengths and weaknesses. Two games in particular are analyzed, *Windlands* and *Hotdogs, Horseshoes & Hand Grenades* (*H3VR*) for their usage of rope-based mechanics and their influence on motion sickness [1], [2]. The research uses the keywords “Vive,” “Vection,” “VR Locomotion,” and “motion sickness in VR” to find relevant blogs, articles, and Game Developer Conference (GDC) videos to understand the aspects of Virtual Reality locomotion mechanics that have and have not been successful. Articles and sources are from 2010 and onward, as Virtual Reality is becoming more popular due to advancements in hardware and increased availability.

Oculus’ documentation on best VR practices provides a large amount of detailed research for methods that work well in a Virtual Reality environment. Oculus’ article titled “Simulation Sickness” talks about this aspect of Virtual Reality and how to counteract it [3]. Simulation sickness, which is a induced form of motion sickness, is caused by three notable aspects: ataxia (sense of disrupted balance), vection (illusory perception of self-motion), and oculomotor discomfort (eyestrain) [3]. The article notes that slow movement speeds feel comfortable, but the main source of concern is acceleration. If acceleration is used, it should be used only in quick bursts and never as a gradual acceleration. The article also stresses to never remove control of the camera from the player, as that separates the connection of the player’s immersion. The article suggests methods to counteract motion sickness, such as utilizing a static skybox and implementing a persistent grid in the play area to provide a point of reference.

The second Oculus article discusses input and navigation in VR [4]. As of the time of writing, Oculus devices have no dedicated motion controllers, which may be why the article suggests tank-like controls over traditional navigational methods. By having fixed amounts of movement, along with the separation of camera and movement, the author of the article believes this approach to be the most comfortable.

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J. Treleaven’s "Simulator sickness incidence and susceptibility during neck motion-controlled virtual reality tasks" study discovered that 80% to 95% of people that use a Head-Mounted Display (HMD) experience some form of motion sickness [5]. On top of this, a wide range of 5% to 50% of this population experience an extreme form of motion sickness, where the feeling persists for hours after playing. These numbers show that it is difficult for anyone to create a VR game or product that does not make players motion sick. Treleaven suggests a maximum playtime of fifteen minutes when performing playtests. Lastly, Treleaven recommends using positive language when asking questions to players, such as asking if the player is feeling “well” rather than feeling “sick.”

The Game Developer’s Conference (GDC) talk by M. Yasser delves into interaction design in VR [6]. Yasser discusses the concept of “Input Streams,” where inputs from a traditional controller equate to specific body parts on the player. With the Vive and its motion controllers, a developer must be mindful of the interactions the player wants to perform in the real world and must figure out methods to make that translate easily in the game world. Teleportation locomotion mechanics are successful because it handles large movements while letting the player use Room Scale to explore smaller, more intricate movements. Yasser suggests using affordances to hint to the player as to what an object can do. Yasser mentions a unique example, where the player ignored the green or red lights near objects and instead cared more for the giant shiny handle near the object they were meant to interact with. Yasser highly recommends using haptic feedback, which is vibrations on the controller, particularly continuous haptics for friction and texture. Lastly, Yasser suggests that all gestures should be meaningful to avoid simulation fatigue.

The GDC talk by P. Hackett, C. Hickman, T. Hurd, A. Schwartz, and S. Stephan features many developers as they talk about the games they released for the launch of the HTC Vive [7]. One speaker talked about how to represent the controllers within the game environment. He suggested making them smoky, letting them phase through objects, but also granting the player the knowledge of where they are in the game space. He also suggested making the controllers match closely to their real-world counterpart, as the controllers are the player’s only means of interaction with the game world.

In the Gamasutra article “Tips and advice for VR, from Steam VR game devs,” K. Graft cites Vive development tips provided by VR developers [8]. A majority of the developers stated that quick iteration is imperative to finding what works in VR. Spending too much time on the design document will not be as beneficial as quick iteration and playtesting.

Epic Games’ documentation on virtual reality best practices repeats similar concepts that Oculus’ best practices documentation stated [9]. One concept that Epic Games repeated in their documentation is the avoidance of quick acceleration of the player, pointing specifically to walking upstairs in VR as it does not feel natural. Movement must be at a constant speed, as quick visual jumps in view disorient the player if no additional effect is applied to mask it.

For field review, the researcher looked into *Windlands* for its rope-based navigation [1]. *Windlands* is a first-person platformer where the player navigates the game by using grappling hooks to swing around the environment. When the researcher first played *Windlands*, extreme motion sickness was felt after five minutes of playtime and the researcher needed to recover for one hour. Upon the second attempt, the researcher enabled the “Comfort Cage” in the game options, which places a metal cage around the player character’s head. The researcher found that the Comfort Cage significantly reduced motion sickness and was able to play for thirty minutes straight without experiencing motion sickness. The researcher found that the rope mechanic in *Windlands* functioned like a tether, which only pulled the player character towards the anchor point. The researcher could influence player location via the ropes by pulling towards or away from the anchor point, but found that perpendicular motion had no effect on movement.

A second field review that the researcher conducted was on the “Gunasium” level of *Hotdogs, Horseshoes & Hand Grenades* (*H3VR*) for its ledge-pulling mechanics [2]. *H3VR* is a first-person gun simulator that allows the player to interact with individual aspects of the guns. The “Gunasium” level challenges the player by requiring them to navigate the environment, avoiding walls while shooting targets and hitting checkpoint buttons placed throughout the obstacle course. The mechanics used a one-to-one movement of the player when pulling, giving the player free reign of where they can move as long as they can hold onto a grab point. Gravity is not present in *H3VR*, so when the player lets go of a ledge the player stays fixed in space. The researcher discovered that the following movements do not feel natural and cause dissonance: pulls that are too close to the player, large quick pulls, and pulling while the player is above the grapple point. The researcher also found that the following movements caused no problems: small pulls that are close together, overhand grabs, and grabs by the side of the player – but only if the grabbed object is not within the player’s “body.” The researcher also believes there is merit in placing world objects away from where the player believes his body is located.

III. Methodology

A. *Introduction*

Based on the research conducted, there is no ideal way to develop a VR game, but there are some practices that should be avoided. It is important to maintain the player’s sense of their own body while playing and avoid utilizing gameplay mechanics that go against what the player’s body expects to experience. With the Vive, any movements in the virtual world must be performed by walking around the play area, via teleportation to simulate movement, or by some force via a constant rate of speed. Utilizing points of reference for the player to focus on while moving is beneficial, as a fixed point in the world provides an anchor for the player’s navigation of the world. Applying haptics with thoughtful motion interactions can help cement the player's immersion in the VR play space. Lastly, it is important to remember that people experience varying levels of motion sickness, so discovering a "perfect" gameplay mechanic will be challenging if not impossible.

These findings were applied to the artifact by being mindful of the pitfalls that can arise from development on the Vive. Automated mechanics would not remove player control or separate movement of the HMD and the movement of the camera. However, as important as it is to allow the player full range of motion, evidence from the field research indicates that allowing the player to enter invalid world locations or objects feels wrong and disorients the player. Due to this, the artifact investigates methods of limitation of the player's navigation to maintain the player's immersion of the virtual world.

B. *Technology and Assets*

This project uses the Unity engine with C# and the VR community-developed Virtual Reality Toolkit (VRTK) plugin to aid with development of features, and freely available assets from the Unity Asset Store. Taylor Gallagher created a comfort cage model for the testing of comfort options. Andy Wang created two levels for the purposes of demonstrating and testing the developed mechanics. The first level demonstrates the climbing mechanics, while the second level demonstrates the rope making feature.

Figure 1 - The first level, which focuses on climbing mechanics.

C. *The Initial Plan*

The goal of this project was to make rope-based locomotion functional within VR, while aiming for the final product to be fun and induce the least amount of motion sickness.

The first step was to test a basic grab-and-pull-based locomotion on a handrail, then implement the locomotion mechanics on physics-based ropes. After a solid implementation of rope-grabbing locomotion was developed, further tasks would be determined iteratively based on user feedback.

Testing will involve presenting to the tester all features present in the artifact at the time of testing. More recent features will involve testing different setting configurations and tracking the tester's opinion of each setting. When developing features, the majority of its variables will be exposed in the editor or tied to an in-game Options Menu in order for configurations to be changed without removing the tester from the artifact. During testing, testers will be encouraged to provide preferences for how they would like features to behave, or new features that they feel could improve the artifact. If multiple testers express the desire for features that solve a problem in the artifact, then that problem would be the focus of the next milestone. When developing a feature, feedback will be analyzed across all testers to find the root of the problem and the testers' suggestions will be considered for the attempted approach to the solution.

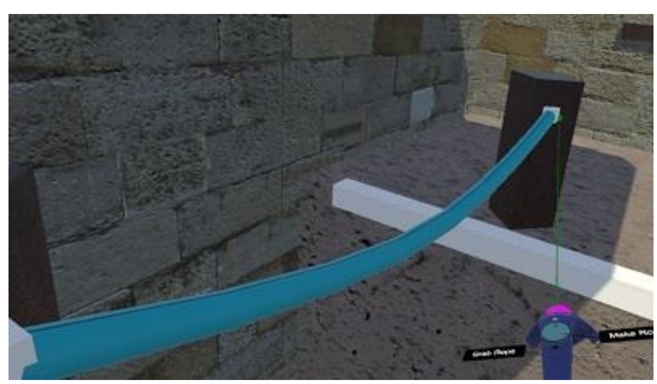
While testing was underway, the next step was restrictions on the locomotion, such as reducing the speed of the movement and preventing the player from being inside the rope, in order to match the locomotion closely to the limitations of similar actions in the real world. After the implementation of locomotion limitations, the comfort cage will be tested as an option to users, to assist with any discomfort during testing. Lastly, a safety harness will be implemented to aid with users who feel extreme discomfort from the falling sensation within VR. The goal is to polish and refine the mechanics while exploring as many options available to this style of locomotion.

D. *Development*

The first priorities of the planned development of the artifact were being able to move via grab-and-pull locomotion, followed by being able to use physics-based ropes to navigate the environment. A basic form of teleport was implemented as well, to allow users to compare the two forms of locomotion at the same time. These features were added quickly, as it was simple to add locomotion functionality to VRTK's grab events. Players could grab an object tagged as climbable, and a world point was stored as the origin of movement, allowing the player to set their current position based on a vector from the grabbed controller's current world position and its corresponding initial grab world position.

To generate physics-based ropes, players could pinpoint two locations with attachable surfaces as connection points via a laser pointer on the controller. Once the two anchor points were chosen, a series of cylinder shaped rope segment objects were generated along the path between the two points. These cylinders were connected via a series of spring joints, which gave the rope a bouncy and lifelike presence. When a user

Figure 2 - A tester creating a rope.



touches a grabbable rope segment, it would change to a yellow color to indicate it can be grabbed.

Testing at this period of development found that players enjoyed navigating to higher points in the environment via user-generated ropes. After placing a rope from the ground to the top of a tower, then climbing up the rope, the player would look back on the distance climbed and feel a sense of progress. After rope generation was added, the researcher added a rigid body collider on the player, which allows the player to influence the ropes by moving their torso into the rope segments.

Testing with the rigid body collider enabled produced some unexpected results. The researcher found that the ropes felt more real since they reacted to the player's body, causing them to sway or move when bumped into. However, the researcher also found the simulation sensation broken once climbing of the ropes began. While climbing the ropes, the researcher found that the rope would sway far away from the initial grab position, making subsequent grabs on the same rope increasingly difficult. This finding inspired another feature to add to the artifact: an Attached grab feature, allowing the player to be moved along with the rope object. Before this could be implemented, menus and comfort options would have to be implemented first, as there was a potential for users to get uncomfortable if their view moved with the swinging rope, based on Oculus' research on acceleration within VR [3].

The next feature added was the Radial Menu and an Options Menu in order to support the next goal – comfort options and locomotion restrictions. The Radial Menu allows the user to toggle the modes of the right-hand controller, which are the "Make Rope" mode or the "Teleport" mode. The Options Menu is shown when the user presses the Menu button at the top of either controller. A Comfort Cage toggle setting was added to the Options Menu. Also added to the Options Menu was the ability to adjust the speed of the user's climb, which controlled the distance traveled with each pull of the controller.

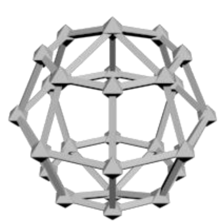


Figure 3 - The Comfort Cage asset used, created by Taylor Gallagher.

During testing, users appreciated the option of the Comfort Cage but saw no need to use it. Users also stated that having the rope movement reduced at all provided a dissonance between the user's body and what they were seeing. This disconnect in motion felt uncomfortable, as the users preferred the previous implementation of the rope movement being one-to-one.

Once comfort options were available, testing showed that users needed an easier way to grab onto a rope while it was swinging. This was accomplished by moving the player when the rope moved. To do this, when the user grabs onto a rope, the rope segment and the position of the controller local to the segment is stored. Then, when an update occurs on the movement script, it converts the local position to a world position relative to the rope segment, calculates the difference in position between where the controller is and where it should be, then moves the user by that difference. By performing this movement every frame, the user moves as the rope moves, and it provides a natural feeling of swaying along with the rope.

To assist with the feeling of falling, an additional comfort option was developed, a safety harness. If the user let go of the rope and dropped a set distance, a safety harness rope would be created between the last grabbed point and the player, which would prevent users from feeling discomfort from falling from high places. However, there was a conflict with the safety harness, the Attached Grab, and the Player Presence. Users would push the rope away from their body while climbing, and since the Attached Grab mechanic always puts the user close to the rope, a repeated cycle of rope collisions occurred. This led to the ropes having an immense physics force placed on them, which destabilized the ropes. Due to this, the safety harness mechanic and the rigid body on the player was removed.

Later in development, the falling problem was revisited using Fade Teleport volumes. Fade Teleport volumes are placed by the designer of the level in areas where the user is likely to fall. If the user falls into the Fade Teleport volume, the headset view fades to black, then the user is teleported to a pre-determined location before the view fades out from black. This implementation was received well by testers, as they were able to enjoy the feel of the initial fall without the nausea that comes from an extended fall.

During testing, a new form of locomotion became apparent, one that involved the player propelling themselves between ropes. By holding on to the rope or any grabbable surface, performing a throwing motion, then letting go of the grab point, users could toss themselves from one point to another. This feature, coupled with controller haptics, and the ability to automatically grab objects while the trigger is held, led to a solid gameplay feature.

Users had hesitation towards the mechanic at first, but quickly found themselves enjoying navigating between ropes. User feedback suggests that by performing the launch themselves, less motion sickness would occur due to being in control of their motions the whole time and the ability to anticipate the movement before it occurs.

Users did have some initial difficulty with the mechanic, as the throw motion wasn't entirely accurate to where the user wanted to go. This was due to the launch velocity being the negative velocity of the throwing controller at the instant the trigger is released. To correct this, a linear regression was performed over the previous five frames on the controller.

With the removal of the rigid body on the player, ropes could not be influenced by the player's actions, and the ropes felt static within the world. To fix this, player mass was added to the artifact by simulating the user's weight on the rope. When grabbing onto the rope, a weight is attached at the exact point where the user grabbed. This weight is removed once the user releases the rope. On top of this, if the user grabs onto the rope with both controllers, the weight is distributed amongst the two grab points. This feature also revealed a new feature of the launching mechanic: the ability to transfer momentum to a rope when grabbing it mid-air. By combining these two features, users found the world to be more believable, as ropes now react more like their real-world counterparts.

The next feature added was the ability to sever ropes. When the controller is set to the "Destroy Rope" mode, users can aim at a segment of a rope and click on the touchpad to destroy that segment of rope. The segment disappears, allowing the adjacent ends of the rope to fall and swing freely.

This feature allowed users to grab onto the moving rope and experience what swinging on a rope would feel like. The researcher and users that tested this mechanic found that navigating along the rope while swinging proved extremely challenging due to the lack of stability. Also, since users are physically standing still while the rope swings back and forth like a pendulum at high velocities, most users felt a form of motion sickness while navigating the swinging rope. The ability to cut ropes was immediately removed due to this feedback.

One of the last features implemented was hoisting. When climbing onto a flat surface, users wanted to feel like they were standing on top of the surface, whereas the original implementation of the climbing mechanics placed the user inside the surface at the spot where the user released their grip of the rope. The first implementation of hoisting involved teleporting the user on top of the surface, which was accomplished by performing a raycast straight down towards the user and then setting the user's position to wherever the raycast hit. Testers appreciated being placed on top of the surface they were climbing but felt the movement was too sudden, as their view was instantly changed. The second implementation of hoisting corrected this by performing a linear interpolation between the user's initial position and the top of the surface. This moved the user slowly to the correct position over the period of a second. Testers preferred this implementation of hoisting over the sudden motion of the previous hoisting mechanic. In addition, testers found the hoist duration of a second to be long enough to ease into the motion of hoisting without impeding their desire to continue climbing.

IV. Conclusion

A. Major Decisions and Problems Encountered

The first major decision was to choose how much of the locomotion system should be based on reality versus having the systems provide a game-like feel. With Virtual Reality, games need to have a proper balance between the two to provide a fully enjoyable experience. In the case of motion constraints, such as the reduction of the player's movement in relation to the controller's movement, testing found that it is preferred to not limit the user's range of motion. Since the controllers have no resistance, preventing the player from moving quickly along the rope when they can pull as fast as they want with the controllers often results in an unpleasant experience.

In a similar vein, when the player grips the rope, the rope sags, resulting in a positive experience for the player, since the rope behaves in a manner that the player would expect from the rope's real-world counterpart. The researcher concludes that within the realm of VR, users' actions should result in expected reactions. As long as features do not inhibit the user's actions, users will react more positively towards the feature.

The second major decision was the removal of the rope swinging mechanic. During implementation of the mechanic, there were several ideas of types of games that could center the artifact on swinging from rope to rope if the mechanic proved successful. However, many playtests determined that the swinging motion felt nauseating, so it had to be removed immediately.

One of the major problems encountered while working on the artifact was accounting for users' varying heights and arm lengths. While some gaps between ropes were easy to traverse for long-armed testers, testers with shorter arms had a much harder time of reaching the ropes. The solution for this problem was solved in two ways: by making the gaps smaller and by allowing testers to use the launch mechanic to travel between ropes.

B. Major Takeaways

The biggest takeaway discovered during development of the artifact was the scale of movement users can accept. When users directly control their movement, either in small amounts via rope movement or in larger amounts via launching, users were less likely to feel motion sickness. However, longer and faster movements that are not directly influenced by the user's input, such as rope swinging, were more likely to make users experience motion sickness.

Quick iteration was another major takeaway from this artifact. By quickly prototyping and testing features every milestone, the important features were easily identified for polish. On top of this, it was important to not be attached to any feature and not be afraid to cut features if they were not working. This allowed only the best ideas to stick and allowed for more development time to refine those features.

Another takeaway from this artifact is that comfort options are helpful for users in VR. While not every user will need comfort options, the testers of the artifact appreciated having the ability to toggle options like the Comfort Cage. On top of this, modifying features to be more comfortable, such as the lerping of position for hoisting or fading the screen to black before teleporting, makes these features more pleasurable for users. By easing into game-driven motions forced onto the user, features can elicit a more positive response from the users.

C. Future Work

One method to expand the artifact would be to test the locomotion system without gravity enabled. Removing gravity would remove the need for mechanics that manage weight to support believability within the game, and would allow the developers to focus more on the climbing locomotion mechanics.

Another method to expand the artifact would be to explore more game-like elements, such as adding shock balls that travel along the rope, forcing the player to jump between ropes quickly, or adding a timer to levels to encourage the player to traverse the level as quickly as possible. Exploring this locomotion method within a stronger game-like setting could provide a more thorough test of the validity of the locomotion.

A minor feature that testers enjoyed in the artifact was the grabbable trophies scattered throughout the test levels. Testers experimented with the trophy and the ropes and found that they could use the rope as a slingshot to launch the trophy. This unintended feature could be expanded upon to create a fun and interesting game.

Figure 4 - A tester using the rope to slingshot a trophy.

In its current implementation, the ropes resemble a series of blue cylinders barely touching each other, which is not how ropes look in the real world. Skinning is one way to improve the ropes' appearance. By constructing bone joints along the rope segments, generating a mesh, and lerping a rope texture between the joints, a more realistic rope could be created.

Another direction to take this artifact would be to create a mountain climbing game with the rope system, while exploring other methods for a successful safety harness fall prevention feature. Early in development of this artifact, the safety harness did not work due to the rope being inside the player's collision volume. If a functional safety harness feature were to be developed alongside this rope climbing system, it could lead to a fun mountain climbing game, as a safety harness would greatly help with immersion.

One other option to expand on the artifact would be to add a detection method for players' height or arm length, then dynamically adjust the spacing of ropes based on this metric. Levels within the artifact required ropes to be spaced close enough so that most testers could progress without issue, but testers with longer arms had an easier time navigating the levels. By dynamically scaling the spacing of the ropes, a more balanced level could be generated for each user.

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