VR Locomotion: Evaluating a Speed-Based Approach to the Human Joystick Technique

Student Name: Ethan Sanderson

Supervisor Name: Frederick Li

Submitted as part of the degree of MSci in Computer Science and Mathematics to the Board of Examiners in the Department of Computer Sciences, Durham University

Abstract — Virtual Reality games require methods of locomotion for players to navigate virtual environments. For an environment much larger than the real-world space available, the simple Real Walking technique is no longer viable. This project proposes and tests a new method, based on the existing Human Joystick technique, that aims to reduce motion sickness by matching the player's speed, while still providing an immersive and enjoyable experience. It was found that this new method fails to compare to existing methods, stemming mainly from the fact that the current implementation appears to be too awkward to use for it to be significantly enjoyable. Hence, future work on this project would involve a second implementation that aims to be more natural and intuitive to use.

Index Terms—Virtual reality, locomotion techniques, Human Joystick, VR gaming

1 INTRODUCTION

This project aims to investigate and evaluate existing locomotion methods for Virtual Reality (VR) games, as well as design and test a proposed new method.

1.1 Background

The main goal of VR technology is to provide full immersion into a virtual world; however, VR games also attempt to provide an enjoyable experience for the player. Because of this, the various aspects implemented in VR games need to be considered carefully; they need to provide a sufficiently immersive experience to justify being in VR in the first place, while also being comfortable and enjoyable enough to use for prolonged periods of time. One main aspect to consider is locomotion within the game, since for many games the virtual world tends to be larger than the real-world space available to the player. Thus, techniques other than Real Walking are needed for traversing large distances. Interestingly, it has been found that players generally show a preference for playing in a fully immersive virtual environment over playing the same game in a non-immersive setting, despite the former nearly always resulting in significantly poorer performance [1]. This suggests that in-game performance might not be the most important or influential measure for judging aspects of VR gaming.

Studies have shown that well designed low-fidelity interaction techniques or natural high-fidelity techniques are greatly preferred over semi-natural techniques [2], [3]. However, the reason for this is debated; [2] suggests that this is caused by a lack of familiarity with lesser known semi-natural methods, compared to natural methods (which, by definition, are familiar) and non-natural methods that tend to be more common (e.g., a controller). Conversely, [3] proposes that, instead of lack of familiarity, the issue is that semi-natural techniques are too similar to more familiar natural techniques, resulting in the player experiencing a false sense of familiarity (an "Uncanny Valley") and consequently not performing as well (for example, in [3] the semi-natural method used is a VirtuSphere-based device [4], [5] which is very similar to the natural method Real Walking but not exactly the same since the ground isn't flat. Hence, the player finds it hard to become accustomed to this similar method). The study conducted by McMahan *et al*. that also investigated display fidelity [6] found that players performed best when both were at the same level. In particular, they found that both low interaction fidelity paired with low display fidelity (e.g., using a mouse and keyboard with a single monitor) and high interaction fidelity paired with high display fidelity (e.g., using the Human Joystick method found in [6] with an HMD or CAVE-based [7] setup) resulted in significantly improved performance when compared to a combination of low and high fidelity for display and interaction, respectively (and vice versa). Since VR, by design, uses high display fidelity, this suggests that achieving the best possible VR experience would require a more advanced and high-fidelity locomotion technique, as well as a more advanced control scheme in general.

The high-fidelity interaction method used in [6] is the Human Joystick, which involves tracking the player's real-world movements and treating their relative position as input for a joystick that controls the player's movement in-game. I.e., the player's distance from the centre of the 'joystick' (the centre of the play space) controls the speed at which their avatar moves, and the angle they are at from the centre determines the direction. Depending on the amount of space available to the player, this method could be implemented by walking around the play space, or by standing still in the centre and leaning in the desired direction. For either implementation, the player's movement can be detected by tracking the position of their head (using the position of the HMD) relative to the centre of the available space. However, if the leaning method is used, this could be detected using a balance board, such as the Wii Balance Board made by Nintendo, to determine the amplitude and direction of the leaning, as demonstrated in [8], [9]. Alternatively, the movement could be detected using a more advanced method, such as extra body sensors or external camera tracking, to track the position of the player's feet instead of the head, which might feel more natural if the player is walking instead of leaning.

1.2 Motivation

The goal of this project is to design and test a new method for locomotion in VR games, specifically games that have significantly large environments that the player could not realistically traverse using one-to-one movement in the real world. The new locomotion method is based on the Human Joystick technique used in [6] but aims to improve on this method. The review of VR locomotion techniques performed by Cherni et al. [10] found that the main weakness of the Human Joystick method was that it often induced motion sickness. This is likely due to the difference in acceleration being perceived in the game and the real acceleration experienced by the player, since this is the most common cause of motion sickness in VR and this method does not match acceleration at all. Hence, the proposed locomotion method for this project is a modified version of the Human Joystick method (specifically head tracking based) which attempts to reduce the level of motion sickness experienced while still providing an engaging and immersive game experience. This method is also specifically aimed at virtual environments that are larger than any space a player would realistically have available, as well as being mainly, but not exclusively, targeted at fast-paced FPS-style games which require moving and changing directions quickly. Another reason for using the head tracking Human Joystick method as a base is that it requires no extra equipment and can be used even in small spaces, making it much more accessible to the average VR player.

The new method, described in Figure 1, is a hybrid method that incorporates two main ways of moving; Real Walking and Continuous Movement. The available play space is divided into two zones; a central ring and the area outside of the ring. When inside the ring, the player uses the Real Walking method, and when outside the ring the player uses the Human Joystick method but with one major change: the speed the player moves at continuously is determined by the speed at which the player moved out of the ring. The motivation behind this change was to reduce the effect of motion sickness when compared to the standard Human Joystick, since the speed and acceleration perceived in-game will more closely match that which the player is experiencing. This should also help make the experience more immersive as the player's actions will better match their in-game movements. Another weakness found with the standard Human Joystick method was that small and precise movements were difficult to perform, likely due to how much the player would have to move to change directions quickly. This, as well as the preference for natural techniques found by Nabiyouni *et al.* [3], motivated including the Real Walking method for moving small distances inside the inner circle, which should allow for much more precise movements over small distances while still allowing for easier and faster movements over greater distances.

A ring around the player will be the boundary separating the zones in which each method will be used, as shown in Figure 1. The central circle around the player will be used for Real Walking (i.e., the movements of the player and their virtual self will be one-to-one), whereas outside this ring the player will move at constant speed inside the game but will remain still in real life. They can also change the direction of the movement by moving around the ring, similar to the Human Joystick.

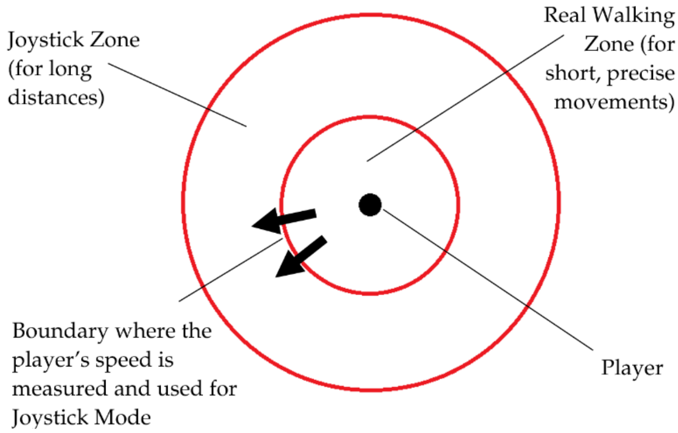


Fig 1. Diagram showing the layout of the proposed new method and the "zones" it consists of

1.3 Objectives

- **Minimum -** Design and implement a working VR FPS game using Unity that makes use of a standard method of player movement and control: using controller joysticks. The game should include large environments (significantly larger than the real-world space the player is using) to highlight how the chosen methods deal with traversing long distances at potentially high speeds in a confined real-world space. The game should also include obstacles for the player to avoid, forcing them to also focus on more dynamic and precise movements. Tasks typical of FPS games (such as aiming and shooting at enemies, avoiding enemy fire, etc.) should also be included in order to show how well the player can navigate the environment when distracted by other tasks.

- **Minimum -** Evaluate the effectiveness of the standard joystick method at providing an immersive, enjoyable, and natural feeling experience for the player.
- **Intermediate** - Implement the new hybrid method to be used in the game and compare its performance and player opinions to that of the standard method. Use the results to evaluate the feasibility of the new method as a potential alternative to standard locomotion techniques typically used in VR games.
- **Advanced** - Implement and test a more advanced movement method, the Human Joystick, and compare this to the new method to determine if it is not only a feasible method but also an effective one that improves on the Human Joystick.

2 Related Work

Nabiyouni *et al.* [3] suggests that locomotion techniques with either high interaction fidelity or well-designed low interaction fidelity often outperform those with moderate fidelity. Specifically, their study compared three methods: a traditional game controller (non-natural), real walking (fully natural), and a technique based on the VirtuSphere device (semi-natural). They found that overall, the semi-natural method resulted in significantly slower and less accurate performances in the various tasks than the other two methods. This result suggests that if a certain level of interaction fidelity cannot be reached then a method with much lower fidelity is preferred, likely due to the semi-natural methods feeling too similar to real life for the player while not behaving in the same way. In contrast to this, a method such as a traditional game controller is far enough from real life that there should be no pre-existing expectations of how it will behave.

A common locomotion technique implemented in many mainstream projects is the *teleport*, or *point-to-teleport, method* [11], [12], [13], [14]. This method usually involves the player somehow indicating a location they want to move to, and then teleporting to this location. The player can use their head to indicate the location, however a more common method is to use a handheld controller with an arc projecting out of the controller and onto the ground, since this is more comfortable than having to point directly at the ground. The teleportation can either be instant or trigger continuous movement towards the destination, however instant teleportation is usually preferred as this reduces any motion sickness caused by smooth movement only in the VE [15].

Paulmann et al. [16] demonstrates a method of achieving seamless locomotion through large spaces by combining natural techniques: 1) *Redirected Walking techniques* [17], [18], 2) *Passive travel* such as lifts, vehicles, etc., and 3) *Indirect movement* such as climbing, pulling a rope to move a raft, etc. These techniques are joined together using physical movements and interactions, such as crawling and jumping, in order to distract the player from the manipulations that occur. This results in seamless, natural navigation of a potentially infinite VE by the player from within a play space as small as 2m by 2m. This technique requires sections of the VE to be predetermined, i.e., linear, since it requires full control of the player's position when manipulating their movements, and would be unable to adapt to any deviation from the predetermined path, within these areas. Hence, this method works very well for more linear, story-based VR games that don't rely on or require much freedom of movement, however, it would not work very well for larger, more open VEs that would warrant much more freedom to explore. Furthermore, these types of technique require the VE to be tailor made with the controls in mind, since the design of the environment itself determines which methods can be used at any given location.

Games that provide a larger VE to explore must employ a locomotion method that is independent of the environment, in order to provide access to all areas. Development of such methods is also more beneficial to the wider VR gaming community, since, by their nature, they could easily be applied to a wide range of games. This allows for aspiring VR game developers to more easily create their own games without also having to design a custom control method from scratch.

Redirected Walking methods, such as those discussed in [12], [17], [19], are often implemented subtly with the aim of manipulating the player's movements without them being aware it is happening. However, Redirected Walking can also be implemented in ways that do not attempt to hide the manipulation, but instead embrace it as an aspect of the game. Examples of such methods include the "Space Bender" method described in [20], which warps the VE whenever the player nears the edge of their play area in order to redirect them back towards the centre. This method can also be implemented in more intelligent ways that incorporate some type of algorithm to determine the best way to warp the environment, as shown in [21]. This method analyses the section of the environment that needs "bending" and attempts to minimise the distortion to feature-heavy areas, i.e., the areas that draw the player's attention the most and would be the most noticeable when warped.

The leaning-based methods found in [8], [14], [22] are similar to the Human Joystick method used in [6], however they don't require the player to move from the centre, only lean in the direction they wish to move. The methods in [8], [14] use balance boards to determine the magnitude and direction of the player's lean, whereas [22] uses a device called the "Joyman" which allows the user to lean much further than they naturally could. However, using a head-tracking based approach, such as in [6], would allow for either a walking based or leaning based Human Joystick using the same technique. All that would need changing would be the sensitivity of the 'joystick', since the player would not be able to lean as far as they could walk. Therefore, the technique could be adapted to fit any size play space available.

A locomotion technique that shares similarities with the proposed new method is the "jumper" method shown in [23]. This method aims to track and use the player's real-life speed, similar to the proposed method. However, instead of moving at a continuous speed, the "jumper" method makes the player "jump" to a new location, with the size of the jump based off the player's speed as they lunge forwards. This method of jumping in-game is more advanced as it is based on the player's movements, instead of controller input.

Habgood et al. proposes continuous, rapid movement between nodes as a locomotion technique that aims to reduce motion sickness [24]. They did find that short and fast motions significantly reduce the motion sickness experienced compared to slower, continuous movements at walking pace. This is likely due to the motions happening so quickly that the player doesn't notice what is happening fast enough for it to make them feel sick.

Omni-directional treadmills, such as those found in [25], are devices that aim to simulate real walking without the player actually moving anywhere. They are an improved version of the Walking-In-Place technique [26] since the player can actually move their feet as if they were walking. However, techniques such as the omni-directional treadmill, "Joyman" [22], or VirtuSphere [4], [5] are let down by their reliance on large and often expensive equipment which would not be accessible to the majority of VR users. Hence, techniques that are not only effective but require no extra equipment to operate are greatly preferred by the wider VR community.

3 Solution

3.1 Hypotheses

The following hypotheses were formulated for this project:

1. The types and severity of sickness or discomfort experienced during gameplay would decrease with the new method when compared to the joystick and Human Joystick methods. This would be because of the new method better matching the speed and acceleration of the player.
2. The time taken to complete the game using the new method and the Human Joystick method could be longer than for the joystick method, due to these methods being more complex and harder to learn to use very well, unlike the joystick method.
3. The enjoyment and immersion could be higher for the new method and the Human Joystick method due to them being more interactive and engaging.
4. The difficulty ratings for the new method and the Human Joystick method could be greater due to a steeper learning curve and the participants being less familiar with these techniques than the joystick method.

3.1 Tools

3.1.1 Development Tools

The implementation for this project was developed using the Unity Real-Time Development Platform [27], which was chosen for several reasons. Firstly, it has a wide range of free assets and extensive online documentation available which helps speed up and simplify the development process significantly. Secondly, Unity is currently the most used platform for VR game developers, with around 60% of VR games currently on the market being developed in Unity, meaning there are many resources and tutorials available to help with integrating VR into the game engine. Also, having already had experience developing with Unity, it made more sense to stick with this platform than switch to a new and unknown alternative. The OpenXR plugin was used for integrating VR into Unity since OpenXR is the preferred API for Oculus headsets (the headset used for testing was an Oculus Rift S).

3.1.2 Testing Tools

The VR equipment used for the testing was the Oculus Rift S HMD [28] with two Oculus Touch controllers. The Oculus software was used in conjunction with Unity and OpenXR to run the games used in the testing process. The Oculus Rift S is a tethered headset, meaning it required a PC to run the software. The PC used contained a Nvidia GeForce RTX 4000 Quadro graphics card, and had 32GB of RAM. These specifications were comfortably good enough to use the equipment and run the necessary software, which was important as any performance issues, such as latency, flickering, etc. would affect the results. Finally, Google Forms was used to host the survey given to the participants during the testing, as it was very simple to use and supplied the data in a convenient csv file, making analysis easy.

3.2 Implementation

To test the methods of locomotion, a small VR FPS-style game was made. The game consists of four rooms, each containing various types of obstacles for the player to avoid, as well as targets for the player to shoot. There is also an initial tutorial room containing examples of everything the player would encounter during the game, allowing the player to learn the mechanics of the game and become acquainted with the current controls. The different rooms are shown in Figures 3 and 4.

3.2.1 Mechanics

The targets were included as something for the player to interact with as they are progressing through the game, while also measuring the player's accuracy to compare between control methods. The targets are required to be shot for the player to progress to the next room, and the accuracy is recorded after a successful shot as well as recording when the player gets a near miss. The purpose of having the player shoot the targets was to compare how their accuracy is affected by the different navigation methods. Hence, the targets were mostly placed at strategic locations where the player would have to keep moving in some way. Also, the targets only become available to shoot when the player moves close enough, as well as some being set back into the wall, to prevent the player shooting all the targets from a distance.

The rooms also contain various red obstacles that the player is told to avoid, such as walls, moving blocks, and mines, which record any time the player collides with them. The purpose of these was to test and compare how well the player can navigate and avoid obstacles when using the different control methods.

In certain areas, there are also turrets that fire rockets at the player when in range. These were included as a way to prevent the player from staying still or moving too slowly for too long, as they would eventually have to move to avoid the rockets. This ensures that the player is constantly having to move at a reasonable speed to better test how well they can navigate using the controls.

3.2.2 Rooms

There are four main rooms, each with different challenges inside, that are connected in a random order determined when the game is first started, such as in Figure 2. This was in order to change the game slightly each time it is played to prevent the participants from learning the layout. Certain aspects of each room are also randomised each playthrough.

Room A is the tutorial room, which has examples of all the mechanics present in the rest of the game.

Room B has fixed red walls inside a corridor with many turrets at the end that each fire at random intervals. There are also moving targets embedded in the walls along the corridor

Room C consists of four different combinations of red walls that move in various ways. The order of these wall sections is randomised, and they each have a target embedded in the wall adjacent to them.

Room D consists of a large open square with long, low red walls configured in a way that forces the player to take a long path around the room to reach the exit door. The whole floor of the room is covered in mines that have varying activation ranges and randomised positions. The orientation of the walls can be flipped randomly, and there are two turrets that are randomly positioned on the edges of walls.

Room E consists of three dropped down sections with moving bridges to cross to get to the other side. If the player falls off, they are teleported back to the start of the room. However, since it is possible to get stuck in this room, the player only gets five attempts before they are automatically teleported to the exit and the door is opened.

3.2.3 Control Methods

The Human Joystick method and the proposed new method are implemented in the ways described in Sections 1.1 and 1.2, respectively. Both of these methods will include a small circle on the floor directly below the player's head and a ring that is fixed on the floor at the centre of the room. For the Human Joystick method, the ring is only there to indicate the centre of the room, however, for the new method the ring indicates the boundary between the two zones shown in Figure 1. The joystick method is implemented using the left controller joystick for movement, and the right for optional snap rotation. For this method, the player can also hold the left trigger to sprint. For all control methods, the right hand will hold a gun that can be fired with the right trigger, and the "A" button on the right controller will make the player jump.

3.3 Measures

3.3.1 Performance

Performance was measured using data automatically gathered during gameplay. For all data recorded, the current room was also recorded so that the data for each room could be compared individually. The data included:

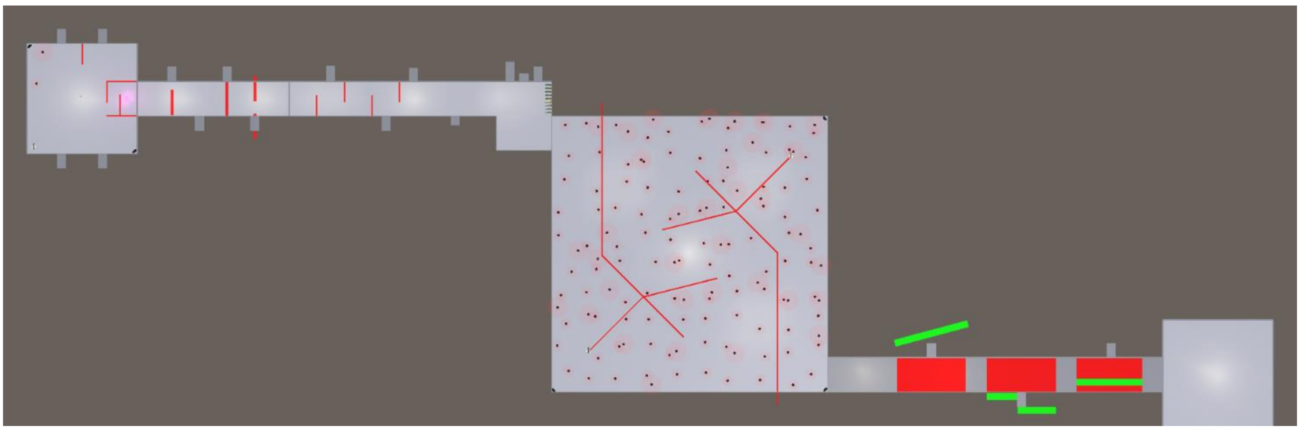


Fig 2. Top-down, isometric view of an example layout of the game, with the tutorial room always at the start, and the other four rooms connected in a random order

1. The time taken for the player to complete each room, which was the time between the entrance door opening and the exit door opening for that room, as well as the total time to complete the whole game.
2. The accuracy of the player's shots at the targets, recorded on a scale from 0-100 with 0 representing a miss and 100 representing a bullseye. Shots were counted as a miss if they were within a certain range of the target but did not hit, in order to discount any stray shots which were likely not aimed at a target.

Fig 5. Game mechanics: A) target, B) mine, C) waypoint in front of a door, D) red walls, and E) turret

Fig 3. Top-down, isometric views of the four main rooms and the tutorial rooms: A) tutorial room, B) - E) main test rooms

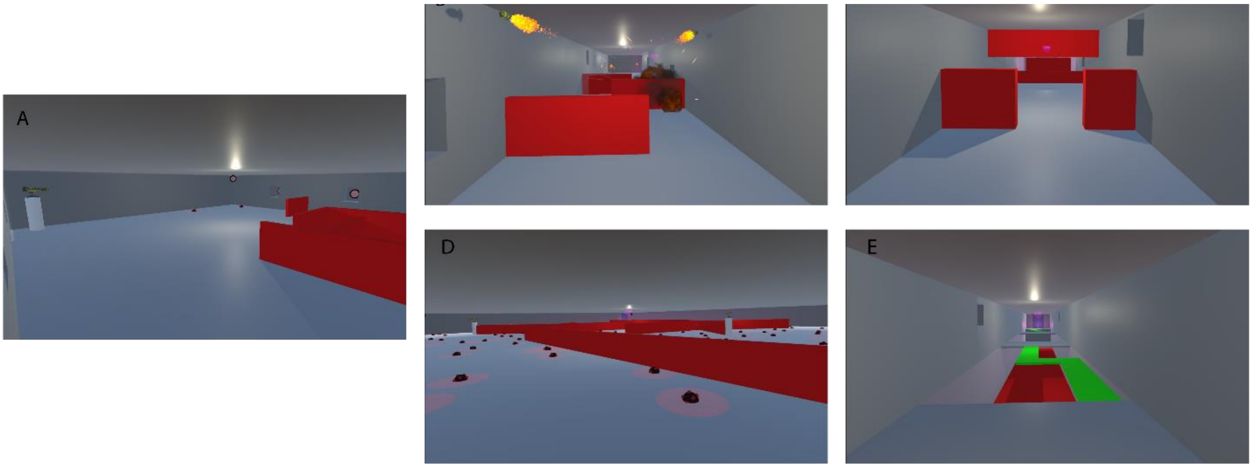
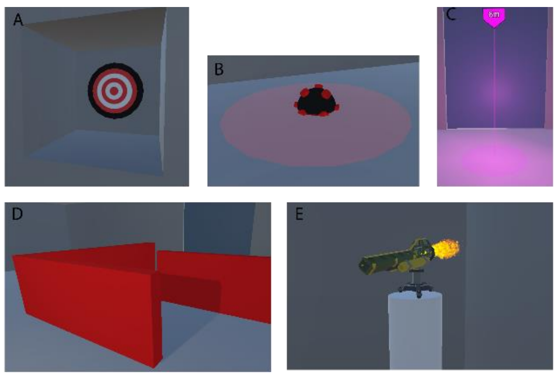
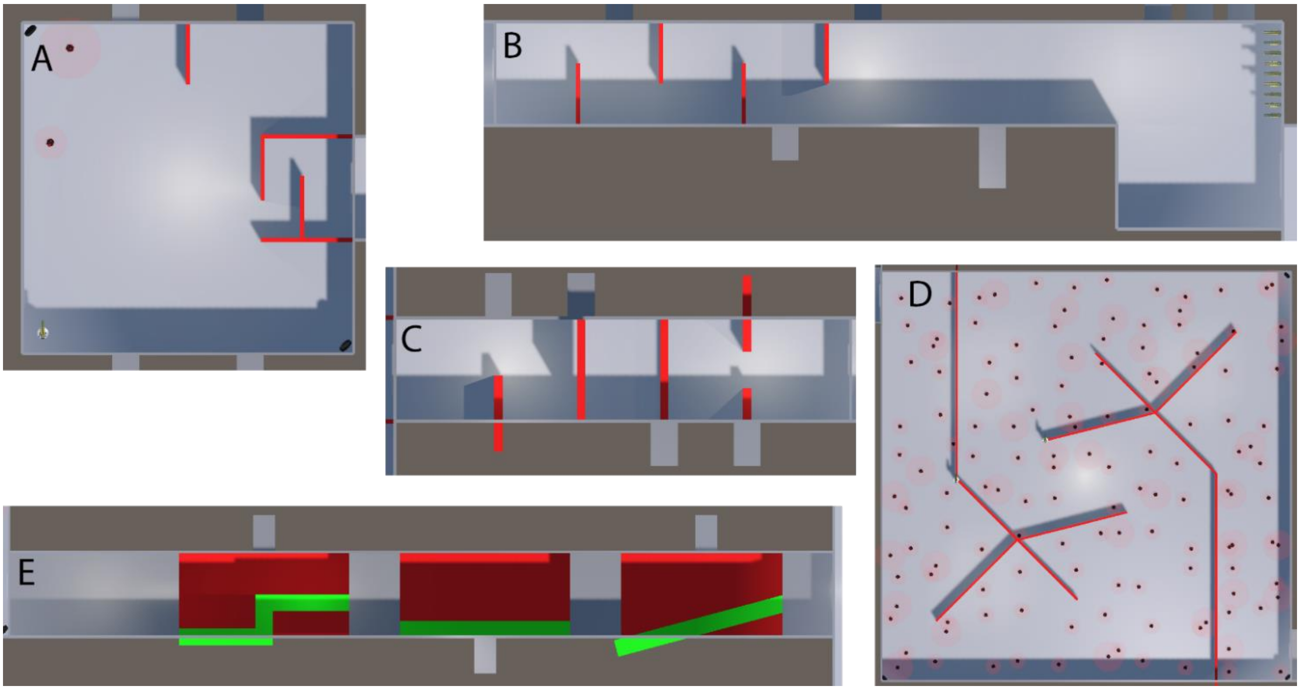


Fig 4. First person views of the tutorial room and the four main testing rooms: A) tutorial room, B) – E) main testing rooms





3. The number of times the player collided with an obstacle while progressing through the game. The obstacles include any red walls, mines, or rockets fired from turrets.

3.3.2 Enjoyment

Enjoyability was assessed as part of the post-playthrough survey in which the player is asked to rate their enjoyment of the control method on a scale from 0 (did not enjoy) to 4 (enjoyed very much). Observations were also made during the gameplay of anything that indicated any level of enjoyment, or lack thereof, such as signs of frustration.

3.3.3 Immersion

The post-playthrough survey also asked the participant to rate the level of immersion they experienced during the previous gameplay on a scale from 0 (no immersion) to 4 (fully immersive).

3.3.4 Difficulty

The survey included asking the participant to rate the difficulty of the control technique they had just used on a scale from 0 (very easy to use) to 4 (very difficult to use). Again, observations were also made during the testing process of any indications of difficulty level. This included the participant struggling to use the controls correctly, in which case, if the player was unable to progress, extra advice was given to aid with understanding the controls better. Observations could also have included if the participant was clearly having little to no difficulty using the controls, indicated by a quick completion of the tutorial room and subsequent rooms.

3.3.5 Sickness

After the gameplay, the participant was asked to describe their sickness/discomfort using the scale “None”, “Mild”, “Moderate”, “Severe”. They were then given a list of symptoms and asked to check whichever they were experiencing, or to leave it blank if they did not experience any sickness/discomfort. The list of possible symptoms was:

1. Headache
2. Eye strain
3. Dizziness
4. Nausea
5. Fatigue
6. Other (with space to write their own answer)

3.4 Procedure

The testing process consisted of three main stages: pre-testing, testing, and post-testing. The first was the pre-test, which was only performed once per participant. This was followed by performing the testing and post-testing stages three separate times, one for each control method being tested: joystick, human joystick, and the new method. The last method tested was always the human joystick, with the first two being the joystick and new method in a random order. The human joystick being last was decided for two reasons; first, it was unknown whether there would be enough time for each participant to complete the testing for all three methods. Hence, the other two methods were tested first since these corresponded to the minimum and intermediate objectives, which had higher priority than the advanced objectives. Second, due to the similarities between the new method and the human joystick method, it was decided that the former should be tested before the latter. This was because it was thought that testing one of these control methods first could affect the testing of the second, since they are both more physical methods compared to the joystick method. Hence, the new method was chosen to be tested first since it is the main focus of this project.

3.4.1 Participants

The experiment originally involved a sample of 17 participants (10 male, 7 female). All participants, except for one, were students at Durham University aged 18-24, with the remaining participant being under 18 and not studying at Durham University. Unfortunately, during the testing, one of the participants (a male aged 18-24) had to stop the process after only a couple of minutes due to sickness, and therefore did not have chance to generate any meaningful data for this project. Hence, the actual results only include data for 16 participants (9 male, 7 female).

Out of the 16 participants, when asked how often they play FPS games, 3 said "Never", 6 said "Rarely (less than once a month", 2 said "Once a month", 3 said "More than once a month", 1 said "Once a week", and 1 said "More than once a week". 12 out of 16 participants answers "Yes" when asked if they had any prior VR experience. When asked about experience with VR games, 4 said "Never played a VR game", 6 said "Played once", 5 said "Played several times", and 1 said "Play regularly". Finally, when asked if they usually experience any type of motion sickness, 9 said "Never", and 7 said "Occasionally".

3.4.2 Pre-Test

Participants were informed, prior to testing, that the purpose of the experiment was to test a new locomotion technique for navigating VR games. They were also informed of the structure of the test, specifically that they would be playing through the same game three separate times with different control methods each time, and would then complete a short survey after each playthrough. Participants were also made aware that engaging in VR gameplay could cause sickness and/or discomfort, and were assured that they could stop the testing process at any time, should they feel they need to.

After being fully informed of the process, the participant was asked to complete the pre-test survey. This included consenting to allow any data recorded during the testing process being used anonymously in this report, as well as answering the following questions using the corresponding options:

1. How old are you?
   a. Under 18
   b. 18-24
   c. 25-34
   d. 35-44
   e. 45-54
   f. 55-64
   g. Over 64
2. What gender do you identify as?
   a. Male
   b. Female
   c. Other (with space to enter own answer)
   d. Prefer not to say
3. On average, how often do you play first person shooter (FPS) games?
   a. Rarely (less than once a month)
   b. Once a month
   c. More than once a month
   d. Once a week
   e. More than once a week
   f. Daily
4. Do you have any experience with Virtual Reality (VR)?
   a. Yes
   b. No
5. How much experience do you have with VR games?
   a. Played once
   b. Played several times
   c. Play regularly
6. How often do you experience any type of motion experience? (e.g., travel sickness, sea sickness etc.)
   a. Never
   b. Occasionally
   c. Often
   d. Very often

The participant was then prompted, if ready, to equip the Oculus Rift S HMD and controllers, with help being offered if they were unsure of how to use the equipment. Once comfortable with the headset and controllers, the participant was guided towards the centre of the play area, which was a square approximately 3m by 3m. Before starting the testing, the participant was informed of the Oculus Guardian system and warned that the appearance of walls inside the game meant they were close to the edge of the play area and should stop moving. The game was then started for the first time using either the joystick method or the human joystick method.

The player started in the tutorial room, in which the various mechanics found in the game were explained and demonstrated, as well as the current control method. This was to ensure the participant's familiarity with the game mechanics and controls before starting the main test game. After this, the player was told they could spend as long as they needed in this room to get acquainted with the mechanics and the current controls, however after a few minutes they were encouraged to continue. Once ready, the player was told to follow the purple waypoint leading to the door to the next room, at which point the door would open and the main game would start. The player was also informed that opening the first door would start the timer for the main game, and that they should aim to complete the game as quickly as possible while also attempting to avoid any of the obstacles presented in the tutorial room. The tutorial room was included to hopefully make sure each participant was at the same level of comfort and familiarity with the game before starting, reducing the effect of initial inexperience on the performance results.

3.4.3 Testing

After reaching the first door, the main testing process began and the player proceeded to complete the rest of the game with little to no extra help or guidance. Only if the player was clearly struggling and unable to continue was assistance provided, and only until they had overcome whatever obstacle was hindering them. An effort was also made to keep the cable connected to the HMD out of the participant's way to prevent any trips or stumbles that were not caused by the gameplay experience itself. Throughout the testing stage, any significant and relevant observations or comments made by the participant were noted.

Once the player reached the final room, the game was finished, meaning the timer was stopped and any data recorded during gameplay was saved to a file. The participant was told they could remove the headset and was encouraged to sit down if they needed to.

3.4.4 Post-Test

After completing the game, the participant was asked to fill out the next section of the survey; the post-playthrough section. This section included the following questions and options, relating to the participant's experiences and opinions of the controls and gameplay:

1. Overall, how would you rate your enjoyment of the gameplay you just experienced?
   a. 0 (did not enjoy at all)
   b. 1
   c. 2
   d. 3
   e. 4 (very much enjoyed)
2. Overall, how would you rate the immersion of the control method you just used to play the game?
   a. 0 (not immersive)
   b. 1
   c. 2
   d. 3
   e. 4 (fully immersive)
3. Overall, how would you describe the difficulty of the controls you just used?
   a. 0 (very easy to use)
   b. 1
   c. 2
   d. 3
   e. 4 (very difficult to use)
4. What level of discomfort/sickness did you experience while playing the game with the controls you just used?
   a. None
   b. Mild
   c. Moderate
   d. Severe
5. What symptoms did you experience? (Leave blank if you did not experience any discomfort or sickness)
   a. Headache
   b. Eye strain
   c. Dizziness
   d. Nausea
   e. Fatigue
   f. Other (with space to enter own answer)

After completing the survey, the participant was offered the chance to take a break for as long as they need before continuing. This gave them the chance to recover from any potential sickness or discomfort they had experienced, which would reduce the effect this could have on any subsequent playthroughs.

If the current method being tested was the final method, the participant was then given one final question to answer:

1. Which control method did you prefer out of the ones you tested?
   a. First method
   b. Second method
   c. Third method

The methods were referred to as "First", "Second", and "Third" instead of their actual names to avoid confusion for the participant since they might not have tested the methods in the same order as they appeared in the options for the question. The order that each participant tested the methods was recorded to ensure the answers for this final question could be interpreted accurately.

If the current method was not the final method, the testing for the next method started once the participant was ready to continue.

Measure	Joystick	Human Joystick	New Method
Time taken (s)	M = 268.78, SD = 110.47	M = 329.86, SD = 70.56	M = 542.85, SD = 193.11
Shot accuracy (%)	M = 28.44, SD = 9.00	M = 30.19, SD = 7.04	M = 30.42, SD = 8.58
Obst[illegible]	[illegible]	[illegible]	[illegible]
Enjoyment	M = 3.31, SD = 0.77	M = 3.31, SD = 0.85	M = 2.75, SD = 0.97
Immersion	M = 2.56, SD = 1.06	M = 3.25, SD = 1.09	M = 2.81, SD = 1.01
Difficulty	M = 0.88, SD = 0.99	M = 1.75, SD = 0.75	M = 2.50, SD = 0.94
Sickness	M = 0.63, SD = 0.48	M = 0.81, SD = 0.95	M = 0.75, SD = 0.83

M = Mean, SD = Standard Deviation.

Table 1
Results of Various Measures

4 Results

4.1 Performance

The time to complete the test game, shown in Figure 6, was subjected to a paired t-test. This revealed that the differences between the time taken for the *new method* (M = 542.85, SD = 193.11) and the *joystick method* (M = 268.78, SD = 110.47) along with between the *new method* and the *Human Joystick method* (M = 329.86, SD = 70.56) were both statistically significant, with $p < 0.001$ for both. Whereas the difference between the *joystick method* and the *Human Joystick method* was not as significant, with $p < 0.1$.

The shot accuracy, shown in Figure 7, was also subjected to a paired t-test, revealing no significant differences between any of the joystick method (M = 28.44, SD = 9.00), Human Joystick method (M = 30.19, SD = 7.04), and new method (M = 30.42, SD = 8.58), with only $p < 1$ for all pairwise comparisons.

The number of obstacles hit by the player, displayed in Figure 8, was subjected to the same test, revealing no significant differences between the joystick method (M = 10.88, SD = 7.60) and the Human joystick method (M = 9.25, SD = 7.04) or the new method (M = 12.73, SD = 5.50), with $p < 0.3$ for both. However, the difference for the new method and the Human Joystick method was slightly more significant, with $p < 0.1$.

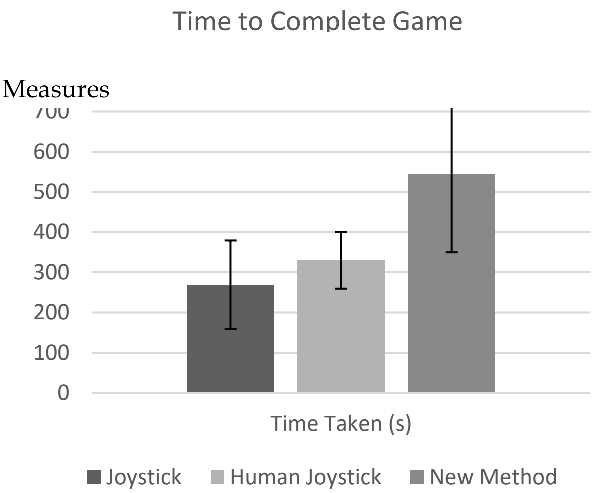
4.2 Enjoyment

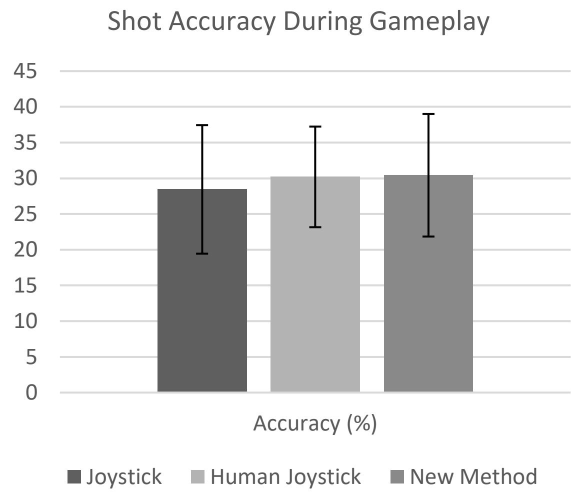
The results for the participants' enjoyment, shown in Figure 9, revealed, after being subjected to a paired t-test, a somewhat significant change between the new method (M = 2.75, SD = 0.97) and the joystick method (M = 3.31, SD = 0.77), with $p < 0.1$. The difference between the new method and the Human Joystick (M = 3.31, SD = 0.85) only gave a value of $p < 0.2$. Interestingly, the joystick method and Human Joystick method gave a value of $p = 1$, since the mean for both was equal.

After testing all three methods, 10 participants said that the Human Joystick was their favourite method, while 4 said the joystick method, and 2 said the new method.

4.3 Immersion

The results for the players' immersion ratings, displayed in Figure 9, revealed, after a paired t-test, that the differences between the new method (M = 2.81, SD = 1.01) and the Human Joystick method (M = 3.25, SD = 1.09), as well as the new method and the joystick method (M = 2.56, SD = 1.06) showed no significance, with $p < 0.2$ and $p < 0.5$, respectively. However, the difference between the Human Joystick method and the joystick method was shown to be statistically significant, with $p < 0.01$.





4.4 Difficulty

The results for the participants' difficulty ratings, shown in Figure 9, after being subjected to a paired t-test showed that the differences between all pairs of methods were statistically significant. The difference between the new method (M = 2.50, SD = 0.94) and the joystick method (M = 0.88, 0.99) gave a value of $p < 0.001$, the new method and the Human Joystick showed a significant difference with $p < 0.05$, and the Human Joystick method compared with the joystick method showed significance, with $p < 0.01$.

Fig 6. Mean time taken to complete the game (± SD)

4.5 Sickness

The results for the severity of sickness or discomfort experienced by the players, shown in Figure 9, revealed no significant differences between any of the methods tested after being subjected to a paired t-test.

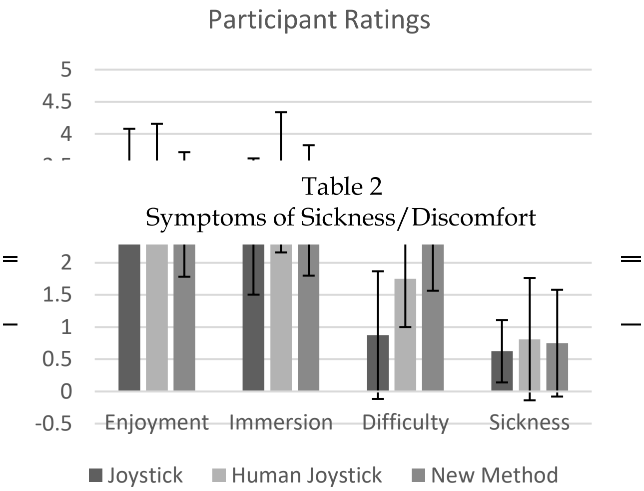


Table 2
Symptoms of Sickness/Discomfort

Fatigue	0	0	0
Neck Cramp	0	1	1
Overheating	0	0	1
Disorientation	1	0	0

The results for the symptoms experienced by the players are shown in Table 2. This contains the symptoms included in the questionnaire, as well as some that the participants added themselves; namely Neck Cramp, Overheating, and Disorientation.

5 Evaluation

5.1 Hypotheses

The results confirmed the hypothesis regarding time taken to complete the game, with the new method resulting in a mean time that was more than double that of the joystick method. However, the time taken for the Human Joystick method was not much greater than for the joystick method. From observing the testing process, it was

Fig 9. Mean ratings by participants for enjoyment, immersion, difficulty, and sickness (± SD)

clear that participants were generally struggling to gain any significant speed when using the new method, whereas the Human Joystick method allowed for quite fast travel when the player moved close to the edge of the play space. Also, it was noticed that many participants repeatedly drifted from the centre of the play space when using the new method, meaning they weren't where they thought they were when trying to move or stop moving. This severely hindered the performance of this method, since the players would constantly have to look at the ring on the floor and readjust. This could be improved by having the floor display also being displayed as part of the player's interface, or by extending the floor ring into a translucent cylinder around the player so they can always see where they are in relation to it without having to look down. This would likely improve the performance significantly, since, from observing the testing, when players were in the correct position and didn't need to adjust, they generally seemed to move quickly and with ease using this method.

The results seemed to disagree with the hypothesis regarding sickness, and instead seemingly confirm the opposite. The severity of sickness reported showed no

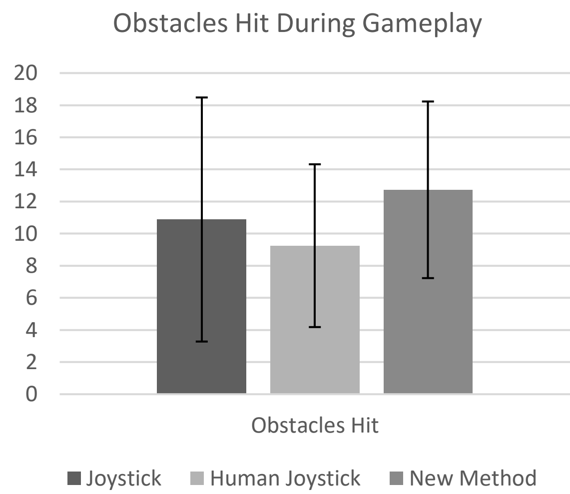
Fig 7. Mean accuracy of shots fired at targets during gameplay (± SD)

significant change, however the number of symptoms reported was greatly increased by the new method and the Human Joystick method over the joystick method. While the sickness caused by the Human Joystick method was expected, the sickness caused by the new method was not. This is likely due to the same issue as discussed previously; the player constantly having to look down and readjust likely worsened any experienced sickness or discomfort. Also, when off-centre, participants would repeatedly lunge back and forth in attempts to move faster or sometimes at all, which would also significantly affect any sickness or discomfort.

The enjoyment ratings for the joystick method and the Human Joystick were very similar, with the new method suffering a quite significant decrease over the other two. This is likely due, again, to the players' frustration of having to constantly readjust their position affecting their overall enjoyment. This does not agree with the proposed hypothesis regarding enjoyment, however, despite the enjoyment ratings for the Human Joystick method being very similar to that of the joystick method, the choice of favourite method was overwhelmingly in favour of the Human Joystick method over the other two.

5.2 Improvements

The tested method could be improved by changing the fixed centre of the "joystick" to follow the player around as they are Real Walking. The continuous motion aspect could then be activated using a controller button, with the



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centre of the joystick being set to the player's current location, similar to the way the "jumper" method works [23]. They could then still move forward and have the speed in-game match their real speed, but would not have to keep readjusting themselves to be in the centre of the room for this to work, since the centre would always be on them instead. The player would also have to be more aware of the edges of the play space since they would likely end up drifting away from the centre of the space.

6 Conclusions

In this paper, three locomotion methods were tested and evaluated, one of which was a new method proposed as an improved version of the Human Joystick that aimed to reduce the effects of motion sickness and increase enjoyment. The results of the testing determined that the new method failed at these criteria, with the Human Joystick being the preferred method for the majority of participants. However, this test did successfully demonstrate and evaluate two existing methods, the Human Joystick and standard joystick methods. This has also shown how much the experienced immersion affects the opinion of the locomotion method, since the Human Joystick was shown to be perceived as significantly more difficult to use than the standard joystick method, but was also significantly more immersive and became the majority's favourite. This suggests that VR game players are not as concerned with the difficulty or performance of the method they use, but with how immersive the experience is.

It was also discovered that the current implementation of the proposed new method has a fundamental flaw, namely the need to constantly look down and readjust your position. While this implementation failed to provide a better alternative to existing locomotion methods, the theory still stands that matching the player's speed would reduce motion sickness. However, in future work, this new method would be implemented again but in ways that don't require the player to be constantly checking their location, and that don't require a fixed centre to work. Likely, the idea of two "zones" would be removed entirely, instead allowing the player to choose when to switch between the Real Walking and continuous movement, such as with a button on a controller.

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