CMSC838C Final Project Report: Virtual Maze Navigation Using Different Locomotion Techniques

Pyone Thant Win, Christabel Acquaye, Sanjaya Lakmal, Pankayaraj Pathmanathan

1. Motivation and Background

Redirected walking (RDW) is a method of locomotion in virtual reality that allows participants to traverse a virtual environment much larger than the physical space being monitored. This technique cleverly alters the visual scene presented to the user, causing them to unknowingly adjust their position and/or direction to account for the perceived movement of the scene. Steering is a method of locomotion in virtual reality that allows the user to move in the virtual environment while staying in place in the physical world. This can be achieved in various ways. One way is by manipulating the position, orientation and tilt angles of the head-mounted display.

While RDW can provide a high degree of immersion to users as it makes users feel as though they are actually walking in the virtual world, it still requires a relatively large physical space to execute this. Steering does not require much physical space since users just need to play with the head-mounted display angle and head/joystick orientation. However, it induces motion sickness to users. The motivation of this study is to implement a hybrid locomotion system that partakes the best qualities of both locomotion methods (immersion and less use of physical space) while reducing the bad qualities from both (motion sickness, lack of immersion, use of a large physical space) for users to navigate virtual environments. We present qualitative and quantitative results based on user studies that were conducted on virtual maze navigation with RDW, Steering and our proposed Hybrid approaches.

2. Related Work

The recent developments in the metaverse has resulted in a large number of publications related to locomotion methods in virtual reality. We discuss three such papers that are closely aligned with our study. The authors of the paper [1] stated that many recently proposed RDW approaches are tested in simulations only. Authors conduct some simulation experiments and show that RDW is a chaotic process and hence the redirection performance for real and synthetic trajectories differs. They conclude that simulations alone are not a valid evaluation method of RDW applied to human users.

This study is inspired by the paper [2]. In this paper, authors published a VR game on a short procedurally generated maze environment. The locomotion methods considered in the paper are arm swing, walk-in-place (WIP), and trackpad movements. Players were directed to a SSQ questionnaire to measure the simulator sickness. Some of their key findings were arm swing was preferred subjectively and walk-in-place was the overall most sickness-inducing locomotion method.

In the paper [3] authors compared the effectiveness of Redirected Free exploration with distractors (RFEDs) with WIP and Joystick. Users had to perform tasks like navigation and object manipulation. Some of the key findings were that RFED interface performance was significantly better and RFED users had higher levels of presence and reported feeling more immersed in the virtual environment.

3. Methodology: Our Approach

3.1. Scene

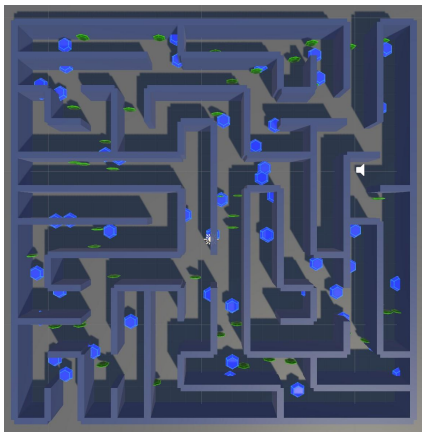
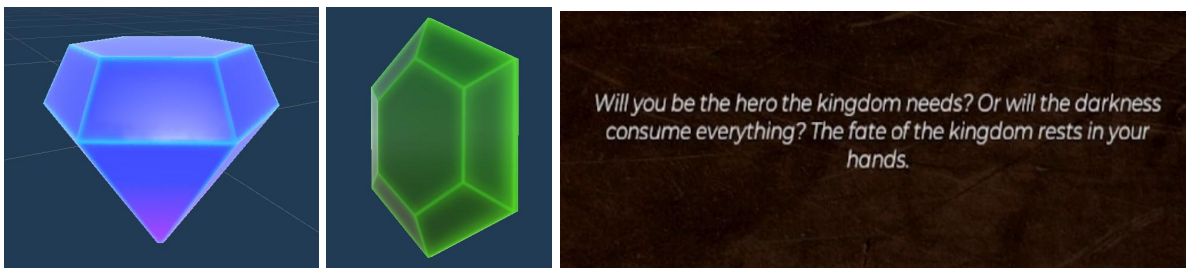


Figure 1. A top view of the virtual maze with the collectibles installed on random locations

A virtual maze with identical lighting and wall materials was designed for the project. The initial concept for the maze design involved constructing the environment with randomized walls to introduce a degree of uncertainty, ensuring that users couldn't exploit their knowledge from a previous run to navigate the maze more easily on subsequent attempts. Although based on the initial feedback the constant lighting and constant wall material was enough to induce an ambiguity over three trials. Thus the maze configuration was kept constant throughout the experiments. Furthermore, in order to induce immersion in the VR scene we have added a storyline with voice over and collectibles as described in Figure 2.



(a) (b) (c)

Figure 2. (a) Blue collectibles add points to the user's score (b) Green collectibles added additional time. A time counter was added for the maze along with the collectible. (c) shows the storyline that was used with a voice over presented to the user before the gameplay.

3.2. Implementation of Locomotion methods

3.2.1. Steering

The steering implementation is based on the PenguFly paper [4]. The tilt angle is computed from the upright position and if it reaches a threshold value the player is moved forward. Also, the speed of motion was proportional to the tilt angle so that users have the ability to navigate the maze in the speed they are comfortable with. The “A” Key on the right controller of the Oculus controller was programmed to start/stop steering on press.

3.2.2. RDW

The primary focus in RDW is to efficiently utilize physical space while meeting the demands of the virtual environment. Translation gain is applied to every step a user takes in the physical world so that users are moved twice the distance in the virtual environment. When a user reaches the physical boundary, we perform “reset” on the user. This is accomplished by adjusting the user's orientation when they reach a physical boundary, without altering the virtual environment. We also gave users an option to reset themselves using the “A” Key on the right controller of the Oculus controller.

3.2.3. Hybrid

The hybrid method combines both the steering and RDW techniques. Users can switch between these methods by pressing the "B" key on the right controller of the Oculus controller button. By default, the system is set to start with Redirected Walking, so pressing the "B" key switches to the steering method.

4. User Study

A user study was conducted to determine the effectiveness of the implemented locomotion methods. In total 12 users participated in the study. Each participant spent between 45 to 60 minutes on the study. A user is given 10-15 minutes to complete the maze for each trial from the 3 locomotion methods and a questionnaire is given after every phase to determine the sickness and immersion for that specific phase. Next a semi-structured interview was performed to gain additional feedback. Trial time and score of collectibles were also recorded for further analysis. These steps were repeated for the other two trials. The three locomotion methods were shuffled for different participants to counter ordering effect.

Figure 4. A participant using RDW to navigate the maze.

5. Results

The questionnaire responses gathered during experiments provides us with useful insights on how users interact with different locomotion techniques in virtual environments. Importantly, the questionnaire feedback revealed that participants did not experience as much discomfort during the Redirected Walking (RDW) sessions as they did for the steering sessions (Figure 1). Overall, the Hybrid sessions induced the least sickness among all three trials.

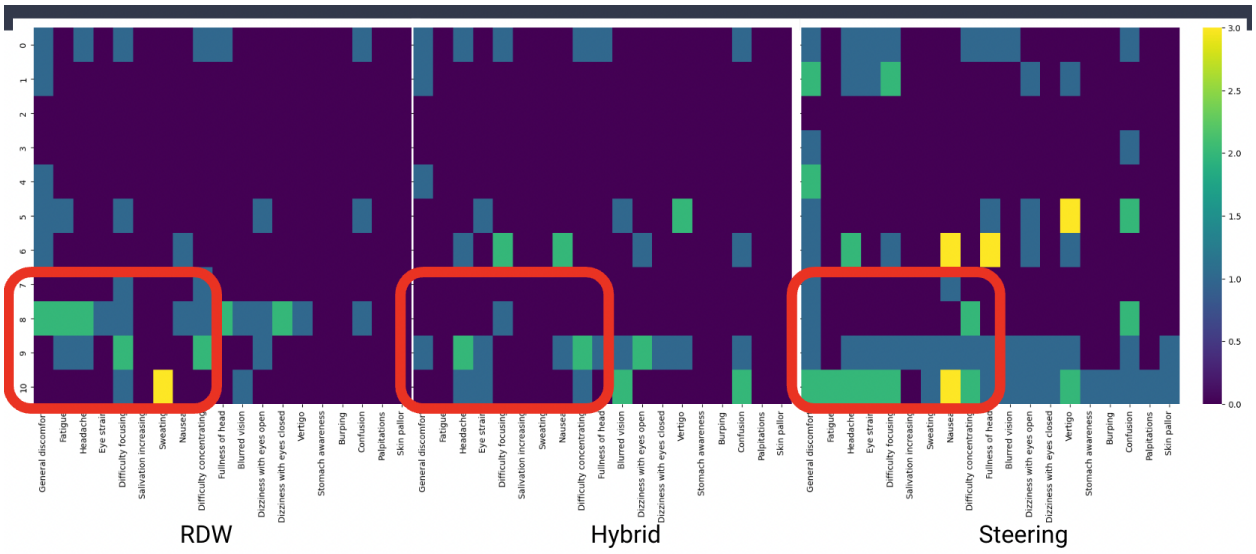


Figure 5: Heatmap Breakdown of the Sickness Questionnaire

The SUS presence questionnaire assesses the sense of immersion for the users. There are 5 questions for users to rate between 1 and 7. 1 indicates the least immersion and 7 indicates the most. Out of 35 total scores, In figure 6, users who started with hybrid sessions first reported the highest level of immersion (Y-axis). In all sessions, regardless of the ordering of sessions, Hybrid sessions resulted in the highest to the second highest immersion.

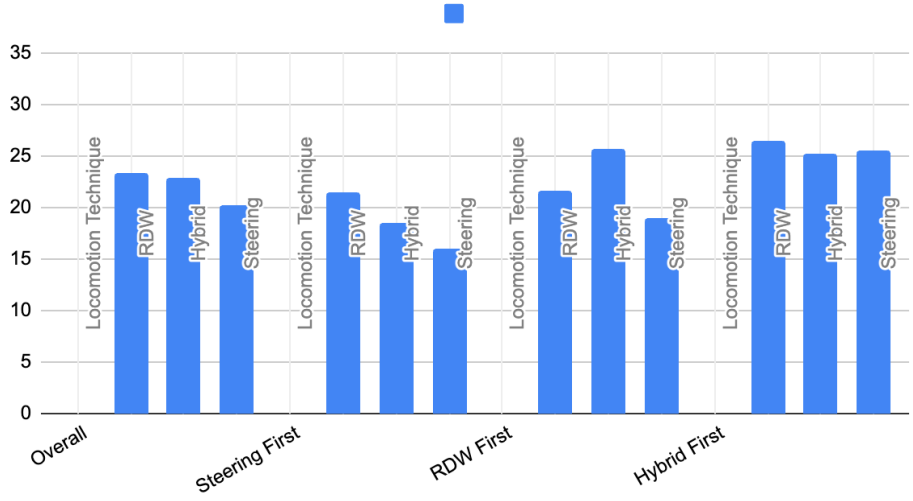


Figure 6: SUS presence questionnaire-overall

The time data collected from the experiments presents an interesting perspective on the effects of different locomotion techniques (Steering, Redirected Walking, and Hybrid) on user performance in terms of how much time they spent going through the maze and the collectibles they were able to pick up. More notably, it provides an initial exploration of the impact of the order in which these methods are experienced. The order of the experiments appears to have a significant impact on both time taken and scores achieved (Figure 7). For instance, users who performed the Steering experiment first (S-R-H) generally took less time compared to those who performed the same experiment later in the sequence, such as in the R-S-H and H-R-S orders. The same pattern is observed in the Redirected Walking experiment, where users who encountered it first (R-S-H) tended to score higher compared to when the experiment was performed later (Figure 8).

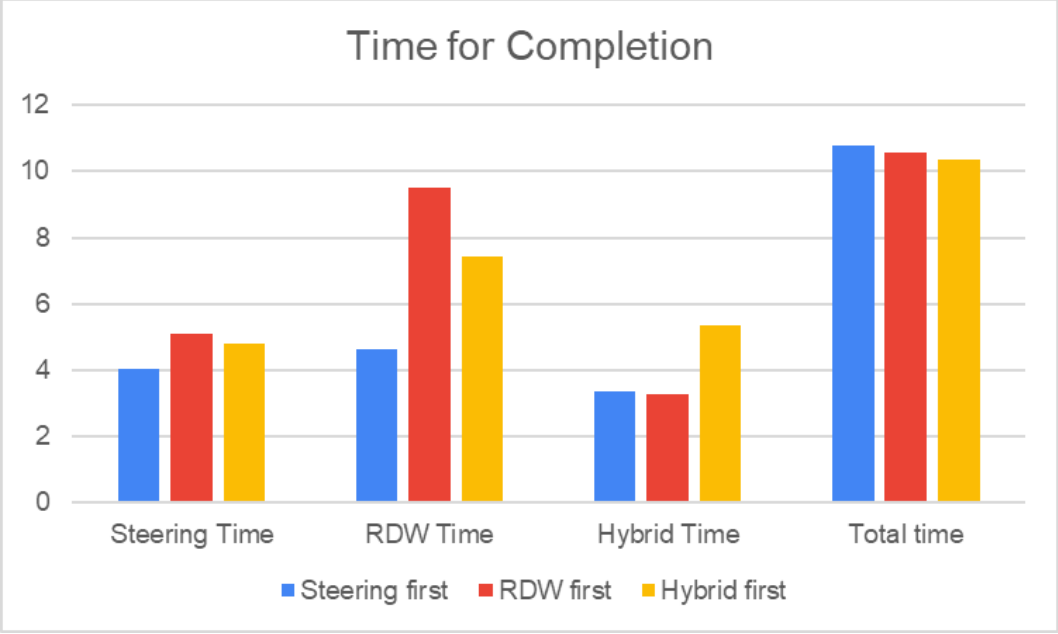


Figure 7: Time Completion vs Experiment Order

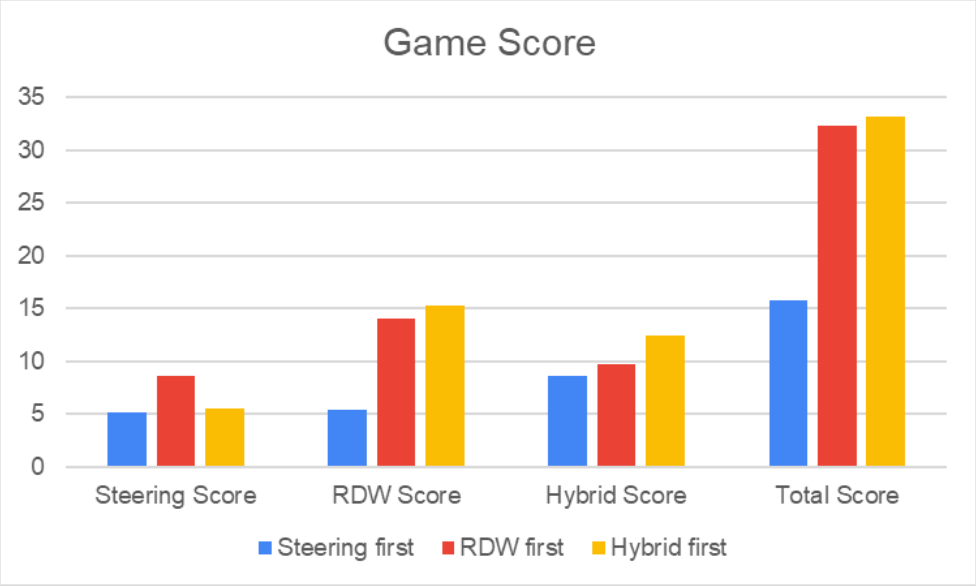


Figure 8: Score vs Experiment Order

Finally, the qualitative feedback from participants highlighted the unique challenges and enjoyable aspects of each locomotion method. For example, some found the Hybrid method initially difficult to get used to due to the nature of switching with button press and another button press for activation but reported to be enjoyable once mastered. There were 3 participants who liked the hybrid option and the fact that it allows users to switch between them. This subjective feedback provides an additional layer of understanding beyond the time data, helping us identify areas for improvement and potential user preferences. Additionally, having a storyline helps with immersion for many users. However, there was also a report that a limited space makes it less immersive.

6. Conclusion

In our final project for CMSC838C, we explored different locomotion methods for virtual reality, specifically focusing on combining steering and redirected walking (RDW) to create a hybrid system that is more user-friendly. To analyze the performance of this method, we also conducted a user study to evaluate. Based on the questionnaire and in-game analysis, our results consistently indicate that the hybrid approach is superior compared to the traditional methods in terms of the user immersion and the level of motion sickness.

One of the key challenges we faced was with the method of changing between two methods of locomotion and activating them. This proved to be less than ideal as most users forgot to press the activate key after the method was changed. Another challenge was ensuring safety and avoiding potential collisions or boundary breaches. For longer pathways in the maze, users tend to move faster so when they reach the boundary and see the Oculus guardian, they tend to get surprised.

Despite these challenges, the results from our user study indicated that the hybrid locomotion method was preferred due to its flexibility. Future research could explore different combinations of locomotion techniques and different virtual environments to investigate whether our results will stay consistent.

7. References

[1] C. Hirt, Y. Kompis, C. Holz and A. Kunz, "The Chaotic Behavior of Redirection – Revisiting Simulations in Redirected Walking," 2022 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), Christchurch, New Zealand, 2022, pp. 524-533, doi: 10.1109/VR51125.2022.00072.

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