Virtual Maze Navigation Using Different Locomotion Techniques

Pankayaraj Wen, John Feng

1. Introduction

In this project, we experimented with different locomotion methods present in the VR literature. We present qualitative and quantitative results based on a user study that was conducted on virtual maze navigation. Locomotion in VR can be categorized into 3 main categories: namely, Walking, Steering, and Selection based. Walking is more natural than the other two categories as the user can experience kinesthetic and vestibular stimulations. However, it is not always feasible because of limited physical space constraints. Redirected Walking (RDW) is a solution for the physical space constraints. Users are prompted when they reach a physical boundary to avoid any collisions. In steering, users have to direct a body part to move in a given direction. It can be categorized into view directed, hand directed, torso directed, and lean directed. The third category locomotion based on a selection. For example, when the user selects an object in the environment the user is teleported to that location. In this project we experimented only with the first two locomotion methods.

Several criteria should be considered when implementing RDW and Steering. The algorithm should be generalizable to suit different VR environments and any number of users. Also, safety is one of the most important considerations in the implementation. Cases such as collision with obstacles or other users and moving out of the boundary should be handled properly. Another aspect is the user experience. Users need to feel the immersive experience while devoid of the side effects such as motion sickness.

The motivation for this study comes from the lack of generalization of current state-of-the-art locomotion methods. Most of them are tested either using simulations or pre-defined paths. Hence, the results might not always be applicable to in-the-wild scenarios. This study is concerned with finding the middle ground between spatial gain and user immersion.

2. Related Work

The recent developments in the metaverse have 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 [1,9] 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 [2,5,6]. 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 where arm swing was preferred subjectively, and walk-in-place was the overall most sickness-inducing locomotion method.
In the paper [3,7,8] 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

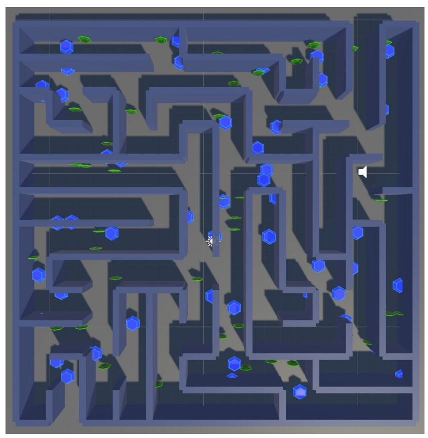
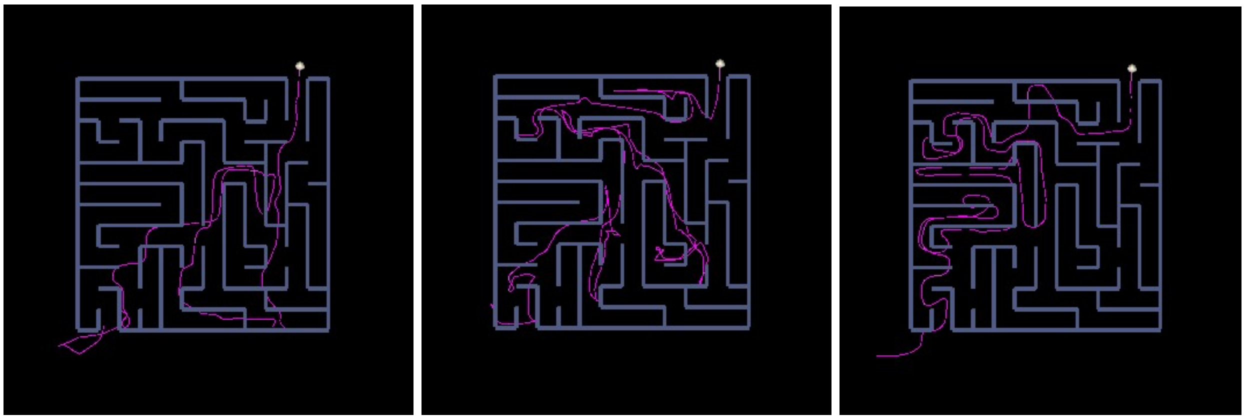


Figure 1. A top view of the virtual maze with the collectibles installed on random locations

In this project the scene was modeled after a virtual maze which had identical lighting and wall materials. The initial concept for the maze design involved constructing the environment with randomized walls. This was intended 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 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, 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.



(a) (b) (c)

Figure 3. The three diagrams showcase some typical paths of the users throughout the maze.

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 can 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. This is accomplished by adjusting the user's orientation when they reach a physical boundary, without altering the virtual environment. Additionally, we employed translation gain to optimize space usage. We also used the "A" Key on the right controller of the Oculus controller to help the user reset their orientation in the physical world.

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. After pressing "B," they need to press "A" to activate their desired locomotion method. 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. The user is given 10-15 minutes to complete the maze 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 remove the biases generated by a particular method.

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

5. Results

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. 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.

Previous research in the field has typically looked at individual locomotion methods in isolation. Our study extends this by considering not just the effects of different locomotion methods, but also the sequence in which they are experienced. Our results suggest that the order of exposure to different methods can have a significant impact on user performance. This adds a new dimension to our understanding of locomotion in virtual environments and suggests that future research should take into account the sequence of exposure to different methods.

Our analysis indicates that both the type of locomotion method and the order in which they are experienced significantly affect user performance. The Steering method generally took less time but offered lower scores, while Redirected Walking was more time-consuming but offered higher potential scores. The Hybrid method appeared to offer a balance, but was not completed by all participants, indicating a possible increased complexity.
This time sheet data also examines how switching locomotion methods impact user performance and, potentially, enjoyment in virtual environments offer users the flexibility to switch between methods as they see fit.

The addition of user-reported experiences and perceptions from the questionnaire responses from the experiments further enriches our understanding of user interactions with different locomotion techniques in virtual environments. Firstly, the questionnaire responses indicate that participants generally did not experience significant discomfort during the RDW walking sessions. Secondly, the sense of immersion, an integral aspect of the VR experience, varied across participants. This could potentially be attributed to the different locomotion methods and their order of exposure. For instance, it might be that certain methods, such as the Hybrid method, provide a higher sense of immersion, but this is only felt if participants have already experienced the other two methods. Future work could seek to explore this interplay between locomotion methods and the sense of immersion.

Thirdly, 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 but enjoyable once mastered. This subjective feedback provides an additional layer of understanding beyond the time data, helping us identify areas for improvement and potential user preferences.

Finally, the comparison between the three locomotion methods based on the questionnaire responses complements the findings from the time data. For instance, while the time data suggested that the Hybrid method might be more complex due to its incomplete completion rate, the questionnaire responses provided insights into why this might be the case, such as the initial difficulty in understanding the hybrid controls.
Importantly, our results suggest that the order of exposure to different locomotion methods can significantly influence user performance. This finding is a novel contribution to the body of knowledge in this field. It suggests that virtual environment designers should consider not just the choice of locomotion method, but also the sequence in which users are exposed to different methods. Future research could further explore this sequence effect to help optimize user performance in virtual environments. See Appendix for more details on these results.

6. Conclusion

In our final project for CMSC838C, we explored different locomotion methods for virtual reality, specifically focusing on steering and redirected walking (RDW). Our main motivation was to improve upon current locomotion methods, which lack generalization and often fail to perform well in real-world scenarios. We also introduced a new hybrid method, a combination of steering and RDW, and conducted a user study to evaluate these three locomotion methods.

One of the key challenges we faced was with the implementation of RDW. We needed to optimize the physical space to meet the requirements of the virtual environment, which required triggering the user to press a key to reset their view upon reaching a physical boundary. This proved to be less than ideal as most users forgot to press the same key again after the reset was completed.

Another challenge was ensuring safety and avoiding potential collisions or boundary breaches. User experience, such as preventing motion sickness while maintaining an immersive experience, was also a

critical consideration.

Despite these challenges, the results from our user study indicated that the hybrid locomotion method was preferred due to its flexibility. Interestingly, the order in which the users were exposed to the different methods significantly influenced their performance, a novel finding which adds a new dimension to our understanding of locomotion in virtual environments. Future research could further explore this sequence effect to optimize user performance in virtual environments.

7. References

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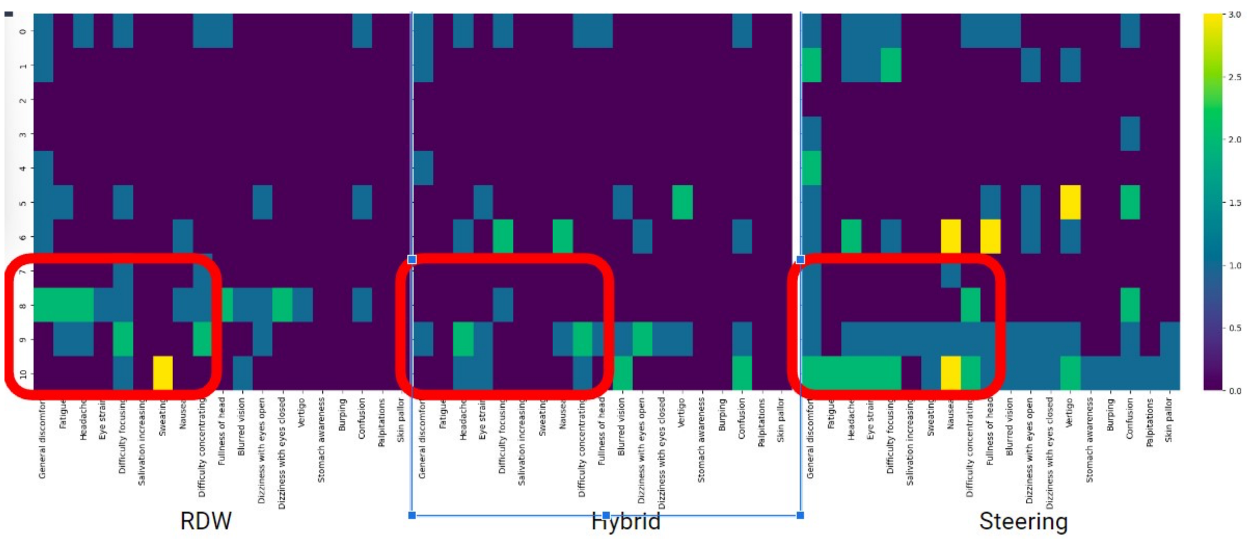
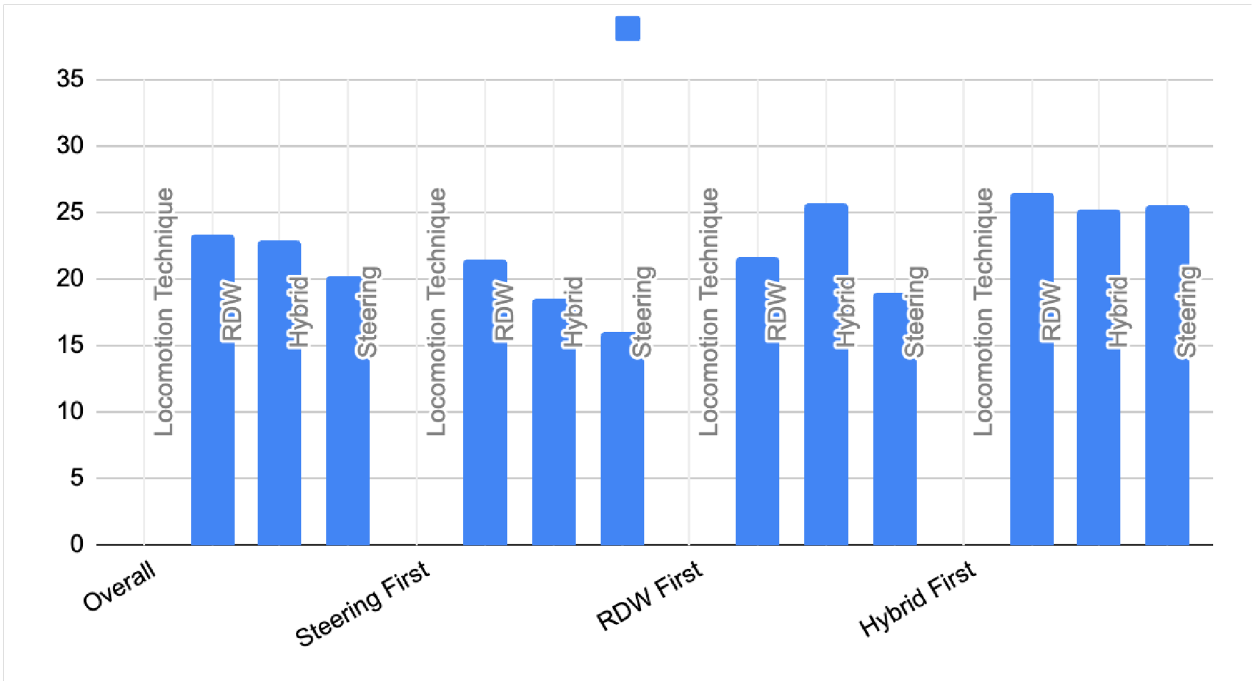
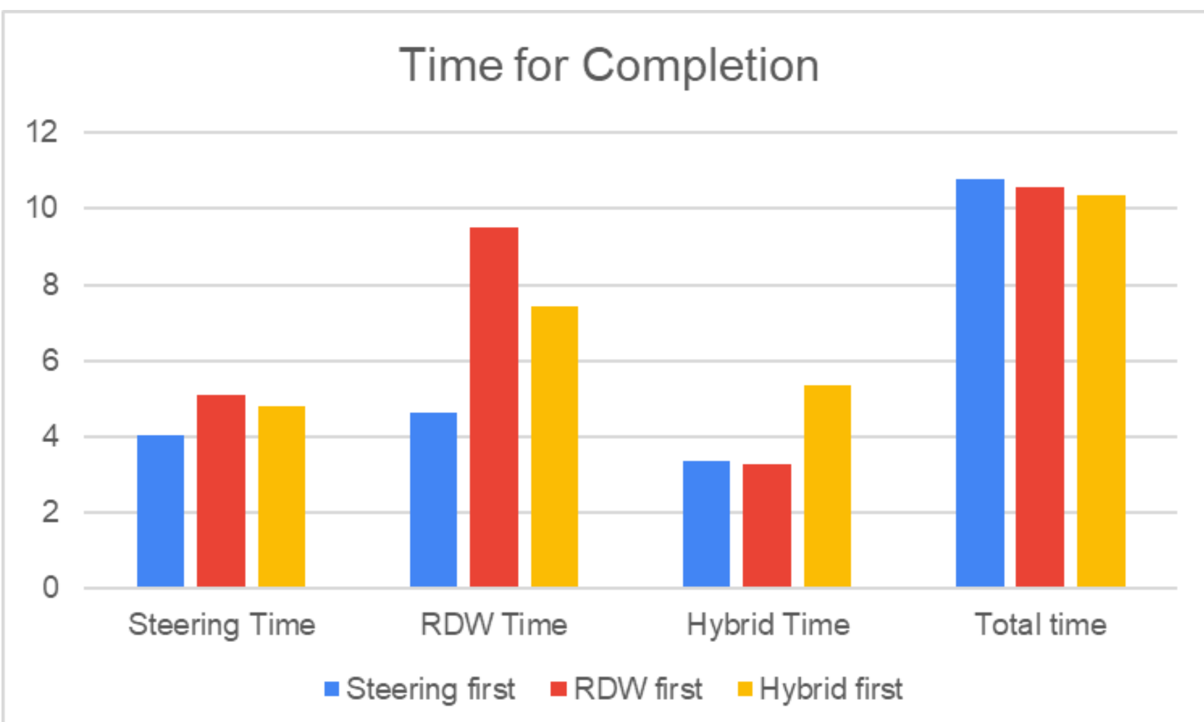
8. Appendix:



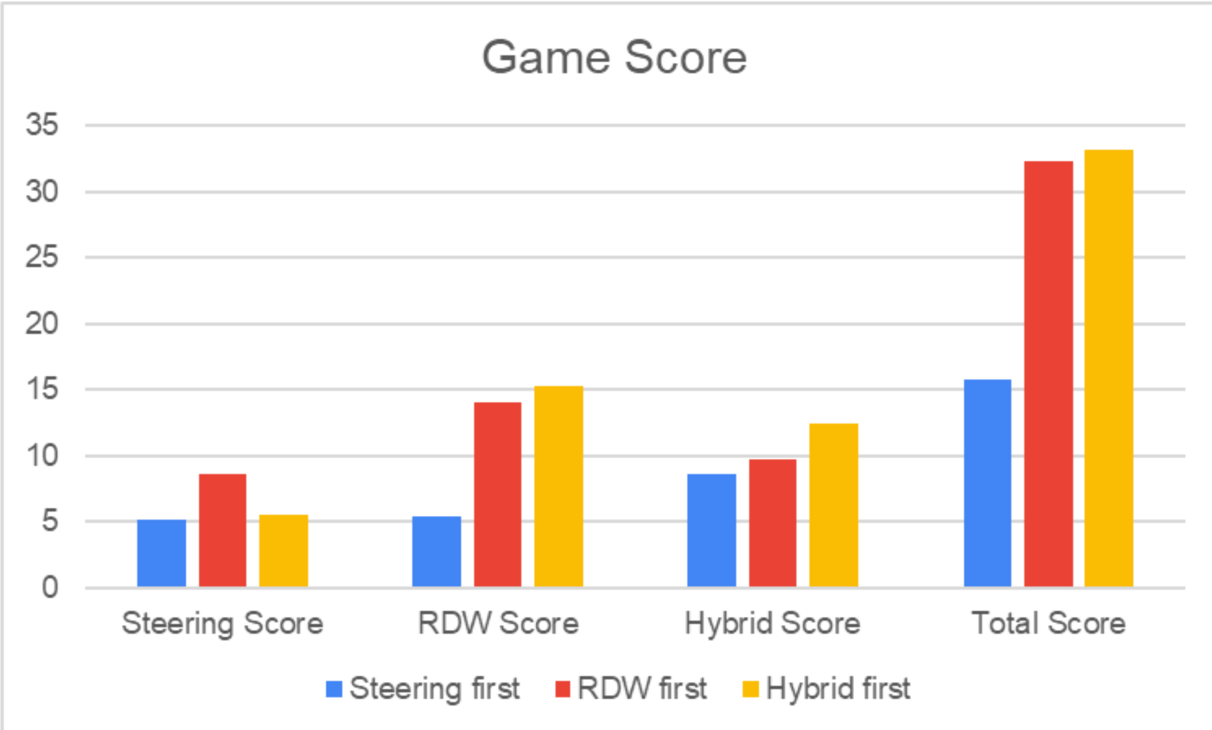
Sickness Questionnaire - Overall



SUS presence questionnaire-overall



Time Completion vs Experiment Order



Score vs Experiment Order