Redirected Walking on Meta Quest 2

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Table of Contents

Introduction

Tietronix Software, Inc. is working on addressing the problem of traversing large virtual environments while being physically present in a small room using Redirected walking (RW) algorithms in VR devices. So, they can train astronauts by providing an immersive experience through infinite walking on virtual worlds like Moon and Mars surfaces while confined to limited physical space in the real world.

Although VR has tremendous potential in training sessions due to its immersive capabilities, the user's physical location can still limit their experience. Achieving infinite walking in a virtual world with limited physical space is a challenging problem, but it has garnered significant research interest in recent years.

We aim to research how we can use various existing RDW algorithms to achieve Infinite walking while using VR devices to explore large virtual spaces. Also, to find which redirected walking algorithm is suitable to achieve these criteria.

Applications/Benefits

Here are some current works in this area:

1. Redirected Walking: Redirected walking (RDW) is an algorithm that uses subtle changes in the virtual environment to trick the user's senses into thinking they are walking in a straight line while, in reality, they are walking in a circle. This technique enables users to walk infinitely in virtual space while being physically present in a limited space.
2. Omni-Directional Treadmills: Omni-directional treadmills are platforms that allow users to walk in any direction while remaining in a small physical space. These treadmills typically use a low-friction surface and a curved platform to enable users to walk in any direction.
3. Wearable Haptic Devices: Wearable haptic devices are devices that provide haptic feedback to the user's feet to simulate walking. These devices can be worn on the user's feet and use vibrations or pressure to simulate walking.
4. Room-Scale VR: Room-scale VR is a VR experience that allows users to physically walk around in a designated area while wearing a VR headset. The VR system tracks the user's movements, allowing them to move around in the virtual world as they would in the real world.

In this paper, we compared the Redirected Walking algorithm present in the paper [1] with other methods in papers [2][3][5], concluding how this method helps achieve an immersive experience causing no scene distortions or noticeable translation/rotation gains to the virtual world view while redirecting users. Moreover, it showed the importance of saccades for implementing this algorithm. This algorithm is practical for redirected users in spaces as small as 12.25 sq.m. Furthermore, we can extend this algorithm to track multiple users and redirect them along a predetermined path.

Related Research

There are several approaches that our team has come across while researching redirected walking. The approach we're trying to implement is "Using Dynamic Saccadic Redirection to redirect user in achieving infinite walking".

The other research that our team has come across are as follows:

In the process of researching alternatives available for redirected walking algorithms, we identified other research on achieving infinite walking in virtual reality (VR) with limited physical space is being conducted by various researchers and organizations worldwide. Here are some current research efforts in this area:

1. University of Illinois at Urbana-Champaign: Researchers at the University of Illinois are developing a system called "walk-through virtuality," which uses a combination of redirected walking, room-scale VR, and omnidirectional treadmills to enable users to walk in any direction while remaining in a small physical space.
2. University of Tokyo: Researchers at the University of Tokyo are working on a technique called "omnidirectional walking-in-place," which uses a combination of wearable haptic devices and visual stimuli to simulate walking in a virtual environment. The system allows users to walk infinitely in any direction while remaining in a small physical space.
3. Stanford University: Researchers at Stanford University are working on a system called "Wireality" that uses a combination of redirected walking and physical wires to enable users to walk infinitely in a virtual environment while being physically confined to a small space.
4. Fraunhofer Institute for Telecommunications: Researchers at the Fraunhofer Institute for Telecommunications in Berlin are developing a system called "RoomShift," which uses a combination of sensor fusion and redirected walking to enable users to walk infinitely in a virtual environment while being physically confined to a small space.
5. University of Canterbury: Researchers at the University of Canterbury in New Zealand are working on a system called "Cybershoes" that uses a combination of wearable shoes and sensor fusion to enable users to walk in a virtual environment while remaining in a small physical space.

As VR technology continues to advance, we can expect to see further research in this area, leading to even more innovative solutions.

The "dynamic saccadic redirection" algorithm has an advantage over other research efforts in that it does not require any additional hardware or equipment other than a VR Head Mounted Display (HMD) and a small physical space. This means that users can walk indefinitely in a virtual environment without the need for costly treadmills or other specialized equipment.

Furthermore, this algorithm is intended to be adaptable to various virtual environments and user preferences. Based on the user's eye, head and body movements, the algorithm can adjust the redirection angles and distances, making the experience more natural and comfortable.

Another benefit of using this algorithm is that it can reduce motion sickness and other discomfort associated with virtual reality experiences. The algorithm can help to maintain a user's sense of balance and reduce the risk of motion sickness or other adverse side effects by dynamically adjusting the redirection angles and distances.

Overall, this algorithm provides a simple, flexible, and comfortable solution for infinite walking in virtual reality with limited physical space, making it a promising approach for future VR applications.

Requirements

Meta Quest-2

Meta Quest-2 is a virtual reality headset from Meta, and formerly named Facebook reality labs. Released in 2020 and successor of Meta Quest. It is powered by Qualcomm Snapdragon XR2 processor including the resolution of 1832 x 1920 pixels per eye and 90Hz refresh rate with field view of 100 degrees. It is used for a variety of applications which are compatible with a wide range of VR software.

It provides developers with the ability to build, test and optimize VR applications by allowing the developers to set up the development environment. It also provides different kinds of features like collaboration and publishing. Developers can work on the same VR project even if they are in different locations and able to publish it on the Oculus Store or any other platforms.

Unreal Engine

Unreal engine is a game engine developed by Epic games, which provides a set of tools and features to create complex VR experiences. It is known for its advanced graphic capabilities including a real-time rendering system. It is used to create interactive experiences such as virtual reality and augmented reality applications.

In addition, Unreal Engine offers built-in support for VR devices and allows developers to easily create VR experiences that are optimized for specific hardware, and to quickly iterate and test their projects in a VR environment. Features available in Unreal engine are High-quality 3D graphics, Blueprint visual scripting, VR support, Cross platform development, blueprint networking, live coding, Asset management.

Android studio:

Android studio is an IDE (Integrated Development Environment) used to develop Android applications. It is developed by Google, and it is based on the IntelliJ IDEA community edition. It provides a set of tools for developing, testing, and designing android applications. Features that are available in android studio are Layout editor, Code editor, Gradle build system, Android emulator, Debugging tools, Testing tools and Collaboration tools.

Android studio is not implicitly used for developing the intended software; however it can be used to develop VR applications for android devices that are built using Google VR SDK, also known as Google cardboard SDK. Some of the available key features are Head tracking, Rendering, Input Handling and Audio.

Visual Studio

Visual studio is an IDE developed by Microsoft, which is used for developing different kinds of applications like desktop applications, web applications, mobile applications, and video games. It supports multiple programming languages including C++, C#, Java, Python, and others. Key features of visual studio are Code editor, Debugging tools, Testing tools, Project management, Solution management, UI design tools, Cross-platform development, Azure integration, Extension support.

System Architecture

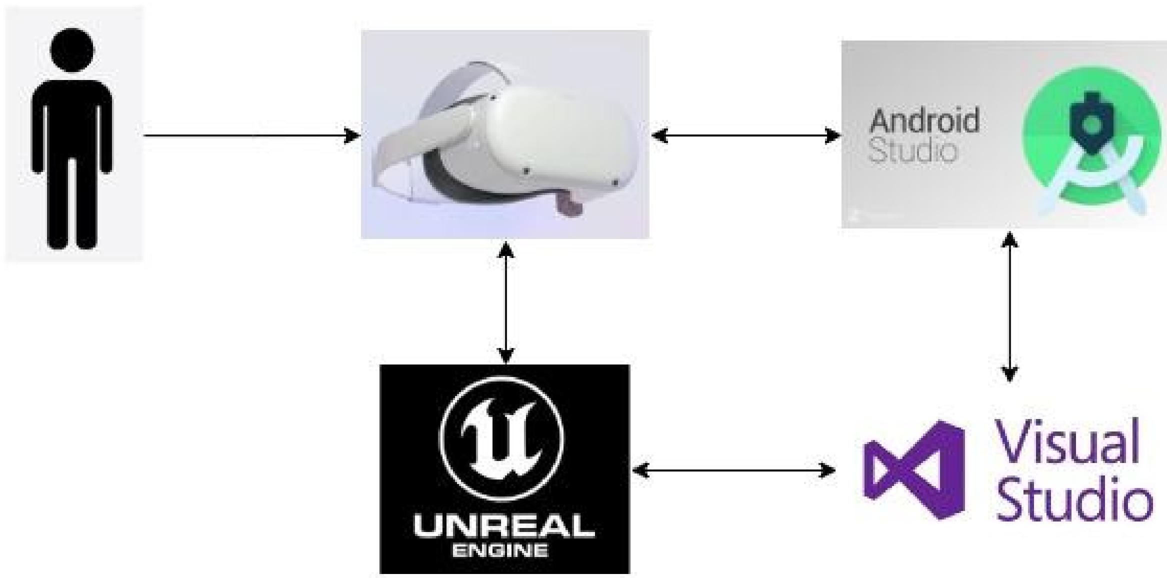

Fig. 1 System Architecture (User, Meta Quest 2, Android Studio, Visual Studio, Unreal Engine

Developers will set up a development environment that includes installing Android studio, Unreal Engine and Visual studio. Unreal Engine is the core game engine and the developing environment that provides the tools and frameworks for developing the intended application. Both android studio and visual studio are intended to write code that interfaces with the engine and to manage in the process of build and deployment for the application.

Primarily Android studio is used for deploying applications on android devices like Meta Quest-2. It provides all the necessary tools and frameworks for building the application including Android SDK and NDK. By integrating android studio to Unreal engine editor, we can use full advantages and capabilities of the android platform.

On the other hand, visual studio is used primarily for writing C++ code that interfaces with the Unreal engine. The intended code for the development of project is written in C++ and visual studio provides a powerful IDE for developing and debugging the code.

Implementation / Methodology

To implement the saccadic redirection method in the redirected walking algorithm, we first conducted a thorough review of existing literature on the topic. We then designed a series of experiments to test and optimize the effectiveness of the saccadic redirection method in our virtual environment.

During the experiments, we tracked the user's movements in real-time using the Oculus Quest 2 and recorded their walking path in the virtual environment. We then analyzed the data to identify the user's saccadic eye movements and their impact on the user's perception of their walking path.

Based on our findings, we developed and refined the saccadic redirection algorithm to ensure that it provides a seamless and natural VR experience for users. We also performed several user testing sessions to obtain feedback and further optimize the algorithm's effectiveness.

Overall, our methodology involved a combination of literature review, experimentation, data analysis, and user testing to develop and refine the saccadic redirection method in the redirected walking algorithm, and to ensure that it provides a compelling and immersive VR experience for users.

The saccadic redirection method is a redirected walking technique that leverages the natural eye movements known as saccades to subtly manipulate the user's perception of their virtual environment. Saccades are rapid eye movements that occur when the eyes shift focus from one point to another, and they are a natural part of human vision.

In the context of redirected walking, the saccadic redirection method works as follows:

1. The user is walking through a virtual environment that is smaller than the available physical space.

2. As the user's eyes make saccadic movements, the virtual environment is subtly adjusted in the direction of the saccade, typically during the brief moment of eye movement when the user's vision is temporarily suppressed.

3. The adjustments to the virtual environment are carefully calculated to be imperceptible to the user, so that they do not notice the changes.

4. By using these subtle adjustments, the user's perception of their position and direction of motion can be altered without them realizing it.

5. The saccadic redirection method can be combined with other techniques, such as curvature gain or change blindness, to further enhance the effectiveness of redirected walking.

6. The adjustments to the virtual environment can be dynamically adapted based on the user's movements and eye movements, so that the virtual environment always feels natural and intuitive to navigate.

The saccadic redirection method has been shown to be effective at increasing the perceived size of a virtual space, but it does have some limitations. For example, it requires precise tracking of the user's eye movements, which may not be available in all VR systems. Additionally, it may not be effective for users who have impaired or limited eye movements, or who are prone to motion sickness or discomfort in VR environments.

Project Management

This section describes the project milestones, their due dates, and their current status. The milestones in this report should match those on the team web site. If any milestone was late or not completed, you may provide an explanation.

Key code:
S1 = Boinapally, Sushmitha Rao
S2 = Kerketta, Vandana
S3 = Maram, Bharath Reddy
S4 = Vangaveti, Jagadeesh Chandra

Comment: The Key code is a way to abbreviate student names. Notice the names are in alphabetical order by last name.

Table 1: Project Timeline and Contributions

Sprint	User Story	Percent Contributions	Status
Sprint 1	User Story 1	S2 (100)	**Completed**
Sprint 1	User Story 2	S1 (20), S2 (80)	**Completed**
Sprint 1	User Story 3	S3 (50), S1(50)	**Completed**
Sprint 1	User Story 4	S4 (100)	**Completed**

Sprint	User Story	Percent Contributions	Status
Sprint 1	User Story 1	S2 (100)	**Completed**
Sprint 1	User Story 2	S1 (20), S2 (80)	**Completed**
Sprint 1	User Story 3	S3 (100)	**Completed**
Sprint 1	User Story 4	S4 (100)	**Completed**

Conclusion

Our project focuses on enabling infinite walking in VR while present in limited physical space. Traditional methods such as treadmills are expensive and restrict user movements, so we have developed an optimization that considers user behavior and physical changes, while avoiding static obstacles.

Our approach utilizes saccadic redirection, where we modify the camera viewport based on head rotation or ongoing saccade, subject to perpetual limits. We also employ saccadic detection, which calculates the angle difference between the current and previous gaze direction, setting the saccade gain threshold if the difference exceeds a certain threshold.

To determine the best virtual camera orientation for redirection, we use dynamic path planning based on the saccade detection thresholds and the physical space around the user. After the final iteration in path planning, a direction and magnitude of desired redirection are returned.

In addition, we have incorporated temporally-modulated stimuli in a user's visual periphery to induce visual saccades, using a technique called SGD. Our approach is useful for training astronauts on the moon surface, providing a complete immersion effect, and achieving infinite walking in limited physical space.

Future Work

- **Rotation-based redirection during saccades** is effective in both room-scale and large-scale VR.

- The GPU implementation allows for **real-time path planning** and dynamic adjustment to **moving obstacles** and **changing geometry**.

- **Future improvements** may involve **robotics and AI** for faster and more robust redirection planning in dynamic environments.

- The current approach uses only **rotational gain**, which simplifies real-time planning. Future work aims to include **translational gain** without losing real-time performance.

- Opportunities for system enhancement include:
  - **Saccade prediction** to reduce tracking latency.
  - **Learning-based approaches** to improve gaze guidance.
  - **Redirection during blink suppression** for more frequent opportunities.
  - **Distractors** to encourage more eye movement.

- Compared to **warping-based methods**, the **rigid-transformation-based redirection** avoids distracting visual distortions, making it more suited for open virtual spaces.

- Future work may explore **limited warping** to enhance consistency between virtual and physical environments, especially in mixed reality.

- The **space-saving benefits** of the system increase with larger physical areas.

- Further tuning for **larger physical areas** could provide additional gains.

References

[1] Qi Sun, Anjul Patney, Li-Yi Wei, Omer Shapira, Jingwan Lu, Paul Asente, Suwen Zhu, Morgan Mcguire, David Luebke, and Arie Kaufman. 2018. Towards virtual reality infinite walking: dynamic saccadic redirection. ACM Trans. Graph. 37, 4, Article 67 (August 2018), 13 pages. https://doi.org/10.1145/3197517.3201294

[2] J. Thomas and E. S. Rosenberg, "A General Reactive Algorithm for Redirected Walking Using Artificial Potential Functions," 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), Osaka, Japan, 2019, pp. 56-62, doi: 10.1109/VR.2019.8797983.

[3] Qi, M., Liu, Y. & Cui, J. A mapping-based redirected walking algorithm for large-scale VR. Virtual Reality 27, 2745–2756 (2023). https://doi.org/10.1007/s10055-023-00841-9

[4] M. Qi, Y. Liu and J. Cui, "A Novel Redirected Walking Algorithm for VR Navigation in Small Tracking Area," 2021 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), Lisbon, Portugal, 2021, pp. 518-519, doi: 10.1109/VRW52623.2021.00141.

[5] T. Dong, Y. Song, Y. Shen and J. Fan, "Simulation and Evaluation of Three-User Redirected Walking Algorithm in Shared Physical Spaces," 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), Osaka, Japan, 2019, pp. 894-895, doi: 10.1109/VR.2019.8798319.

[6] E. Hodgson, E. Bachmann and T. Thrash, "Performance of Redirected Walking Algorithms in a Constrained Virtual World," in IEEE Transactions on Visualization and Computer Graphics, vol. 20, no. 4, pp. 579-587, April 2014, doi: 10.1109/TVCG.2014.34.

[7] C. T. Neth, J. L. Souman, D. Engel, U. Kloos, H. H. Bulthoff and B. J. Mohler, "Velocity-Dependent Dynamic Curvature Gain for Redirected Walking," in IEEE Transactions on Visualization and Computer Graphics, vol. 18, no. 7, pp. 1041-1052, July 2012, doi: 10.1109/TVCG.2011.275.

[8] R. R. Strauss, R. Ramanujan, A. Becker and T. C. Peck, "A Steering Algorithm for Redirected Walking Using Reinforcement Learning," in IEEE Transactions on Visualization and Computer Graphics, vol. 26, no. 5, pp. 1955-1963, May 2020, doi: 10.1109/TVCG.2020.2973060.

[9] M. Kanani, Y. Al-Jabir, S. Al-Ghanim and O. Halabi, "Enhanced redirected walking algorithm," 2017 6th International Conference on Information and Communication Technology and Accessibility (ICTA), Muscat, Oman, 2017, pp. 1-2, doi: 10.1109/ICTA.2017.8336063.

[10] N. L. Williams, "Robust Redirected Walking in the Wild," 2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), Christchurch, New Zealand, 2022, pp. 922-923, doi: 10.1109/VRW55335.2022.00312.

[11] E. Hodgson and E. Bachmann, "Comparing Four Approaches to Generalized Redirected Walking: Simulation and Live User Data," in IEEE Transactions on Visualization and Computer Graphics, vol. 19, no. 4, pp. 634-643, April 2013, doi: 10.1109/TVCG.2013.28.

[12] L. Bölling, N. Stein, F. Steinicke and M. Lappe, "Shrinking Circles: Adaptation to Increased Curvature Gain in Redirected Walking," in IEEE Transactions on Visualization and Computer Graphics, vol. 25, no. 5, pp. 2032-2039, May 2019, doi: 10.1109/TVCG.2019.2899228.

[13] M. Azmandian, R. Yahata, T. Grechkin, J. Thomas and E. S. Rosenberg, "Validating Simulation-Based Evaluation of Redirected Walking Systems," in IEEE Transactions on Visualization and Computer Graphics, vol. 28, no. 5, pp. 2288-2298, May 2022, doi: 10.1109/TVCG.2022.3150466.

[14] S. -H. Zhang, C. Chen and S. Zollmann, "One-Step Out-of-Place Resetting for Redirected Walking in VR," in IEEE Transactions on Visualization and Computer Graphics, vol. 29, no. 7, pp. 3327-3339, 1 July 2023, doi: 10.1109/TVCG.2022.3158609.

[15] D. -H. Min, D. -Y. Lee, Y. -H. Cho and I. -K. Lee, "Shaking Hands in Virtual Space: Recovery in Redirected Walking for Direct Interaction between Two Users," 2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), Atlanta, GA, USA, 2020, pp. 164-173, doi: 10.1109/VR46266.2020.00035.

Glossary

- **API - Application Programming Interface.** It is a set of rules and protocols that allows different software applications to communicate with each other.
- **AR - Augmented Reality.** It is a technology that overlays digital information (such as images, sounds, or text) onto the real world, enhancing the user's perception of their physical environment.
- **HMD - Head Mounted Display.** It is a device worn on the head that displays images or video directly in front of the user's eyes.
- **IDE - Integrated Development Environment.** It is a software application that provides comprehensive tools to help developers write, test, and debug their code efficiently.
- **NDK - Native Development Kit.** An NDK is a specialized development kit that allows developers to write portions of their software in native code (such as C or C++) instead of relying entirely on higher-level languages like Java (in Android development).
- **Saccades -** Saccades are rapid, jerky movements of the eyes that occur when a person quickly shifts their focus from one point to another.
- **SDK - Software Development Kit.** An SDK is a set of tools, libraries, documentation, and code samples that developers use to create software applications for specific platforms or environments.
- **SGD - Subtle Gaze Direction.** It is a technique used primarily in virtual reality (VR) and augmented reality (AR) environments to gently guide a user's gaze to specific points or objects without them being consciously aware of it.
- **Simulation** - A simulation is a method or process of creating a model of a real-world system, process, or environment in order to study, analyze, or interact with it without affecting the real thing.
- **VR - Virtual Reality.** It is a technology that immerses users in a fully simulated, computer-generated environment, often using a head-mounted display (HMD) like the Meta Quest, HTC Vive, or PlayStation VR.
- **XR - Extended Reality.** It is an umbrella term that encompasses all real-and-virtual combined environments and human-machine interactions, which include Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR).