Survey of Locomotion Systems in Virtual Reality

Ian Bishop
Dept. of Computer Science
Florida Polytechnic University
Lakeland, Florida, USA
ianbishop0734@floridapoly.edu

Muhammad Rizwan Abid
Dept. of Computer Science
Florida Polytechnic University
Lakeland, Florida, USA
mabid@floridapoly.edu

ABSTRACT

This is a survey paper on various types of virtual reality locomotion systems. This paper will be examining results and making comments on their implementations and techniques in an attempt to see where the virtual reality industry is heading in the near future.

CCS Concepts

Human-centered computing → Human-computer interaction (HCI) → Interaction paradigms → Virtual reality.

Keywords

Virtual Reality, Locomotion Systems, Simulator Sickness, Immersive Virtual Environment.

1. INTRODUCTION

Many locomotion systems are disorienting, nauseating, or limiting. Simulator Sickness is the term for the nauseating effect some users experience with navigating virtual environments. This feeling is reportedly similar to seasickness and has to do with the sense of balance. This unpleasant effect often happens when the view of the virtual environment changes, typically looking around or moving throughout the world. One example of this that rolling the virtual camera around the forward direction often causes sickness in users. However, this can be mitigated or avoided altogether with better locomotion techniques for virtual reality.

This paper first focuses on the meaning locomotion systems. Later, it discusses the various types of locomotion systems with their pros and cons. Finally, we conclude and speculate the potential future of locomotion solutions.

2. LOCOMOTION SYSTEMS

Locomotion system means a system that causes lateral motion in a virtual space. In this context, virtual reality means the user sees a virtual space through a head-mounted display. There are many different methods of interacting with computers, and these methods are always evolving to be more accurate, reliable, and easy to use. Some of the interacting methods are described below:

ICISDM'18, April 9–11, 2018, Lakeland, FL, USA

ACM 978-1-4503-6354-9/18/04…$15.00.
https://doi.org/10.1145/3206098.3206108

2.1 Redirected Walking

Redirected walking [13] is a technique that has the user walk in reality, but their movements are not 1:1 with the virtual space. When people rotate in reality, we can adjust this rotation in virtual reality imperceptibly. This allows the physical space to be reused and helps avoid colliding with a physical wall as seen in Figure 1. The subjects had to walk in a predetermined path in the experiments and had little autonomy, but future works are solving this. No special hardware is needed, it has all the sense of presence that real walking does, and it does not cause simulator sickness. Many researchers have cited this seminal technique and the methods involved have evolved.

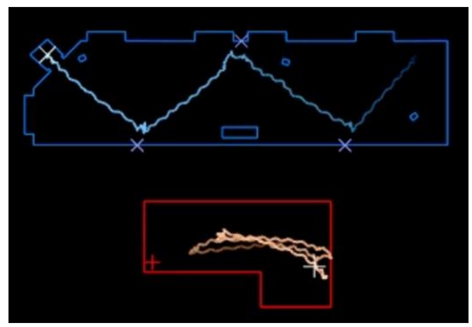

Figure 1: Redirected movement from large virtual space (blue) to small real space (red) [13]

Inspired by the original redirected walking, lot of research is done based on this concept. To a certain extent, it is possible to change the rate of rotation, translation, and world rotation in absence of the user knowledge. This seems to be a form of change blindness. Another technique being tested is having the virtual layout reconfigured slightly to redirect users away from physical boundaries [15]. In the real world, a user may be walking in circles but will be walking in a straight line in virtual reality. Users report that they do not get sick from it, in fact, users never even suspected such a thing has happened. More recent papers use algorithms that can be used to dynamically keep a user within a certain physical area that allows the user freedom to go wherever they please in the virtual world. This is still not a perfect solution yet, especially with small physical spaces and open virtual environments users often reach the bounds of their physical space. But it is still a drastic improvement over non-redirected walking and it is still being improved

2.2 Active Walking Interface

Bouguila et al. [2] present a pressure pad that users stand, step, and jump on to simulate natural locomotion in virtual reality. Users walk in place to simulate real walking, jump to jump, and angle their body to rotate. The pressure pad is a grid of switch sensors and is lightweight and portable. It is known as the Walking-Pad as shown in Figure 2. It can detect walking direction, speed, standstill, jumping, and walking inputs and send it to the virtual reality simulation. The pressure pad is designed to be omnidirectional and simple to set up. Further testing is required to see if using this device in conjunction with a Head Mounted Display causes sickness or not.

Figure 2: The Walking-Pad in use [2]

2.3 Natural, Semi-Natural and Non-Natural Locomotion Techniques

In this study [10, 11], three locomotion techniques are compared: Controller-based joystick movement, the Virtusphere [10] as shown in Figure 3, and real walking. This research work aims to determine the differences between locomotion techniques of varying fidelity using these three techniques. The results show that the Virtusphere is significantly less precise and harder to use than the other techniques. This is caused by the interior angles of the sphere when walking and its momentum. Essentially it does not accurately represent inertial feedback experienced by real walking. Real walking and using the controller are about the same in ease of use, precision, and fatigue. The controller lacks interaction fidelity, but that is fine because it is not trying to. This research work states that both low-fidelity (controller) and high-fidelity (real walking) are better than medium-fidelity (Virtusphere) locomotion techniques.

Figure 3: A Virtusphere [10, 11]

2.4 Infinite Floor

Another researcher [7] proposed an infinite surface by using a system of 12 treadmills in a torus shape. The treadmills align with one direction and together form another treadmill moving perpendicular to the others as shown in Figure 4. Linear actuators are placed on the treadmill surface that can extend to represent uneven surfaces in virtual reality. It can work without a harness or other device and the movement of treadmills give the direction and intensity of the user’s walking. This technique is designed to enable natural walking without having the user move in reality. The user cannot move too fast and the device needs performance improvement. But there has been great progress on this device as there are now companies commercially developing infinite floor devices. However, still it does not accurately represent inertial feedback experienced by real walking and most solutions use a harness on the user.

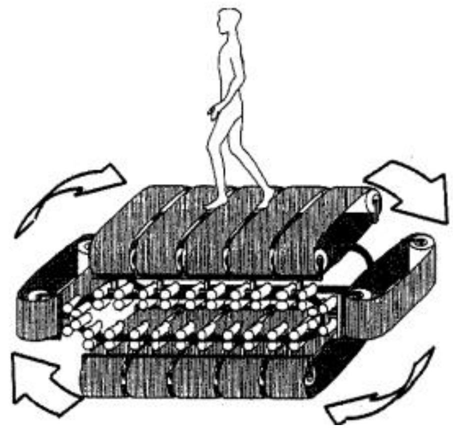

Figure 4: The Torus Treadmill [7]

2.5 Cyberith Virtualizer

The locomotion technique in this research work [4] has the user stand on a device with a low-friction floor and a ring harness around the waist, see Figure 5. When the user wants to walk, they push against the ring and naturally try to walk with their feet sliding backward on the floor underneath them. The harness will keep the user upright and the ring contains sensors to know what direction and the intensity of the users walking. This allows the user to walk without moving in reality, similar to the infinite treadmill, but this device is typically smaller and requires the user to wear specially-designed footwear to help the user slide on the surface.

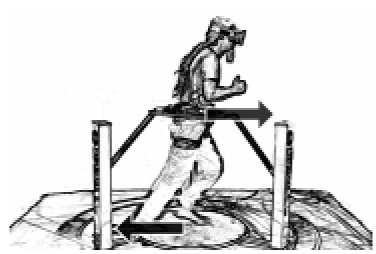

Figure 5: Low friction device with harness [4]

2.6 Walking vs Walking in Place vs Flying

This research work [14] tested subjects with three different software based locomotion systems: real walking, virtual walking in place by bobbing head, and flying by moving in the head direction. The researchers conclude that real walking is best out of these techniques for presence in virtual spaces, but one needs to have the floor space for it. Also, the virtual walking method could be improved, but it is reportedly better than the flying method.

2.7 Seven League Boots

Seven League Boots [6] has the user walking in reality, but distance in the intended walking direction virtually in scaled up.

The user could take one step in the real world, and move seven steps virtually. This research work compares four methods of walking: real walking with no scale, walking with uniform scale, walking with uniform scale only in the intended walking direction (to account for head swaying) and virtual walking with a joystick. The uniform gain method was significantly worse than the rest of the methods due to head bobbing while walking also being scaled. The other methods were reportedly similar on average in ease of use and cyber sickness inducing, though the unscaled walking provided a better impression of distance.

2.8 Controller-Based Locomotion

Julian et al. [5] compared four different wand controller locomotion methods: Free teleport (point to any reasonable space and press a button to teleport), fixed point teleport (user can teleport to a fixed area by pointing at its beacon), and an on-rails guided motion (user cannot move autonomously, only look), and touchpad motion (similar to a joystick, but a flat surface). As shown in Figure 6 for a short-ranged free teleport with the Vive wand controller. Results indicated that free teleport was less discomforting and gave users a higher presence than the other methods, while the guided motion method was rated the worse.

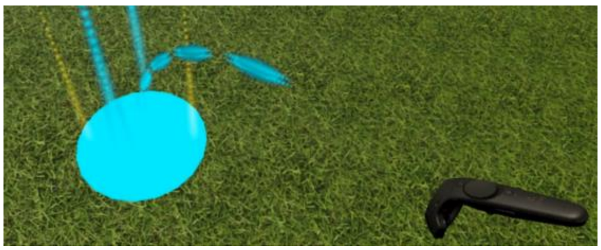

Figure 6: Free teleport using a Vive wand controller [5]

2.9 Gaze Teleportation

Gaze teleportation [9] teleports the user to the direction they are looking when they hit a button, rather than to where a wand controller is pointing. This requires a Head Mounted Display and an eye tracker so the program knows where the user is looking. Controller-based teleportation is already a very prominent method for moving around large areas without getting simulator sickness. This technique has been found to be good when users are expected to teleport forward and without too many distractions. It is reported to be quicker, less complicated, and feels more natural than using a controller to teleport around a virtual environment.

2.10 Travel in Virtual Environments

Travel in Immersive Environments [3] provides a list of quality factors for effective travel techniques in virtual reality: Speed, Accuracy, Spatial Awareness, and Ease of learning, Ease of use, Information gathering, and Presence. The importance of each item depends on the context the locomotion system is being used in.

This research work also compares steering techniques for flying in virtual reality. Gaze-directed steering and pointing techniques for both absolute (to a target) and relative motion (to a point a distance from a target) were tested. Gaze-directed steering is easier to learn and slightly more accurate, while pointing allows the user to look around while moving and is more comfortable. Results from the experiments show that pointing is faster for relative motion, but both methods perform equally in the absolute motion test.

2.11 Tunnel Window

Kiyokawa et al. [8] propose a tunnel window for navigation and remote object manipulation in virtual reality. A tunnel window is a tunnel or a portal that appears in space near the player and shows a remote view from another point in the world. Moving through this tunnel window allows the player (or objects) to teleport to its connecting point as shown see Figure 7. This locomotion method does not induce sickness, as evidenced by the fact a form of it is already being used in a VR game. The tunnel window can provide the user with a preview of the point they are teleporting to, which appears to alleviate some of jarring nature of teleporting to a different location.

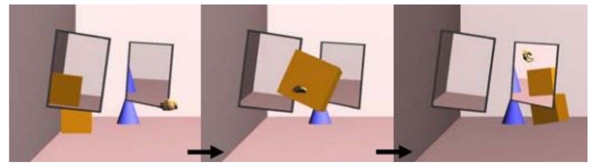

Figure 7: Tunnel windows to teleport in virtual reality [8]

2.12 Miniatures

A World-in-Miniature [12] is a hand-held miniature 3D map of the user's local virtual environment as shown in Figure 8. This is very useful for understanding the layout of a space but can also be used for navigation. Moving a camera icon on the miniature via a hand controller moves the player avatar which shifts the user's view. An instantaneous movement may be nauseating, so the transition should take place after the user stops manipulating the miniature camera icon but the miniature should be updated to match the player real-time. The transition to the new point could take a number of forms, such as translating the player to the new position over time, teleportation, or even moving the user to that position into the miniature while it grows in size and becomes the world around them and a new miniature appears, but further research on this would be needed to determine the best solution.

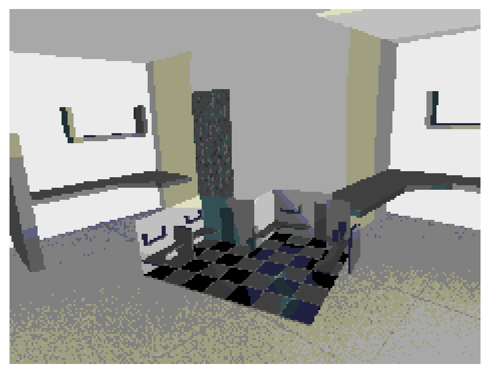

Figure 8: Miniature of the world with the player [12]

There are other techniques such as Arm swinging and many more [1] but they are not as successful as we discussed above.

3. CONCLUSION

There are many different techniques for locomotion in virtual reality, but none are perfect. There are some very promising techniques being researched for locomotion in virtual reality, but we have a strong feeling that still there is much work to be done. There are still some unanswered questions such as: Will there only be one commonly adopted technique or will there be multiple for different use cases? Do any of the techniques shown here have a use in other applications? What will become the standard locomotion method in VR?

4. REFERENCES

[1] Costas Boletsis. The new era of virtual reality locomotion: A systematic literature review of techniques and a proposed typology. *Multimodal Technologies and Interaction*, 1(4):24, 2017.

[2] Laroussi Bouguila, Evequoz Florian, Miche`le Courant, and Be ́at Hirsbrunner. Active walking interface for human-scale virtual environment. In *11th International Conference on Human-Computer Interaction, HCII*, volume 5, pages 22–27, 2005.

[3] Doug A Bowman, David Koller, and Larry F Hodges. Travel in immersive virtual environments: An evaluation of viewpoint motion control techniques. In *Virtual Reality Annual International Symposium, 1997., IEEE 1997*, pages 45–52. IEEE, 1997.

[4] Tuncay Cakmak and Holger Hager. Cyberith virtualizer: a locomotion device for virtual reality. In *ACM SIGGRAPH 2014 Emerging Technologies*, page 6. ACM, 2014.

[5] Julian Frommel, Sven Sonntag, and Michael Weber. Effects of controller-based locomotion on player experience in a virtual reality exploration game. pages 1–6, 08 2017.

[6] Victoria Interrante, Brian Ries, and Lee Anderson. Seven league boots: A new metaphor for augmented locomotion through moderately large scale immersive virtual environments. In *3D User Interfaces, 2007. 3DUI'07. IEEE Symposium on*. IEEE, 2007.

[7] Hiroo Iwata. Walking about virtual environments on an infinite floor. In

Virtual Reality, 1999. Proceedings., IEEE, pages 286–293. IEEE, 1999.

[8] Kiyoshi Kiyokawa and Haruo Takemura. A tunnel window and its variations: Seamless teleportation techniques in a virtual environment. In *HCI International*, 2005.

[9] Andreas Linn. Gaze teleportation in virtual reality, 2017.

[10] Eliana Medina, Ruth Fruland, and Suzanne Weghorst. Virtusphere: Walking in a human size vr hamster ball. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 52, pages 2102–2106. SAGE Publications Sage CA: Los Angeles, CA, 2008.

[11] Mahdi Nabiyouni, Ayshwarya Saktheeswaran, Doug A Bowman, and Ambika Karanth. Comparing the performance of natural, semi-natural, and non-natural locomotion techniques in virtual reality. In *3D User Interfaces (3DUI), 2015 IEEE Symposium on*, pages 3–10. IEEE, 2015.

[12] Burnette Pausch and Weiblen Brockway. Navigation and locomotion in virtual worlds via flight into hand-held miniatures. University of Virginia, 1995.

[13] Sharif Razzaque, Zachariah Kohn, and Mary C Whitton. Redirected walking. In *Proceedings of EUROGRAPHICS*, volume 9, pages 105–

106. Manchester, UK, 2001.

[14] Martin Usoh, Kevin Arthur, Mary C Whitton, Rui Bastos, Anthony Steed, Mel Slater, and Frederick P Brooks Jr. Walking ¿walking-in-place ¿flying, in virtual environments. In *Proceedings of the 26th annual conference on Computer graphics and interactive techniques*, pages 359–364. ACM Press/Addison-Wesley Publishing Co., 1999.

[15] James Walker. Redirected walking in virtual environments. Michigan Technological University