# Gesture-Based Locomotion in Immersive VR Worlds with the Leap Motion Controller: Comparison with gamepad and gaze-directed locomotion

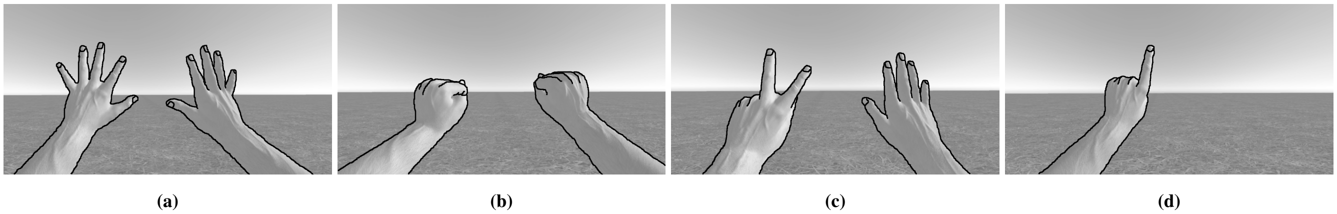
(a) (b) (c) (d)

**Figure 1:** *Hand poses for the LMTravel technique.*

## Abstract

In this paper we present a VR locomotion technique based on the Leap Motion device and compare it to other often-used locomotion techniques – gaze-directed locomotion and gamepad-based locomotion. We performed a user experiment to evaluate the three techniques based on their performance (time to complete the task), comfort (through the ISO 9241-9 assessment of comfort questionnaire), and simulation sickness (through the Simulation Sickness Questionnaire). Results indicate that the gamepad technique is both faster and more comfortable than either the Leap Motion-based or the gaze-directed techniques.

**Keywords:** Interaction Device, Leap Motion, HCI, Virtual Reality, Locomotion, Performance Measurement

**Concepts:** •**Human-centered computing** → **Virtual reality; Gestural input;** *Empirical studies in HCI;*

## 1 Introduction

Locomotion in immersive (headset-based) 3D virtual reality (VR) worlds (e.g. as experienced through the Oculus Rift headset [Oculus VR 2016]) is not a natural task. There have been many studies with real walking techniques where users immersed in a VR world can physically walk in the real world. Currently, however, these techniques still have many limitations: virtual worlds are often much larger than the available physical space and even with redirected walking techniques [Razzaque et al. 2001] the physical space still needs to be clear of obstacles and have a considerable area; consumer VR equipment is not wireless, often requiring the use of cables hanging from the ceiling and help from operators to keep users free from entanglements; wireless solutions with portable computers to exist, but are usually heavy and bulky. Even though there are special purpose treadmills for locomotion in VR worlds such as the Omni [Virtuix 2016], these are usually expensive, hard to set up, and may require considerable learning.

The most common approach for locomotion still requires the usage of some sort of controller. Most often, users are standing, or sitting still, wearing a VR headset and navigate through the 3D world using a joystick, mouse, game controller, or other traditional controller. However, these controllers do not provide a very natural way for locomotion inside a 3D world because they impose an arbitrary mapping between the users actions (e.g. pressing buttons) and the virtual avatar movement inside the VR world. Additionally, these techniques require users to carry this controller at all times – when users drop or puts the device down, it may be hard to pick it up again without taking the headset off.

The Leap Motion (LM) controller is a recent 3D sensing device [Leap Motion Inc. 2016] for hand gesture interaction with a computer. It is capable of sensing the position and orientation of the fingers of both hands, as well as the palm orientation and curvature. The Leap Motion device has been adapted for VR headsets allowing users to use hand gestures to interact with digital objects. At first sight, the Leap Motion appears as an interesting alternative to other controllers because it is worn in the headset itself (users don't need to physically handle another device) and it allows free gestural interaction. The device also allows using the real image of the users hands to be incorporated into the virtual scene (although not in true color with the current version of the device).

### 1.1 The Leap Motion device

The LM is a small input device controller (7.6 x 3 x 1.3 cm) developed by Leap Motion Inc., which detects and recognizes users hands posture and gestures (Figure 2).

**Figure 2:** *The Leap Motion device.*

Programmers can use the Leap Motion SDK to develop applications that take advantage of the devices capabilities. Currently, the SDK provides high-level functions such as:

- Presence/absence of hands within the range of the LM, and

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their 3D position in space.

- Orientation of the palms.
- Curvature of the palms.
- Overall scale, rotation, and translation motions calculated from the movement of the hands.
- Orientation of individual fingers (or tools such as pencils), and normalized 2D pointing position on the screen.
- Pre-defined gestures such as a finger tracing a circle, finger swipe, finger tapping movement, and screen tap.
- Image of the hands.

In a VR setting, the LM can be attached to a VR headset roughly in the same direction as the users eyes providing a natural hands perspective in the VR scene (see Figure 3).

**Figure 3:** *Leap Motion in VR setting.*

### 1.2 Objectives

Few studies have been conducted to evaluate the Leap Motion as a locomotion controller within immersive VR worlds. The objective of this work is to provide an assessment of the LM device for locomotion in immersive VR and compare it with other techniques often used in a headset-based scenario.

For this, we have performed an experimental evaluation and comparison of three locomotion techniques – hand gestures with the Leap Motion, gamepad-based locomotion, and gaze-directed locomotion. We measured the time it took for participants to complete the tasks, and we also gathered subjective feedback through the Simulation Sickness Questionnaire [Kennedy et al. 1993] and the ISO 9241-9 assessment of comfort questionnaire [International Organization for Standardization 2000] The contributions of this paper are as follows:

- A gesture-based locomotion technique for headset-based immersive VR using the LM device.
- An assessment of the overall user experience and performance of using the LM for locomotion.
- The evaluation of a gesture-based locomotion technique and comparison with gamepad-based and gaze-directed locomotion.

## 2 Locomotion Techniques

### 2.1 LMTravel

The Leap Motion locomotion technique (LMTravel) is designed for use with the Leap Motion controller positioned in the VR headset (see Figure 4). We used the VR mount for the Oculus Rift headset provided by Leap Inc.

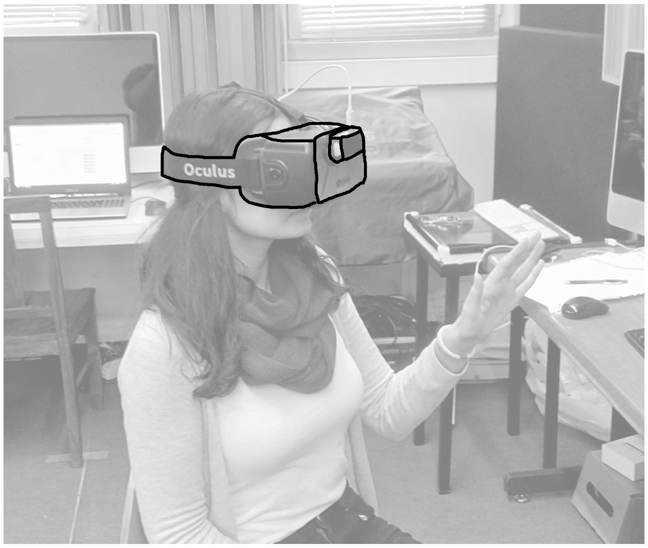

**Figure 4:** *Leap Motion mounted on the Oculus Rift headset.*

The LMTravel is based on hand gestures that allow us to control:

- Movement start/stop. Opening both hands triggers the start of movement (Figure 1a); closing both hands stops the movement (Figure 1b).
- Movement speed. The number of fingers stretched indicate the movement speed: one finger corresponds to the lowest speed; all five fingers stretched corresponds to the highest speed (Figure 1c).
- Rotation. The tilt angle of the right hand maps to the rotation of the avatar.

The technique can also be used without rotation control by the right hand, using instead the rotation from the headset (i.e., the movement is directed by the users gaze). In this case, once the movement has started, the right hand can be lowered and speed can be controlled by the left hand (Figure 1d). In the experiment, the LMTravel technique was used without rotation control in order to give users a level of control similar to the other evaluated travel techniques.

### 2.2 Gamepad

The Gamepad locomotion technique uses a standard gamepad controller. Users control the direction of movement using the gamepad's joystick button. In this technique we opted to allow movement in eight directions as shown in Figure 5. Besides the usual forward, backward, left strafe and right strafe directions, we also allow diagonal directions. This is more inline with what gamepad users would expect from the controller. Again, the forward movement is relative to the users gaze.

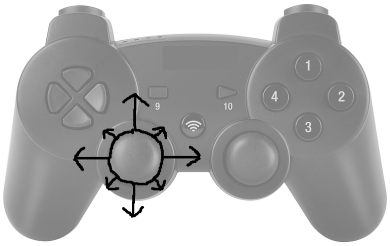

**Figure 5:** *Possible directions for the gamepad technique.*

### 2.3 Gaze

The Gaze-based locomotion technique places a cursor in the center of the screen and a corresponding target icon (a white cylinder) in the floor in case the users gaze intersects the floor. Figure 6 shows an example of a target in the middle of a green field. By pressing a button (for implementation simplicity, we used a wireless mouse) the user moves to the target location. This technique is similar to the one used by [Grasset et al. 2005], but in our implementation users can move to any point in the ground plane provided they can look at it, instead of moving only a step in one of eight directions. In case there are obstacles in the way, our implementation chooses the shortest path.

In the Gaze technique, the user is free to look anywhere while the travelling is in progress.

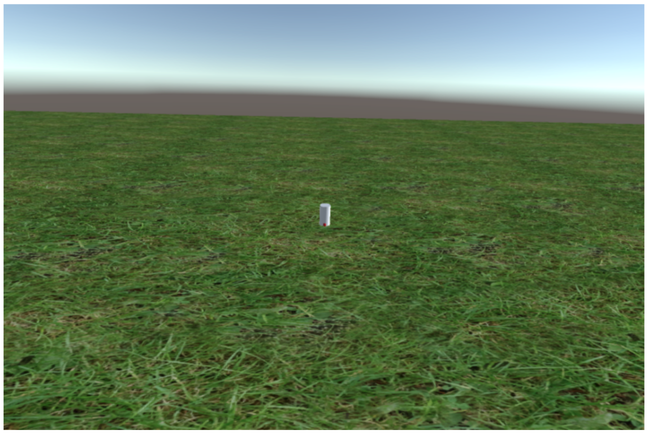

**Figure 6:** *Cursor positioning in the gaze-based locomotion technique.*

## 3 Experiment

The purpose of this study was to compare the efficiency and usability of the various travel techniques. For this, we created a simplified 3D environment with two main areas, where users were asked to perform locomotion tasks.

### 3.1 Tasks

Task 1 was a simple path following task that took place in an open area composed of 7 circular platforms on the ground. The next platform that the user should get to was indicated by a large purple sphere in the air over the platform. Figure 7 shows a top view of the area for task 1, with the purple sphere over platform number 2.

Platforms were logically numbered 1 to 7 and participants were asked to follow the purple sphere (i.e., to reach the corresponding platform). Participants were asked to make 6 sequences, where a sequence would correspond alternately to the following platforms: 1-2-5-6-7-4-3-1, and 1-3-4-7-6-5-2-1.

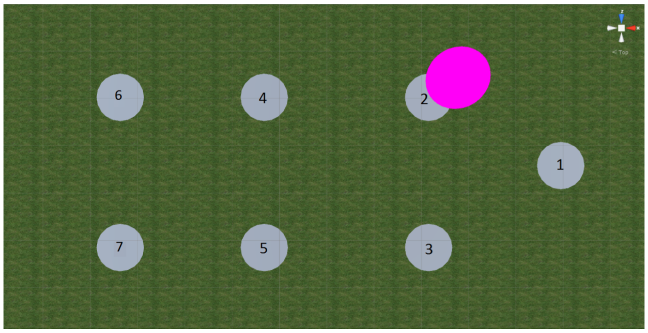

**Figure 7:** *Area for task 1, top view.*

Task 2 consisted in searching for a red vase inside each of the 8 houses in area 2 of the environment (see Figure 8). Each house was identified by a number clearly visible from the front door of any house.

The order in which participants had to visit each house was indicated by the researcher and it was different for each travel technique (but the same for every participant).

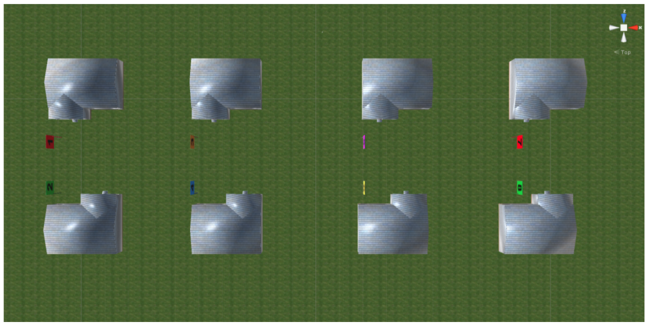

**Figure 8:** *Area for task 2, top view.*

### 3.2 Procedure

The experiment was a within-subjects design where all participants were subjected to the three travel techniques using a Latin square balancing approach.

Participants were introduced to the experiment with a brief description of what they would be asked to do, and with an initial training phase. In the training phase, we equipped participants with the VR headset and Leap Motion and explained how the various travel techniques worked. We then asked participants to explore the VR environment inside and outside a house, informally asking participants to accomplish simple tasks such as entering a specific room. This training phase would end when users said to be comfortable with the workings of the various techniques. Participants sat on a swivel with no armrests, to make it easier to rotate. The computer that drove the VR world (and to which the VR headset was attached) was in a standard computer desk in front of the participant.

After the training phase we asked participants to travel to the starting point of task 1 (platform number 1) and briefly explained the task. After task 1 was completed (all 6 sequences) we explained and asked participants to accomplish task 2. The time it took to complete each task was automatically recorded by the VR environment software.

After both tasks were complete for a given interaction technique, we asked participants to remove the headset and fill in the Simulation Sickness Questionnaire and the ISO 9241-9 assessment of comfort questionnaires in a computer that was setup and dedicated to the questionnaires in the laboratory. We also allowed participants to take a break before or after filling in the questionnaires. After the last travel technique experimented, we additionally asked the participant to fill in a two-question questionnaire where they would state which technique they liked best and which one they disliked the most.

A complete session would last for about 45 minutes.

### 3.3 Participants and Apparatus

Thirty nine participants were opportunistically recruited from the university department, mostly MSc students. However, the final experimental data consists of only 31 participants (6 female, 25 male). The reasons for excluding participants include: not finishing the experiment due to extreme motion sickness, and experimenter error in collecting the log files.

The headset was an Oculus Rift DK2 and the computer that ran the VR world was an iMac capable of driving the Rift at 70 fps. The VR scenarios and logging software was programmed in Unity 3D. We used a Leap Motion device version 1.2.1+10992.

## 4 Results and Discussion

In this section, we report the results from the experiment. In the analysis of these results, it should be noted that the LMTravel technique was the only technique that allowed users to control the movement speed by raising a different number of fingers. We did not record the speed selection of participants along the experiment, but it is safe to assume that participants were not always moving at the highest speed possible when experimenting with the LMTravel technique. (Both the Gaze and Gamepad techniques moved the user at the highest speed.)

During the experiments, we noticed a problem with the physical setup: as users rotated in their chair, the headset cable would sometimes get entangled with the chair and users had to rotate back to a standard position. We did not try to solve this issue during the experiment so that all participants experienced the same conditions.

### 4.1 Trajectories

Looking only at the resulting trajectories from the different techniques, we observe noticeable differences between them. Figure 9 shows a top view of the trajectories performed in task 1 by a single participant. With gaze-directed locomotion, trajectories are essentially straight lines (except in the cases where participants select a different target location before the current movement finishes), but participants often overshoot their targets. This may be due to the fact that the selection cursor of the gaze technique gets smaller as it is placed farther away from the user. Also, at higher distances, the same angular displacement of the head causes a higher linear displacement of the selection cursor, making it harder to position accurately. This issue might have been alleviated with a better visual feedback on the selected target position, for example, by highlighting the objects on which the cursor rests.

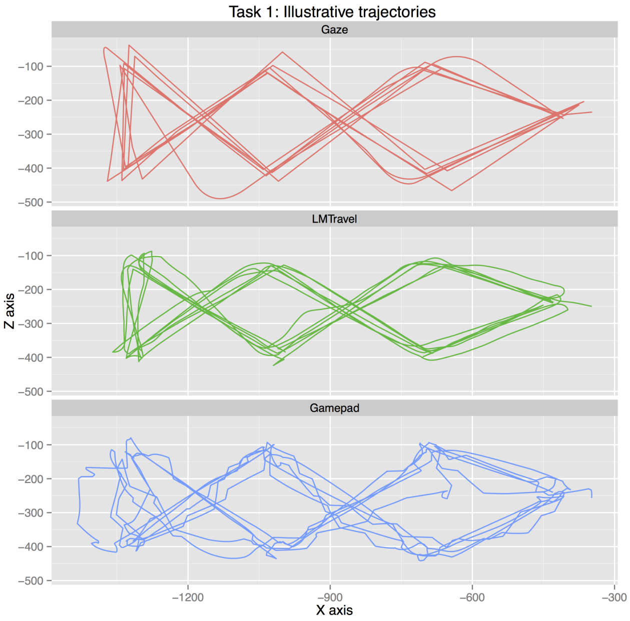

**Figure 9:** *Illustrative trajectories from task 1.*

In terms of trajectory, the LMTravel results in fairly straight lines, indicating a that users have control over the trajectory. In fact, in task 1, the LMTravel technique resulted in the shortest average distance per sequence (Table 1).

**Table 1:** *Average sequence distances for task 1 (VR World units).*

| Technique | Mean (95% conf. int.) | SD | Min | Max |
|---|---|---|---|---|
| Gaze | 3083 (3031, 3136) | 328 | 2592 | 4324 |
| LMTravel | 2737 (2714, 2762) | 152 | 2424 | 3368 |
| Gamepad | 2833 (2810, 2858) | 153 | 2500 | 3365 |

The gamepad technique resulted in jagged trajectories. This may be due to inadvertent changes in direction (users may position the joystick a bit to the sides causing a side short movement) or simply because movement corrections have to be made in a discrete way - the gamepad technique supported only 8 discrete movement directions. However, overall it did not result a substantially higher distance when compared to the LMTravel.

### 4.2 Movement time

We measured how long participants took to complete each sequence in task 1, and how long it took them to complete task 2. For task 1, Figure 10 shows the average sequence movement duration for the 6 sequences, per locomotion technique.

There seem to be an obvious learning effect for Gaze and LMTravel. It is also apparent that the Gamepad technique far exceeds the other in terms of movement performance. In the next comparisons, we have removed sequence number 1 from the data because the learning effect is most obvious for that sequence.

The differences between the techniques in both task 1 and task 2 are very similar. There is a significant difference between Gamepad and both LMTravel and Gaze. Users are much faster with the gamepad, spending about 20% less time in either task, than with Gaze or LMTravel techniques.

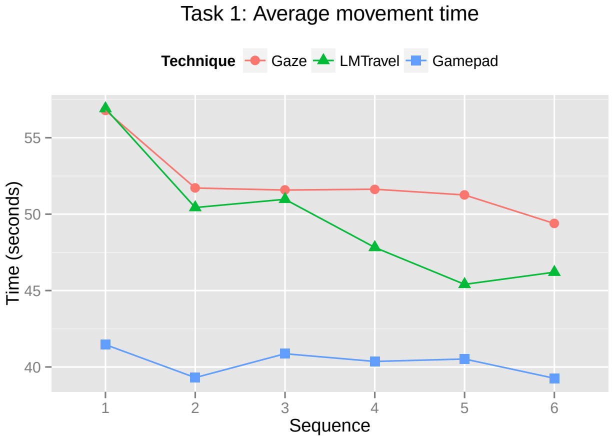

**Figure 10:** *Average sequence movement duration per technique.*

**Table 2:** *Movement duration (in seconds). For task 1, the values correspond to the average sequence duration. For task 2, the values correspond to the average time for completion of the task.*

| Technique | Mean (95% conf. int.) | SD | Min | Max |
|---|---|---|---|---|
| | Task 1 | | | |
| Gaze | 51.2 (49.8, 52.6) | 8.6 | 39.3 | 94.7 |
| LMTravel | 48.2 (46.4, 50.1) | 11.5 | 32.3 | 90.0 |
| Gamepad | 40.1 (38.6, 41.6) | 9.6 | 24.7 | 67.0 |
| | Task 2 | | | |
| Gaze | 218.7 (202.0, 235.5) | 47.5 | 148.0 | 339.4 |
| LMTravel | 213.3 (203.2, 223.3) | 28.6 | 164.2 | 274.4 |
| Gamepad | 165.9 (153.0, 178.8) | 37.2 | 116.5 | 259.8 |

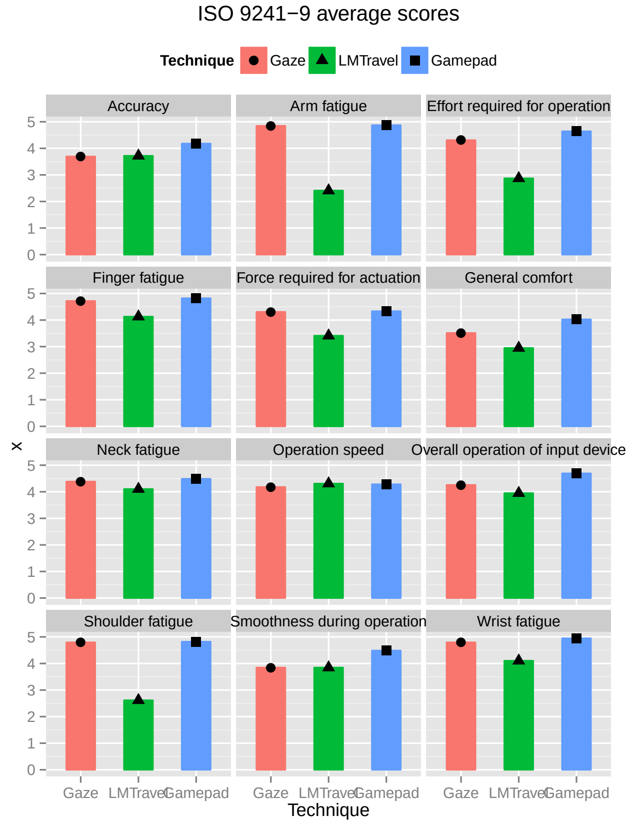

**Figure 11:** *Results from the ISO 9241-9 assessment of comfort questionnaire.*

### 4.3 Questionnaires

The results from the ISO 9241-9 assessment of comfort questionnaire are presented in Figure 11. The Gaze and Gamepad techniques are rated very similarly by the participants of the study (Gaze is rated slightly lower than the Gamepad technique).

The LMTravel technique however, scores negatively in various of the questions, specifically the ones related to the fatigue of the upper limbs. The arm fatigue, effort required for operation, general comfort, and shoulder fatigue items have been rated lower than 2.5, on average. These results are inline with other assessments of the LM device in other situations: [Seixas et al. 2015] evaluated the LM device for desktop 2D pointing and the results of the ISO 9241-9 questionnaire in that study also show low scores in these items. These results are expected as the LMTravel technique requires users to keep their arms lifted in order for them to be detected by the LM device. Without any physical support, the required position is not comfortable and after prolonged use results in fatigue – similar to the gorilla arm effect with prolonged use of vertical touch screens.

The results from the Simulation Sickness Questionnaire (SSQ) are presented in Figure 12. For these questionnaires we used the data from all 39 study participants, since all of them experienced the three techniques long enough to be able to evaluate them in the SSQ. Although results show slightly higher values for the Gaze technique than the Gamepad (with the LMTravel generally in between), the results are not statistically significant.

We also asked participants to explicitely tell us which technique they liked best and which one they disliked most. The percentages for each technique are shown in Figure 13.

Clearly, the Gamepad technique was the favorite: it was chosen as the preferred technique by almost 60% of the participants. The Gaze-directed technique was the least liked: chosen by 56%. The preference for the LMTravel technique was more divided: 33% chose it as the preferred technique, and 28% chose it as the least preferred technique.

Unfortunately, we did not follow up the responses to this last questionnaire to determine the reasons for the participants preferences.

## 5 Related Work

Few studies of the LM device within immersive VR have been conducted thus far.

[Lee et al. 2015] developed TranSection, a game where users interact with hand-based gestures detected by the LM device. In this game, users are immersive in a 3D world representing a typical computer desk configuration. The avatar cannot move in the 3D world, but can pick up objects from the desk and type in the virtual keyboard. The game itself is played in the virtual computer via the keyboard, but in some points of the game, objects come out of the virtual screen and the avatar has to interact via one of the objects in the virtual desk. One of the objectives of TranSection was keeping the interface natural, so the hand-gestures detected by the LM device are not used to click on virtual pop-up menus: all the interactions correspond to natural gestures one would perform while sitting at a computer desk. Although it does not provide any locomotion of the virtual avatar, TranSection is an example of how the LM can provide a natural interaction mechanism for VR worlds. In this

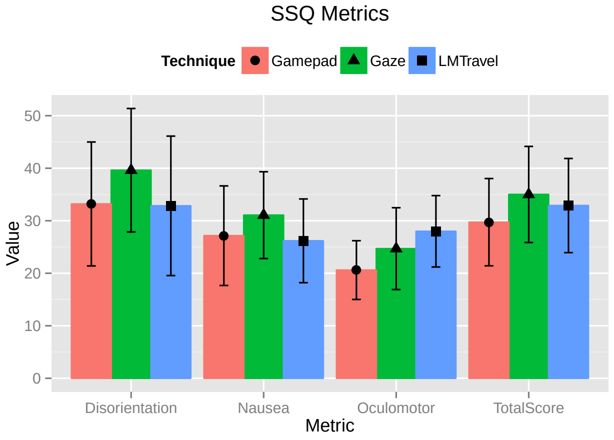

**Figure 12:** *Simulation Sickness Questionnaire calculated metrics.*

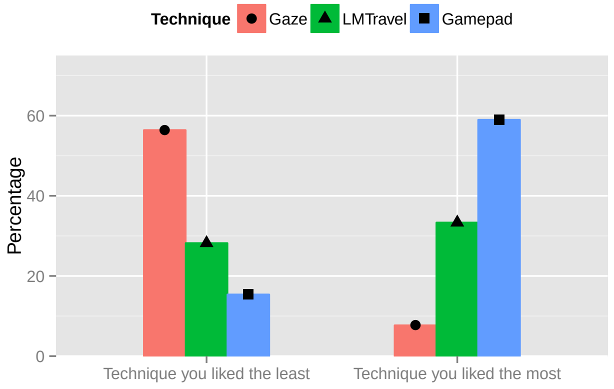

**Figure 13:** *Technique preference.*

work, our objective was not to try to keep the gestures completely natural, but to assess the overall user experience and performance of using the LM for locomotion.

[Webel et al. 2013], used the LM in a cultural heritage exhibition setting. Users could experience a virtual replica of the Siena Cathedral using the Oculus Rift headset. For navigation, an LM device was positioned at lap height in a tripod in front of the user (which must thus stand in a predetermined location). To navigate, users put a hand above the LM and move it horizontally (parallel to the floor) to translate the virtual camera. The camera keeps moving until the users hand goes back to a standard position, or stops being detected by the LM. To rotate the camera, users can rotate their the hand along its roll axis. Again, the camera keeps rotating until the hand is rotated back to its normal orientation or stops being detected. In this project, the usage of the LM device was not evaluated or compared to other interaction techniques. Also, the required hand positions are very different from what they would be in a situation where the LM is mounted on the VR headset.

[Nabiyouni et al. 2014] performed a usability testing in order to find which of five LM based 3D travel techniques was the most efficient in bare-hand interaction. The five techniques were tested in a set of 3 tasks and the interaction was performed through the use of the LM controller. The techniques developed were based on a Camera-in-hand metaphor, where the LM workspace was directly mapped to the virtual world, and an Airplane metaphor, that, similar to driving a vehicle, had the camera always moving straightforward being the user responsible for controlling its velocity and orientation (the orientation was the same as the hand). A 3D virtual scenario, modelled as a city, was used to perform the tests. This evaluation was performed in a desktop setting, i.e., not in an immersive headset based VR. The LM was positioned on top of the computer desk and the 3D world was visualized in the desktop monitor. Also, no comparison was done with non-LM based techniques.

[McCullough et al. 2015] developed a locomotion technique based on the Myo armband [Thalmic Labs Inc. 2016]. The technique consisted in swinging the arms to initiate locomotion in the direction of the user's gaze. The faster the swinging, the faster the user moved in the virtual environment. One advantage of the Myo device for gesture controls is that it is not vision-based: users can keep their arms in any position, unlike the LM which requires users' hands to be ”visible” by the device. Another advantage of this technique is that users mimic more closely the (arm) movements of natural walking and thus potentially provides a more natural way of locomotion based on gestures. [McCullough et al. 2015] compared their technique to joystick and real locomotion, however only turning errors and delay were measured, it is not clear how much effort or how comfortable the technique is compared to the alternatives.

## 6 Conclusion

We have presented the results from an experiment designed to study the Leap Motion device as a locomotion controller for immersive VR Worlds and compare it with more standard techniques such as Gaze-based locomotion and Gamepad locomotion. We compared the performance (movement speed), as well as the effort required, and the simulation sickness effect for the three techniques.

The results indicate that the Leap Motion performs (movement speed) better than the Gaze technique but worst than the Gamepad technique. Also, results show that the effort required to operate the Leap Motion in these conditions is considerably higher than the effort required to operate the Gamepad or the Gaze-based techniques.

In this study, we did not refine the LMTravel technique very much, as we wanted to get an initial feedback on the possibilities of the device for locomotion within VR. It is possible to conceive interaction techniques for the LM device that do not require users to keep their arms extended, hence reducing the effort of using the device. However, the current results are an indication that the LM-based techniques should not be used in situations of prolonged use.

While the LMTravel technique is not as performant as the Gamepad technique, it is nonetheless worth considering in many situations. The LM device has the obvious advantage of not requiring users to hold a physical device, making their hands free to pick up physical objects.

## Acknowledgements

## References

Grasset, R., Lamb, P., and Billinghurst, M. 2005. Evaluation of mixed-space collaboration. *Proceedings - Fourth IEEE and ACM International Symposium on Symposium on Mixed and Augmented Reality, ISMAR 2005 2005*, 90–99.

International Organization for Standardization. 2000. Ergonomic Requirements for Office Work with Visual

Display Terminals (VDTs): Requirements for non-keyboard input devices. Tech. rep.

KENNEDY, R. S., LANE, N. E., BERBAUM, K. S., AND LILIENTHAL, M. G., 1993. Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness.

LEAP MOTION INC., 2016. Leap Motion.

LEE, P.-W., WANG, H.-Y., TUNG, Y.-C., LIN, J.-W., AND VALSTAR, A. 2015. TranSection: Hand-Based Interaction for Playing a Game within a Virtual Reality Game. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA '15*, ACM Press, New York, New York, USA, 73–76.

MCCULLOUGH, M., XU, H., MICHELSON, J., JACKOSKI, M., PEASE, W., COBB, W., KALESCKY, W., LADD, J., AND WILLIAMS, B. 2015. Myo ArmSwinging to explore a VE. In *Proceedings of the ACM SIGGRAPH Symposium on Applied Perception - SAP '15*, ACM Press, New York, New York, USA, 107–113.

NABIYOUNI, M., LAHA, B., AND BOWMAN, D. A. 2014. Poster: Designing Effective Travel Techniques with Bare-hand Interaction. In *EEE Symposium on 3D User Interfaces (3DUI)*, Center for Human - Computer Interaction and Department of Computer Science, Virginia Tech, Center for Human-Computer Interaction and Department of Computer Science, Virginia Tech, 139 – 140.

OCULUS VR, L., 2016. Oculus Rift.

RAZZAQUE, S., KOHN, Z., AND WHITTON, M. C. 2001. Redirected Walking. *Proceedings of EUROGRAPHICS*, 289–294.

SEIXAS, M. C. B., CARDOSO, J. C. S., AND DIAS, M. T. G. 2015. The Leap Motion movement for 2D pointing tasks: Characterisation and comparison to other devices. In *Proceedings of the 5th International Conference on Pervasive and Embedded Computing and Communication Systems (PECCS-2015)*, SCITEPRESS Science and Technology Publications, Lda.

THALMIC LABS INC., 2016. Myo.

VIRTUIX, 2016. Virtuix Omni.

WEBEL, S., OLBRICH, M., FRANKE, T., AND KEIL, J. 2013. Immersive experience of current and ancient reconstructed cultural attractions. *Proceedings of the DigitalHeritage 2013 - Federating the 19th Int'l VSMM, 10th Eurographics GCH, and 2nd UNESCO Memory of the World Conferences, Plus Special Sessions fromCAA, Arqueologica 2.0 et al. 1*, 395–398.