# MANILOCO: A LOCOMOTION METHOD TO AID CONCURRENT OBJECT MANIPULATION IN VIRTUAL REALITY

by

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To my dear mom Dan Liu, my advisor Yingjie Chen, and all my friends

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# ABSTRACT

In Virtual Reality (VR), users often need to explore a large virtual space within a limited physical space. However, as one of the most popular and commonly-used methods for such room-scale problems, teleport always relies on hand-based controllers. In applications that require consistent hand interaction, such teleport methods may conflict with the users' hand operation, and make them uncomfortable, thus affecting their experience.

To alleviate these limitations, this research designs and implements a new interactive object-based VR locomotion method, ManiLoco as an eye- and foot-based low-cost method. This research also evaluates ManiLoco and compares it with state-of-the-art Point & Teleport and Gaze Teleport methods in a within-subject experiment with 14 participants.

The results confirm the viability of the method and its possibility in such applications. ManiLoco makes the users feel much more comfortable with their hands and focus more on the hand interaction in the application while maintaining efficiency and presence. Further, the users' trajectory maps indicate that ManiLoco, despite the introduction of walking, can be applicable to room-scale tracking space. Finally, as a locomotion method only relied on VR head-mounted display (HMD) and software detection, ManiLoco can be easily applied to any VR applications as a plugin.

# 1. INTRODUCTION

## 1.1 Background

Virtual Reality (VR) has been widely used in training and gaming due to its capability of training users in an immersive environment with hand-on experience. One main challenge is that the user may only have a limited physical space (e.g. her own desk space) but need to conduct her operation with many objects spread in a much larger virtual space (e.g. accessing different scientific devices in a lab). Thus, locomotion, a self-propelled movement in the virtual world [1], has becoming one of the essential components of interaction in VR [2]. It enables the user move in a large virtual space within a limited physical space. Several approaches have been proposed, such as Redirected Walking (RDW) [3]–[5], or Walk in Place [6], [7]. These methods have different performances in terms of freedom, immersion, interaction efficiency, and VR sickness.

As one of these methods, controller-based teleport method allows users to move freely in virtual environments which are much larger than the tracking space while ensuring minimal motion dizziness. Such teleport locomotion method has been widely used in today's VR application, with HTC Vive[1] and Oculus[2] supporting this locomotion method by default. It is also considered the most efficient way to move in room-scale tracking space, especially when few obstacles are in the scene [8], [9]. However, teleport has the drawback of missing spatial sense, and potentially break the user's immersive feeling and cognitive process in the virtual environment [10], [11].

## 1.2 Problems

The current dominant teleport methods are based on controllers accompanied by VR devices. Users need to manipulate the joysticks or buttons to control the teleport location and trigger the mechanism. However, this method will undoubtedly interfere with the original interaction of the hands. Many VR applications require users to use their hands to perform actions similar to reality to enhance their immersion. For example, VR shooting games

[1] ↑https://www.vive.com/
[2] ↑https://www.oculus.com/

(Population: One[3]; The Walking Dead: Saints & Sinner[4]) need users to hold the gun with one or both hands and pull the trigger with the index finger. Also, in some VR simulation (CryoVR[5]) or casual (Vacation Simulator[6]) applications, users need to grasp or move specific items with their hands.

So the main problem is that the hand-based teleport methods become unsuitable under these hand interaction prerequisites. The users need to perform hand interaction while also triggering the teleport with their hands. Such locomotion technique may interrupt the users' original mindset of hand manipulation, thus affecting their experience. Therefore, researchers want to transfer the teleport interaction to other parts of the body. In this way, users can still interact with their hands while enjoying the convenience of teleport to explore the virtual space.

Eye gaze has been used in recent years to solve the localization problem in teleport [12]. It has shown effectiveness, but the method still requires a button on the hand controller to trigger the teleport. Similarly, the foot has also become an alternative. For example, Podoportation [13] is an entirely foot-based teleport method. Their experiment has indicated that this method improves efficiency but reduces accuracy and convenience compared with hand-based teleport methods. Bolte, Steinicke, and Bruder [14] have combined the eyes with the feet, using the eyes for localization and the "jumping" motion for teleport. However, the introduction of jumping affects the efficiency of the interaction, forcing users to pay more physical effort. Moreover, it makes the method no longer fully applicable to room-scale space.

### 1.3 Research Questions

This research presents the following research questions in response to the above problem:

1) Can hand-based teleport method maintain its original suitability in VR applications where the hand interaction is dominant?

[3]↑https://www.populationonevr.com/
[4]↑https://vrwalkingdead.com/
[5]↑https://va.tech.purdue.edu/cryoVR/
[6]↑https://www.vacationsimulatorgame.com/

2) Is there a teleport method that can transfer the users' hand pressure to the other parts of their bodies?

3) Can such transfer allow users to concentrate more on their hand interactions in these applications? How is its efficiency?

4) Can this method also be applied to room-scale conditions?

## 1.4 Contributions

This research designs and develops a new hand-free VR locomotion method, ManiLoco. ManiLoco is implemented by replacing the three components of teleport, Activate, Locate and Teleport, with Backward, Look and Walk, respectively. This method is based on the feature that "people look at their destination when walking normally" [15], [16]. In addition, it transfers the teleport interaction method from the hands to the head and feet. While looking at the object, users can take a step toward that object to reach it. At the same time, the room-scale problem is solved by introducing a specific offset to guide users back to the center of the room.

This research conducts a user experiment to compare ManiLoco with two other popular hand-based VR teleport methods: Point & Teleport [17], and Gaze Teleport [12], through a simple VR chemistry experiment application. The experiment explicitly compares efficiency, presence, and usability. It also explores the sensations these methods bring to the participants' hands and their concentration on this chemistry experiment.

The results indicate that ManiLoco, as a new VR locomotion method, has similar efficiency and presence with the other two methods. Also, in this testing application, ManiLoco shows higher usability, generates less pressure on the users' hands and allows the users to feel more comfortable and focus more on their hand operation. However, the users may need to take a higher task load as a trade-off. During the experiment, the users can move freely in a $3\,\mathrm{m} \times 8\,\mathrm{m}$ virtual environment within a tracking space of $1.8\,\mathrm{m} \times 1.8\,\mathrm{m}$, arguing that ManiLoco is a room-scale method.

For many VR applications where the hand interaction is dominant, ManiLoco can be a locomotion option. Designers can design the hand interactions in the application more freely because it does not take up any hand resources. On the other hand, ManiLoco allows users to focus more on their hand operation while helping them to move around in a larger virtual space. The room-scale method also ensures that users do not need to worry about the size of the available space. Besides, the method does not introduce any special hardware devices; it is only based on the VR head-mounted display (HMD), ensuring universality.

This research also aims to better provide insights to future VR studies by describing the designs and implementations of ManiLoco in detail.

# 2. REVIEW OF RELEVANT LITERATURE

Locomotion has been a hot topic of research in the VR field. The main challenge is enabling users to move freely in virtual scenes while maintaining their immersion and spatial sense and minimizing their sickness. The room-scale locomotion limits this problem to the size of a regular room such as an office, living room, or bedroom. However, considering the inevitable presence of tables or chairs in the daily living environments, the actual tracking space will be much smaller. In response to this problem, many researchers have proposed their solutions.

## 2.1 Room-Scale Virtual Reality Locomotion

**Natural Walking** is undoubtedly the most realistic and immersive method [18]. However, limited by room size, this method is not suitable for large virtual environments. Inspired by this, many methods have improved. Methods based on **Specialized Hardware** allow the user to walk without any natural movement, making it possible to limit the user's range of motion while preserving immersion. Typical examples are the omni-directional treadmill [19], [20] and the ball bearing-based concave surface [21], [22]. However, expensive and bulky hardware devices are not suitable for general home users, so there are limitations in the adaptability of this approach.

**Redirected Walking** (RDW) and **Walking in Place** are two other popular approaches. Redirected walking leads the user to walk in circles in the room by translating, rotating, or curving the path in the user's field of view [3], which allows the user to walk naturally in the virtual environment [4], [5]. This method is particularly suitable for large open scenes, making path distortions small enough to be unnoticeable to the user. Walking in place is one of the pose-based locomotion techniques, which aims to imitate walking without changing position. The direction of the character's movement in the virtual environment is determined by the user's head orientation, while the forward speed is by the stepping speed [6], [7]. Tregillus and Folmer [23] used inertial sensors to detect the user's walk, thus enabling an entirely hand-free locomotion method. Bhandari, Tregillus, and Folmer [24] combined walking in place with natural walking to enable mass navigation. Ke and Zhu [25] used pose swing amplitude instead of speed to control the character's movement speed.

However, walking in place needs more physical effort than redirected walking [9]. Moreover, considering the resulting indirect movement, walking in place may cause potential motion sickness [26], [27].

**Step scaling** is another effective method for the limited space. This technique changes the original distance mapping by introducing a scale factor [28] or enlarging the player character [29]. As a result, it can produce a broader range of locomotion depending on the degree of scaling. However, the scale factor has an upper limit, so that the virtual space cannot be scaled up indefinitely. When the scaling degree is too large, the difference between the actual action and the motion results in the virtual world will become too large, increasing the risk of motion sickness [30].

The above methods aim to give the user a continuous space of motion, but none are suitable for totally stationary users. **Point & Teleport**, as one of the most popular teleport methods, acts as a discrete motion input, allowing the user to point to their destination and instantly move to that location without movement in the real world [17].

There are two general challenges with the teleport approach. The first is spatial sense loss [10], [11] caused by it. Some researchers have proposed improved methods to address this issue, including introducing explicit curved paths [31], optical flow information [32], or the agents for labeling destinations [33]. The second key point is the interaction method, and the dominant method now relies on the input from the user's hand controllers. Users often trigger teleport functions via specific buttons or joysticks. The benefit is that it can be effortless and easy to learn [34], but it may also interfere with other hand interactions, such as grasping. Therefore, studies have started to transfer the interaction method of teleport to gaze- and foot-based approaches.

## 2.2 Gaze- and Foot-based Interaction

Early researches have shown that interaction using eyes in a head-mounted display (HMD)-based VR environment is more efficient than using hands [35]. The idea of the **Gaze**-based approach is the selection according to the users' gaze [36], which can be applied to locate the destination, thus enabling navigation function. Furthermore, the users' gaze time is generally used to determine their intention, thus avoiding the regular scanning. For novices, a dwell time between 450ms to 1s is more appropriate [37]. Linn [12] used this approach to develop a gaze-based teleport method. When the users continuously gazed at a location for 200ms, pressing a button would teleport themselves to that point. The experiment has shown that gaze can be used in VR teleport as a novel, fun, and easy way to interact. Similarly, Habgood, Moore, Wilson, *et al.* [38] developed a node-based continuous motion method. In their method, the users could trigger a continuous gentle movement of the character by pressing a button after continuously gazing at the icon of a navigation node, thus attempting to overcome the spatial awareness loss caused by teleport. However, the biggest problem with theses gaze-based methods is accuracy, as it is difficult for people to keep their heads or eyes stable because of physiological reasons [39]. Moreover, the noise can pose a precision challenge for gaze-based localization especially considering the other inevitable physical movement [14].

**Foot**-based interaction has also been a hot topic in human-computer interaction (HCI), especially in industrial design [40]–[42]. The advantage of using the foot is to transfer some reasonable interactions to the foot, such as stepping or striding, thus enhancing the users' understanding and perception of these interactions. Meanwhile, it can significantly reduce the stress of their hands [43]. LaViola Jr, Feliz, Keefe, *et al.* [44] displayed a top-view map under the users' feet, and the users could step towards a specific location on the map, triggering teleport in VR. Willich, Schmitz, Müller, *et al.* [13] developed an entirely foot-based VR teleport method. The users wore a unique device on their feet that enabled localization and teleport through different feet postures and orientations. This method completely avoids hand manipulation, leaving more space for hand interaction. However, the disadvantage is that it is not as accurate and convenient as the hand-based teleport method, considering that the feet are much less flexible than the hands.

In recent years, there has also been an increasing number of researchers trying to combine gaze- and foot-based interactions. The basic idea is to use eyes to locate while feet to trigger interactions, such as selection and clicking on the user interface [45], [46]. Spurgeon [47] also used such ideas and chose stomp to trigger the teleport. However, the experiment results indicate that this method is inferior to the others. The reason is that when the users perform intense physical actions, it will increase the movement of the whole body, thus affecting the gaze's accuracy. Bolte, Steinicke, and Bruder [14] used "jumping" to trigger the teleport. To reduce errors due to eye jitter, their method projected all the three-dimensional destination points into the two-dimensional image space. Then, suppose all the projected pixel points could be covered with a fixed-size circle for a specific duration. In that case, the method would regard the spatial location of this circle's center as the users' destination. Based on this location, by detecting the users' instantaneous acceleration, the method could judge whether they wanted to trigger the teleport.

Compared with commonly-used hand controller-based teleport methods, combining gaze-based and foot-based has the advantage of being hand-free and easier to learn [14]. Therefore, the users can perform other hand interactions during teleport without any intervention. However, the critical point is how to eliminate the localization error due to eyes and the more physical effort (e.g., jumping) caused by feet. In addition, when the feet begin to move, the method may no longer be applicable to room-scale compared with the entirely stationary teleport methods.

# 3. MANILOCO

## 3.1 Design Challenges

This research designs and implements ManiLoco, a new VR locomotion method. ManiLoco is based on the idea that ”people look at their destination when walking normally” and transfers the hand interaction in Point & Teleport to the eye and foot to achieve hand-free. However, the introduction of eye and foot interaction poses several design challenges (DC).

**DC1**: How to distinguish whether the user is normally scanning the environment or trying to activate a teleport mechanism [37]?

**DC2**: How to overcome the normal physiological jitter of the user's eyes or head that affects localization accuracy [39]?

**DC3**: How to avoid affecting the eye or head localization accuracy due to the activity of the feet [47]?

**DC4**: How to solve the problem that the method is no longer applicable to room-scale because the feet are walking [14]?

**DC5**: How to not use any additional expensive hardware devices?

## 3.2 Implementation

ManiLoco is developed with Unreal Engine (UE) version 4.22 and is based entirely on the existing head-mounted display (HMD) device. Also, to overcome **DC5**, all the eye interactions are solved using the head and obtain its information by visiting the virtual camera. Therefore, such solution ensures that the users will not need additional specialized hardware to use this locomotion technique, thus guaranteeing applicability. Secondly, the method will be based on the UE Blueprint system, making it easily configurable and usable by other users via a plugin.

ManiLoco can be divided into four steps, as shown in Figure 1. These steps implement the specific functionality while overcoming the above design challenges.

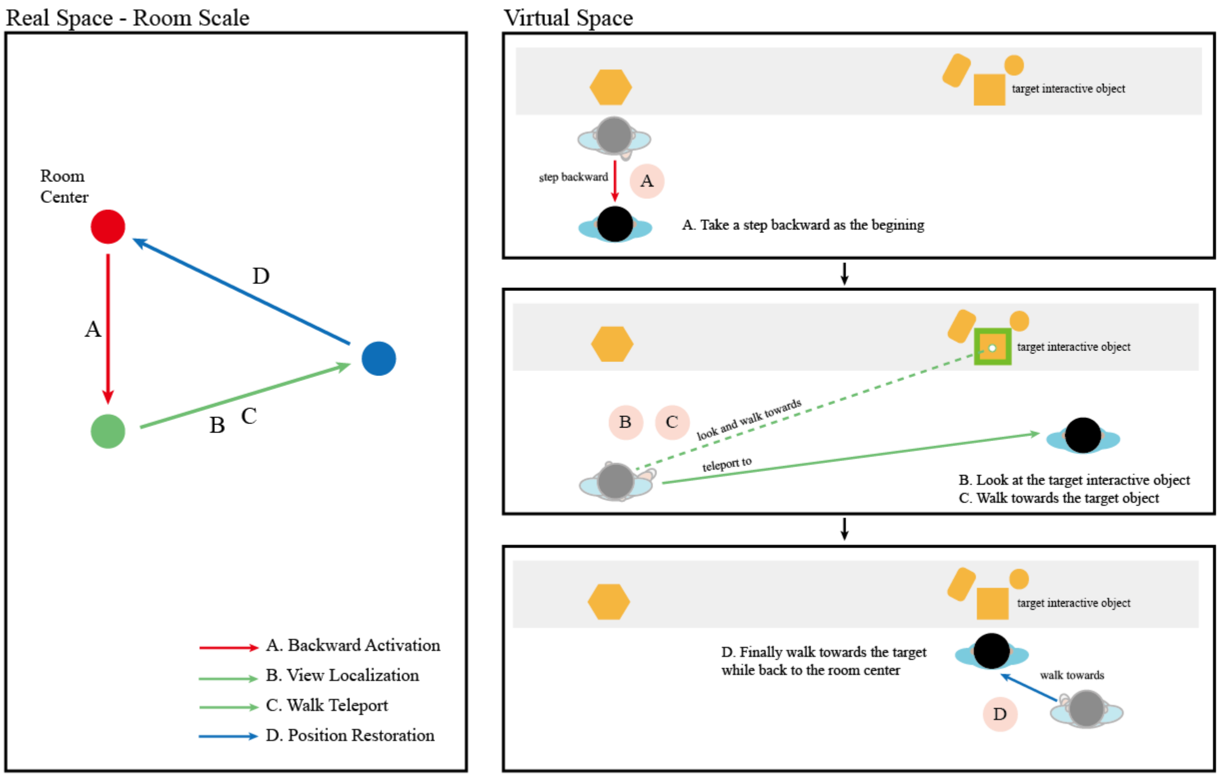


**Figure 3.1.** ManiLoco: (A)Backward Activation (B)View Localization (C)Walking Teleport (D)Position Restoration.

### 3.3 Backward Activation (A)

In order to activate ManiLoco, the users need to take a step backward.

A behavior that is not commonly used in VR can let ManiLoco effectively distinguish it from the users' actions. As a result, ManiLoco can more clearly understand the users' intent and judge whether they want to teleport (**DC1**). Stepping backward is clearly one of them. Also, stepping back sometimes enables the users to see more objects and scan them more efficiently, which is more helpful for the subsequent localization problem.

Specifically, the method will detect such action based on the inequality 3.1:

$$(p_{(t+\Delta t_B)} - p_t) \cdot \boldsymbol{v_{forward.xy}} \geq d_B \tag{3.1}$$

, where $t$ represents the current timestamp, $p$ represents the users' position in virtual world, and $\boldsymbol{v_{forward.xy}}$ is the camera's forward vector in the horizontal plane (unit vector), representing the head orientation. $\Delta t_B$ is a time threshold, and $d_B$ is a distance threshold. The inequality intends to determine whether the users have taken a regular step in their back direction. If the method detects such behavior, it will activate the following teleportation steps.

After testing and fine-tuning, this research sets $\Delta t_B$ to $1\,\mathrm{s}$ and $d_B$ to $0.25\,\mathrm{m}$, which is less than the standard step length of adults, considering that people are not good at such behavior.

## 3.4 View Localization (B)

ManiLoco introduces a new localization method, which is based on the interacting objects. Users often need to reach the target objects and interact with them in VR applications where the hand interaction is dominant.

On the other hand, the object's volume can alleviate the problem that the eyes or head often jitter due to physiological reasons (**DC2**), thus cannot precisely locate. Furthermore, backward activation (A) can effectively circumvent situations of normally scanning the environment. Therefore, ManiLoco does not use the typical gaze method, where the users need to keep looking at the target for a while to determine the destination. Such gaze approach may potentially interrupt the users' mindset, especially when they are focusing on their hand operation.

ManiLoco uses a simple approach instead of an expensive eye tracker to let users locate objects. As shown in algorithm 1, the intersection of the camera's forward vector and the whole scene is first calculated. Then, the method will regard the intersection as the center and find the objects that can interact within a sphere of radius $r$. Finally, the world coordinates of the object nearest this intersection position are used as a reference to guide the next steps. Besides, all objects within this sphere are highlighted as visual feedback to show users the location they are looking, as shown in Figure 3.2.

**Algorithm 1** Object Search

```
object_list = Object[];
hit = RayCast(Camera.position, Camera.forward);
object_list = SphereOverlapObjects(hit.position, r);
Highlight(object_list);
return object_list[0].position;
```

Such a range search can also alleviate the head jitter (**DC2**) and use large objects in the scene to solve the problem of small objects not be easily located. In this research, radius $r$ was set to 0.5 m.

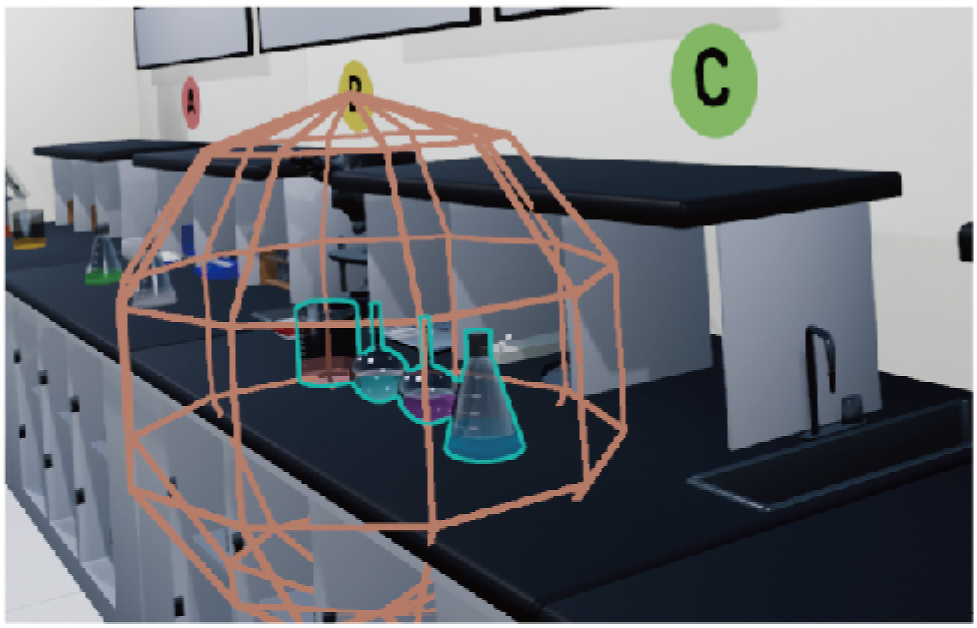


**Figure 3.2.** Visual feedback of range search in View Localization.

### 3.5 Walking Teleport (C)

After identifying the object the users are looking at, the method will start recording the users' movement. Teleport will be triggered if the users accumulates a certain distance towards that sight direction. The detection for triggering is as in inequality 3.2:

$$(p_{(t+\Delta t_W)} - p_t) \cdot \boldsymbol{v_{forward.xy}} \geq d_W \tag{3.2}$$

Similar to inequality 3.1, $\Delta t_W$ is the time threshold, and $d_W$ is the distance threshold. This inequality determines whether the users have taken a step in the direction of the looking object. If the method detects this behavior, it triggers teleport.

After testing and fine-tuning, $\Delta t_W$ is set to 0.4 s, and $d_W$ is set to 0.15 m. The lower time threshold $\Delta t_W$ and the range search in View Localization (B) can effectively alleviate the localization bias caused by the head movement due to foot walking (**DC3**).

### 3.6 Position Restoration (D)

After backward activation (A) and walking teleport (C), the users' are no longer at the room center because they have taken specific steps. Therefore, instead of directly teleporting the users in front of the target object, ManiLoco recalculates the teleport position according to the their current position in the tracking space to solve the room-scale problem (**DC4**). The idea is to offset the users' teleport destination to implicitly guide them back to the room center due to the purpose of interacting with the target object.

In detail, ManiLoco will calibrate the position according to formula 3.3.

$$p = p_{object} + (p_{tracking} - o_{tracking}) \tag{3.3}$$

, where $p_{object}$ represents the world position of the object in view localization (B). Beside, $(p_{tracking} - o_{tracking})$ indicates the user's position in the tracking space, which can be obtained via the VR HMD interface.

This offset can be too small to notice when the users are close enough to the room center, thus no action needed. However, when the users perform multiple rounds of ManiLoco, the offset may become large enough after accumulation. Then the users have to walk toward the target object after teleport to observe it or interact with it, i.e., unconsciously return to the room center.

# 4. EXPERIMENT DESIGN

To evaluate the performance of *ManiLoco*, this research designed a within-subjects experiment with 14 participants. Specifically, the experiment compared the efficiency, presence, task load, usability, and users' perceptions of their hands. As a baseline, two other VR locomotion methods, *Point & Teleport* [17] and *Gaze Teleport* [12], were selected for the experiment. The three methods were tested in random order.

Based on the design features of *ManiLoco*, the research proposed the following hypothesis:

**H1**: In the VR applications where the hand interaction is dominant, *ManiLoco* will not be less efficient than the other two methods (RQ1 & RQ3).

**H2**: Compared to the other two methods, *ManiLoco* will make the user's hands less stressful, thus more focused on hand interaction in the application (RQ2 & RQ3).

**H3**: *ManiLoco* can be used in room-scale tracking space with the introduction of walking (RQ4).

## 4.1 Point & Teleport and Gaze Teleport

This experiment used the default *Point & Teleport* function in Unreal Engine 4.22 VR template project. After the participants pressed the joystick on the controller, the user interface would appear to guide the position, as shown in Figure 4.1. Furthermore, the participants needed to control the destination by controlling the hand position and achieve the teleport by releasing the joystick.

Inspired by Linn [12]'s work, which used eyes to control the teleport destination, this research implemented a simple and low-cost *Gaze Teleport*. The method calculated the intersection of the camera's forward vector with the whole scene in real-time and used a straightforward user interface as visual feedback, as shown in Figure 4.1. The participants needed to adjust the head angle to control the teleport destination and achieve the teleport by clicking the joystick on the controller.

**Figure 4.1.** Visual feedback of Point & Teleport (left) and Gaze Teleport (right).

## 4.2 User Task

In order to integrate hand interaction and locomotion methods more naturally and increase the participants' immersion and entertainment, the experiment designed a simple chemistry experiment. Its task was to obtain a special chemical liquid, for which the participants had to mix several specific chemical liquids. These liquids were contained in different types of containers on different tables and had different colors. Moreover, the liquid surface would tilt with the container to improve the application's realism, as shown in Figure 4.2.

(a) (b)

**Figure 4.2.** (a)Different chemical liquids in different containers; (b)Liquid surface would tilt with the container

In one round of chemistry experiments, the participants needed to complete 12 steps in two categories, as a balance between testing validity and participants' work load. (1) Hand interaction task(**H**): garbing the target containers or mixing different liquids; (2) Locomotion task(**L**): moving to another table.

A crossover existed between the two categories, e.g., carrying a liquid from table A to table B. Therefore, the participants had to complete the locomotion assignment in this step while maintaining their hand interaction. Specifically, the template of 12 steps is shown in Table 4.1, containing 10 (**H**) steps and 7 (**L**) steps.

**Table 4.1.** Steps in each round of chemistry experiment.
$T$ - Table, $C$ - Container. The specific items referred to changed in each round.

| **Index** | **Description** | **Type** |
|---|---|---|
| 1 | Go to $T_1$ | **L** |
| 2 | Pick up $C_1$ at $T_1$ | **H** |
| 3 | Take $C_1$ to $T_2$ | **H**, **L** |
| 4 | Mix liquid in $C_1$ and $C_2$ at $T_2$ | **H** |
| 5 | Take $C_2$ and $C_3$ to $T_3$ | **H**, **L** |
| 6 | Go to $T_1$ | **L** |
| 7 | Pick up $C_4$ at $T_1$ | **H** |
| 8 | Take $C_4$ to $T_3$ | **H**, **L** |
| 9 | Mix liquid in $C_3$ and $C_2$ at $T_3$ | **H** |
| 10 | Take $C_2$ and $C_5$ to $T_4$ | **H**, **L** |
| 11 | Mix liquid in $C_2$ and $C_6$ at $T_4$ | **H** |
| 12 | Store $C_6$ at $T_5$ | **H**, **L** |

In order to minimize the impact of proficiency on metrics, the target liquids were filled in different containers at different tables and in different colors. However, the route length (distance between tables) in each step the participants needed to travel were kept the same in each round of the chemical experiment.

Another point is that when the container was tilted to a certain angle, the liquid in the container would begin to lose. If there were not another container at its mouth to receive the liquid, the liquid would be spilled out to the ground. Therefore, if one of the necessary liquids were all spilled, it would be regarded as an experiment failure.

## 4.3 Application

The research developed a simple VR testing application [1] based on CryoVR, a VR-based application for teaching the operation of biological instruments. Figure 4.3 shows the design of the virtual scene and the final effect. The scene was prototyped as a workbench in a chemistry lab and contained four tables A, B, C, and D. The size of the entire virtual scene was $3\,\text{m} \times 8\,\text{m}$. The width of all tables was 1.8 m. Two containers with different chemical liquids were placed on each table. The participants were spawned close to one of the tables and needed to finish all the steps as instructed.

The application used audio, text, and special user interfaces to guide the participants. At the beginning of each step, instructional audio was played to inform the operation needed. In addition, there was an instruction board near each table to show the text to prevent the participants from not hearing the audio clearly. Further, red arrows and outline effects guided the participants to find the target in each step, as shown in Figure 4.4.

In the application, all hand interaction only relied on the index finger trigger on the controller. The participants needed to press the trigger to pick up the object and release it to drop. Besides, the interaction between the object simulated real-life interaction methods. For example, to pour liquid from container $C_1$ into container $C_2$, the participants needed to align the mouths of the two containers and perform the pouring action in the virtual world, without any additional buttons. Therefore, it ensured that the hand interaction would not conflict with the locomotion method.

The application was developed with Unreal Engine 4.22, using HTV Vive Cosmos as the VR HMD. The participants' activity space, i.e., the tracking space, was set to $1.8\,\text{m} \times 1.8\,\text{m}$, as shown in Figure 4.5. It means that if the participants only relied on natural walking, they would not be able to reach the other tables to get the target containers.

## 4.4 Procedure

After a brief welcome, the participants were first introduced to the background and the purpose of this research. Then, following an overview of the experiment's procedure, the

[1] ↑https://github.com/Wandayu/Look_and_Walk


**Figure 4.3.** Designs of the virtual scene and the final effect in VR.

participants were asked to sign a consent form. Next, the participants provided demographics and reported the time they experienced VR. Afterward, the participants were introduced to the VR testing application, including the chemistry experiment, the overall task, and cautions for liquid pouring. In addition, they were explicitly notified of the liquid being spilled on the ground and the consequences. Finally, the participants were instructed to wear and adjust the VR device and the functions of the controllers. After ensuring that the participants did not have any questions, the experiment began.


**Figure 4.4.** Instructions in the application

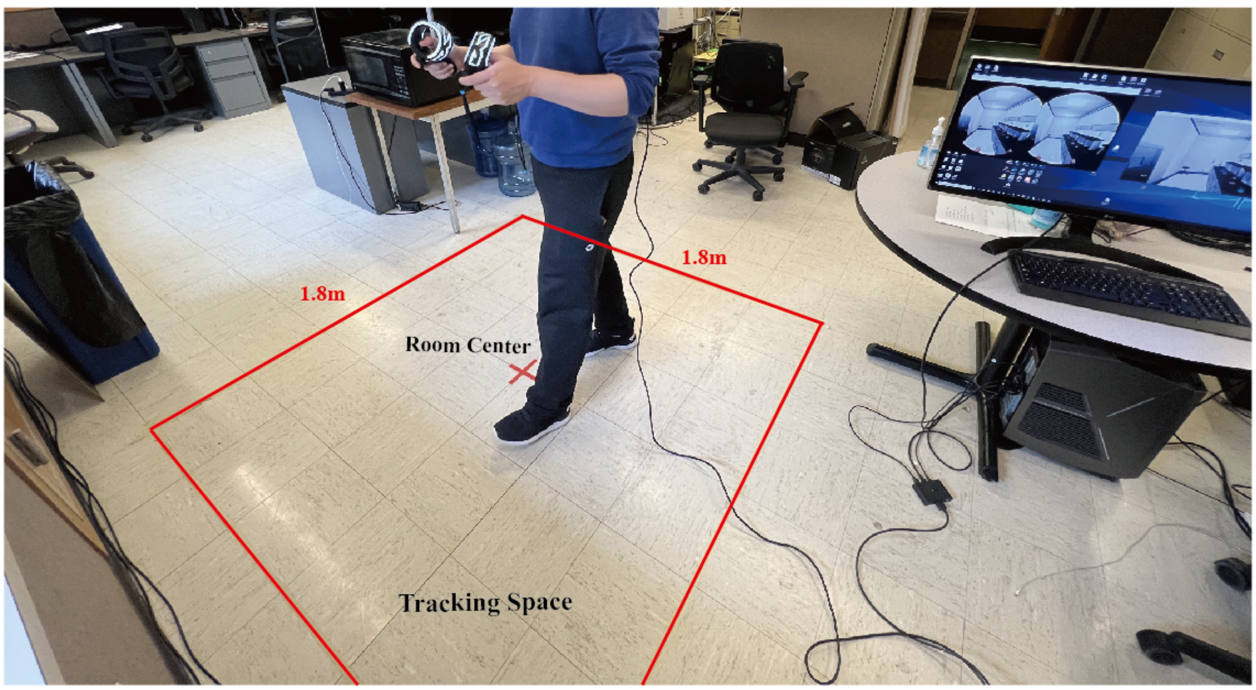


**Figure 4.5.** Test environment in the real world.

The participants first experienced a training level to become familiar with the VR environment, also learn and try the interaction methods necessary in the experiment, including the hand interaction and the three locomotion methods. No data was collected at the training level so the participants could experience as much as they wanted until they thought they were familiar enough with all interactions.

After the training level, the participants had a 2 3 minute break. During this time, the experimenter randomly chose the testing orders of the three locomotion methods.

For each locomotion method tested, the participants were required to complete a full round of chemistry experiment with instruction, i.e., 12 steps, including 10 $H$ steps and 7 $L$ steps. After completing all steps, the participants were asked to take off the VR device and complete a survey about their experience with the current locomotion method. Then, the participants were allowed to rest for 2 3 minutes to relieve fatigue and began the next round of testing.

After all three rounds of testing were completed, a short interview was conducted. The interview specifically asked the participants whether they liked or disliked any aspect of the locomotion and what they might do to improve them. The whole experiment lasted approximately 50 minutes.

## 4.5 Participants

The experiment recruited 14 participants (8 male, 6 female) from Purdue University. The age of the participants ranged from 21 to 30 ($Mean = 25.24$, $SD = 3.01$). Their VR experience spanned a wide range of time, from no experience to 4-year experience. Most of the participants (9/14) have been using or playing VR for about 1 to 2 years. Each participant received a $15 Amazon gift card or cash as compensation at the end of the experiment upon three rounds of testing.

# 5. RESULT

## 5.1 Task-Complete Time

As a measure of the efficiency of the VR locomotion method, the research measured the task-complete time (TCT) of each participant at each step. By accumulating, the researchers obtained the overall time to complete the whole test, as shown in Figure 5.1.

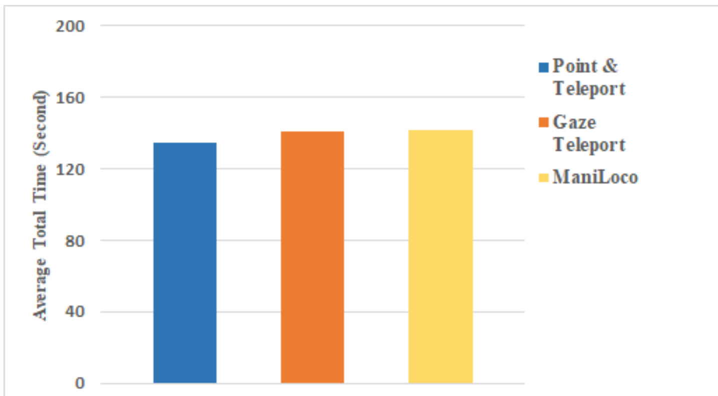


**Figure 5.1.** Average total time to complete the test.

A Shapiro-Wilk-Test showed that the data is normally distributed ($p > .05$). Afterward, one-way repeated measures ANOVA indicated that the overall time of the three methods did not have a significant difference ($F(2, 26) = .491, p = .618 > .05, \eta^2 = .036$).

Then, the researchers compared the TCT of each step, as shown in Figure 5.2.

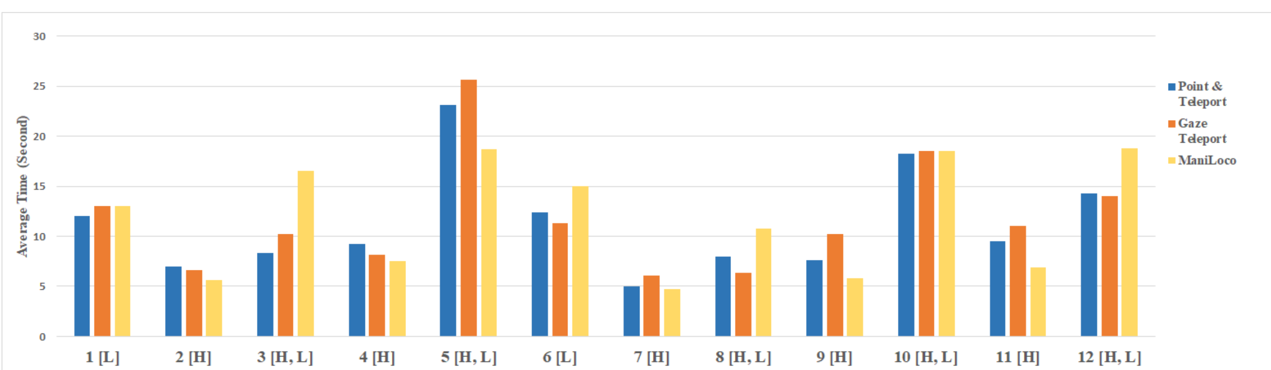


**Figure 5.2.** Average time to complete each step

Notably, one-way repeated measures ANOVA resulted in a significant difference in the $3^{rd}$ step (Take $C_1$ to $T_2$) ($F(2,26) = 8.226, p = .002 < .05, \eta^2 = .388$), and similarly in the $8^{th}$ step (Take $C_4$ to $T_3$) ($F(2,26) = 4.208, p = .026 < .05, \eta^2 = .245$) and the $12^{th}$ step (Store $C_6$ at $T_5$ ) ($F(2,26) = 12.813, p < .001 < .05, \eta^2 = .496$). However, in the rest steps, there was no significant difference.

## 5.2 Presence and Motion Sickness

A modified version of the IGROUP Presence Questionnaire (IPQ) [48] was used in four sub-scales to measure the presence. A Shapiro-Wilk-Test showed that the data is normally distributed ($p > .05$). In Involvement ($F(2,26) = 3.355, p = .051 > .05, \eta^2 = .205$), Spatial Presence ($F(2,26) = .183, p = .834 > .05, \eta^2 = .014$) and General Presence ($F(2,26) = .867, p = .432 > .05, \eta^2 = .063$), one-way repeated measure ANOVA did not get a significant difference.

However, Experience Realism showed a significant difference ($F(2,26) = 5.721, p = .009 < .05, \eta^2 = .306$). When applying t-tests to pairs of methods, the researchers found only *Gaze Teleport* was significantly better than *ManiLoco* ($t(13) = 2.071, p = .024 < .05, Cohen's\ d = .783$).

A modified version of the Simulator Sickness Questionnaire [49] was used with six levels (0: none, 6: very much) to measure motion sickness. The questions measured headache, eyestrain, sweating, nausea, and dizziness. A Shapiro-Wilk-Test represented that the data was not in a normal distribution ($p < .05$). Therefore, a Friedman test was used and showed no significant difference ($\chi^2(2) = 1.857, p = .395 > .05$). Results for presence and motion sickness are presented in Figure 5.3.

## 5.3 Task Load

The researchers used NASA Raw-TLX Questionnaire [50], which contained the participants' mental, physical and temporal demands, as well as performance, overall effort, and frustration during the experiment. The results are shown in Figure 5.4.

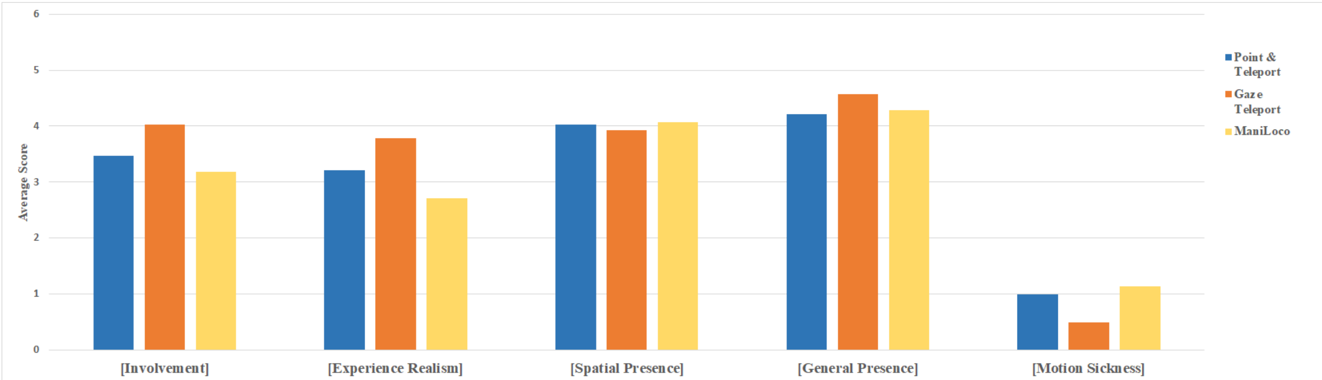


**Figure 5.3.** Presence and motion sickness results for three locomotion methods

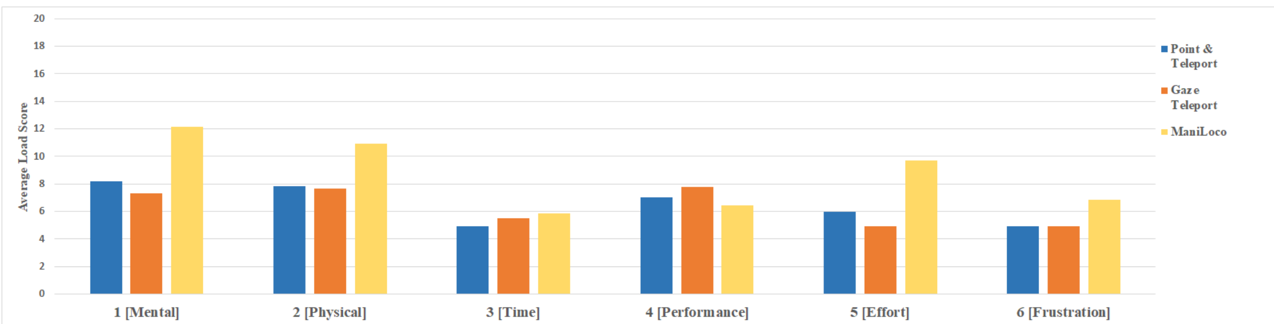


**Figure 5.4.** Task load results for three locomotion methods

A Shapiro-Wilk-Test proved that the data is normally distributed ($p > .05$). Furthermore, one-way repeated measure ANOVA showed no significant difference in the aspect of physical ($F(2, 26) = 2.173, p = .134 > .05, \eta^2 = .143$), temporal ($F(2, 26) = .454, p = .640 > .05, \eta^2 = .034$), performance ($F(2, 26) = .554, p = .581 > .05, \eta^2 = .041$), and frustration ($F(2, 26) = 1.891, p = .171 > .05, \eta^2 = .127$).

However, the mental demand had a significant difference ($F(2, 26) = 6.675, p = .005 < .05, \eta^2 = .339$). Afterward, the t-tests to pairs of methods indicated significant differences both between *Point & Teleport* and *ManiLoco* ($t(13) = -2.260, p = .016 < .05, Cohen's\ d = .854$), and between *Gaze Teleport* and *ManiLoco* ($t(13) = -3.087, p = .002 < .05, Cohen's\ d = 1.167$).

A similar situation occurred in the overall effort ($F(2, 26) = 7.602, p = .003 < .05, \eta^2 = .369$). T-tests also showed significant differences both between *Point & Teleport* and *ManiLoco*

($t(13) = -2.079, p = .024 < .05, Cohen's\ d = .786$), and between *Gaze Teleport* and *ManiLoco* ($t(13) = -2.843, p = .004 < .05, Cohen's\ d = 1.074$).

### 5.4 Subjective Measures

After each locomotion method, the participants were asked to answer two questions with 5-point Likert-scale items (1 = not at all, 5 = very much). The result is shown in Figure 5.5.

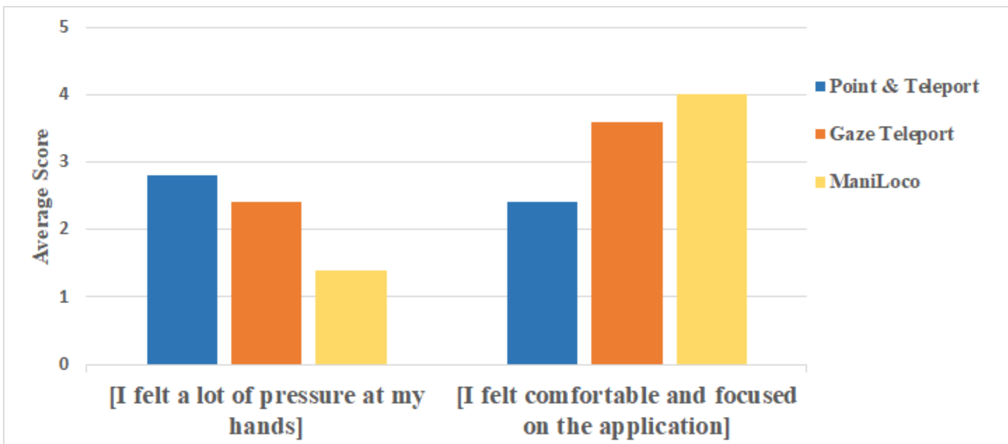


**Figure 5.5.** Subjective measure results for three locomotion methods

As a new question introduced midway through the experiment, the data was only from 5 participants. However, a Shapiro-Wilk-Test showed that the data was in a normal distribution ($p > .05$).

For the first question, the t-tests indicated *ManiLoco* got a significantly better score than both *Point & Teleport* ($t(4) = 2.214, p = .029 < .05, Cohen's\ d = 1.400$), and *Gaze Teleport* ($t(4) = 2.887, p = .010 < .05, Cohen's\ d = 1.826$).

For the second question, the t-tests only showed a significant difference between *Point & Teleport* and *ManiLoco* ($t(4) = -2.359, p = .023 < .05, Cohen's\ d = 1.492$).

### 5.5 Usability Failure Report

Four types of failure were defined to test the usability of the three VR locomotion methods, as shown in Table 5.1.

**Table 5.1.** Failure types and definitions

| Failure Type | Failure Definition |
|---|---|
| **Task Failure** | The test was stuck because of:<br>a. serious bugs in the locomotion method.<br>b. target liquid all spilled out. |
| **Activation Failure** | The participant failed to activate the teleport because:<br>a. He/she forgot how to do.<br>b. The method failed to detect such action. |
| **Localization Failure** | The participant failed to move to the target in one round of locomotion. |
| **Mistakenly Trigger** | The participant triggered the teleport by mistake while he/she did not want to. |

By observing the participants' actions and their view ports in VR, the experimenters counted the number of each participant's occurrences for each type of failure. The average counts of each type of failure are shown in Figure 5.6.

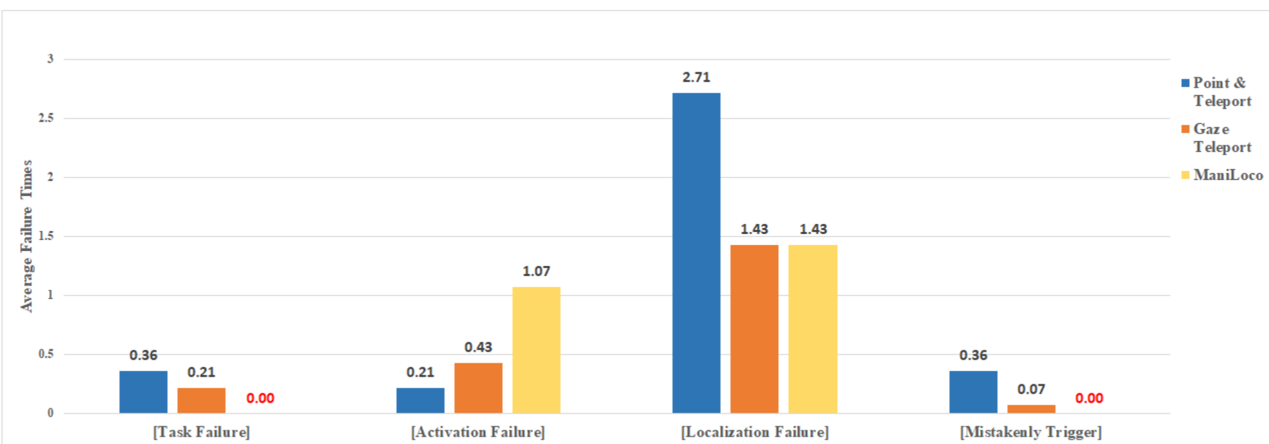


**Figure 5.6.** Usability failure report results for three locomotion methods

## 5.6 Trajectories in Tracking Space

The application recorded the participants' positions in the tracking space in real-time to verify whether they could perform multiple rounds of *ManiLoco* and finish the task in the room-scale tracking space. The other two methods were not recorded because *Point & Teleport* and *Gaze Teleport* literally did not need the participants to move. As a result, 14 participants' activity trajectories in the tracking space are shown in Figure 5.7.

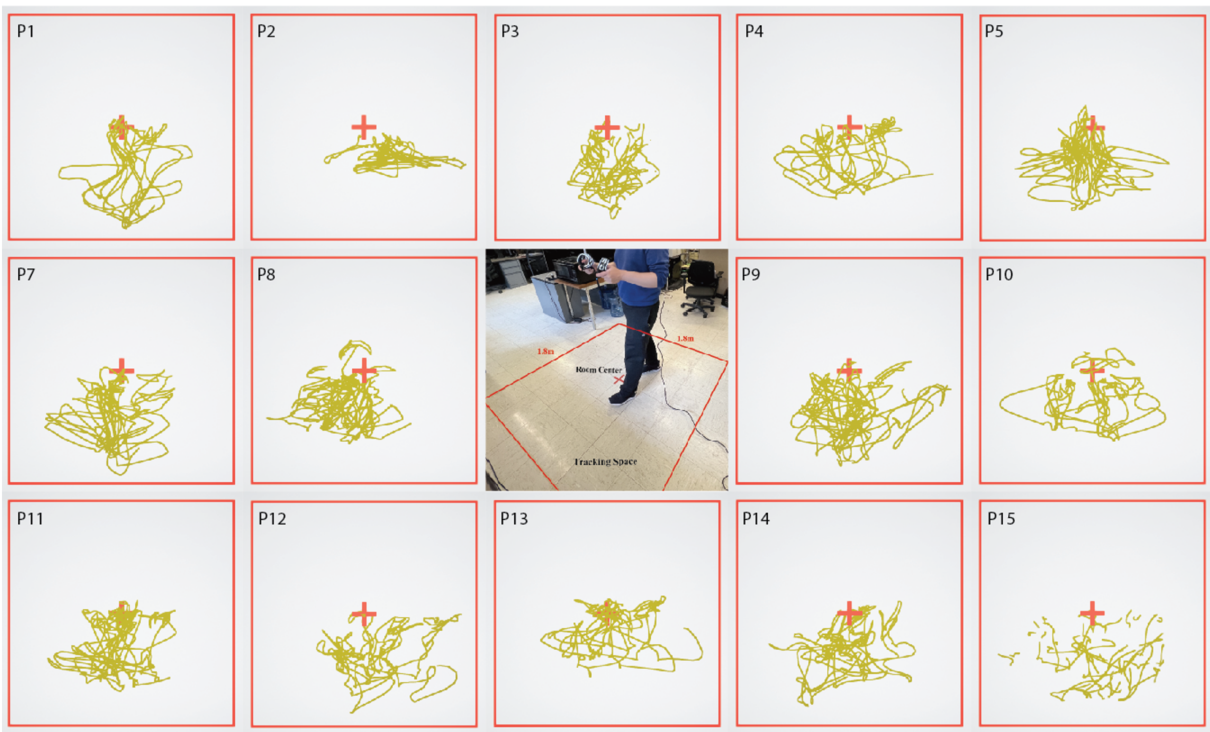


**Figure 5.7.** Tracking trajectories of 14 participants using ManiLoco

## 5.7 Interview

At the end of the experiment, the experimenter gathered comments from every participant about anything they liked, disliked, and suggestions about each locomotion method.

As one of the most popular and commonly-used VR locomotion methods, *Point & Teleport* received high marks from most participants (10/14). They thought it was very easy to learn and efficient. Although grabbing an object, some participants still liked it. For example, P3 said, ”When I need to transfer an object to another place, I am very used to holding the object with my right hand and controlling the teleport with my left, which works well.” However, everyone expressed discomfort when mentioning the steps where the participants needed to use both hands to hold two containers while performing *Point & Teleport*. P10 noted, ”I needed to press the joystick, control the position, and then release the joystick with one hand. Meanwhile, both my hands needed to continuously press the trigger to grab the objects, while I also had to pay attention to the liquid not to spill, which made me exhausted.”

Some participants (4/14) had heard of *Gaze Teleport*, but none had tried it. However, the participants agreed that this method was also very understandable and intuitive. Also, locating with the head was easy and controllable. Compared with *Point & Teleport*, they believed the pressure on their hands was greatly relieved by just clicking a button instead. Many participants (8/14) felt that *Gaze Teleport* was the most efficient locomotion method among these three. However, some participants (4/14) felt that clicking a button still made them uncomfortable. P10 said, ”when releasing the joystick, I always felt like I was to release the trigger as well.”

*ManiLoco* was a completely new method for the participants, with a longer process and more complex steps. One thing that almost all participants (12/14) disliked was stepping backward. They found the backward movement unnatural, uncommon, and weird to achieve. P8 claimed, ”My goal is to get to the object, and it turns out that the first step requires a step backward, which is unintuitive, so why not just go?” P3 also mentioned, ”It is unsettling to always worry about what you will hit when you back up.” However, P6 said, ”During the first try, I felt that stepping back made me uncomfortable. But after many trials and a practical test in the testing level, I might consider that stepping back would give me more space to move around and find the target better.”

Another point that some participants (3/14) disliked was the accuracy of object-based localization. P10 said, ”Locating some small objects far away was a little difficult for me. I must rotate my head carefully.” P8 also represented, ”Unlike the other two methods, the visual feedback for object-based localization was intermittent, and it only appeared when looking at objects, making me upset.”

However, many participants (11/14) also gave their acceptance, and they felt that the design idea of *ManiLoco* and this experiment was great and interesting. They believed *ManiLoco* could likely be a better solution to the locomotion problem when the hands needed to do the interaction. Especially when both hands were holding objects, *ManiLoco* made their hands feel most comfortable. P10 and P11 both mentioned that "After getting used to this method, it became beneficial. It can directly lead you to the target object, and you do not have to worry about hand movements anymore." P1 also stated that "Look  Walk is very suitable for this type of VR application requiring much hand interaction. It made me feel more comfortable and focused on the application." P4 said, "Looking at an object and walking towards it is very natural, as we do in real life."

Regarding the suggestions to the *ManiLoco* method, participants indicated that they had no better ideas. Some suggested replacing the backward stepping action with a less active movement, such as nodding, stomping, speaking, or simply pressing a button.

# 6. DISCUSSION

This research wants to start the discussion from the reports for different types of failures in the experiment because these phenomena can significantly explain the following few aspects.

## 6.1 Usability Failure Report

For **Task Failure**, the number of occurrences was 0 when using the *ManiLoco* compared with the other two methods. While *ManiLoco* did not show a severe bug, the participants did not have to pay additional attention to their hand interactions. Using the other two methods (*Point & Teleport*: 0.36; *Gaze Teleport*: 0.21), on the other hand, some participants had spilled the task liquid or dropped the container onto the ground. The researchers consider this can measure how stable the participants' hands are and the failures can represent a sign of conflict between locomotion methods and hand interactions. Although there is no conflict in the buttons, this unsynchronized operation does not allow the participants to control their hand actions well, thus producing the above failures.

For **Activation Failure**, *ManiLoco* appeared more often. First, *Point & Teleport* (0.21), as a VR locomotion method familiar to most participants, was almost rarely forgotten by the participants. The only times happened to the participants with little VR experience. On the other hand, *Gaze Teleport* (0.43) is easy and much similar to *Point & Teleport*, so they could quickly remember it. The failures in these two methods were mainly due to some participants forgetting exactly which button to trigger them.

As for *ManiLoco* (1.07), from the interview, the researchers learn that, as stepping backward is not a common and natural behavior, so it was difficult for the participants to understand and get used to. These points can explain why the participants occasionally confused it with the other two and assumed that the first step was to press a button. Meanwhile, due to lack of sensors and as a parameter-based detection method, *ManiLoco* may have sensitivity problems. Therefore the number of occurrences was higher for this type of failure.

For **Localization Failure**, *Point & Teleport* (2.71) performed worse. The researchers found that because the participants had to pay attention to the liquid in the container, they could not control the location of the teleport very well. As a result, they always teleported too far or too close to the target, thus adjusting position with a second teleport. *Gaze Teleport* and *ManiLoco*, which used the head for locating, did not have this problem. Such failures mainly occurred in *Gaze Teleport* (1.43) because the participants could not align the target object with the position on the floor well. As for *ManiLoco* (1.43), some participants tended to move their bodies rapidly and intensely , thus shifting the target object and reaching an adjacent position.

For **Mistakenly Trigger**, the count of *ManiLoco* occurrences was 0. Similarly, because the participants were not good at stepping backward, they never triggered it when they did not want to. For the other two methods (*Point & Teleport*: 0.36; *Gaze Teleport*: 0.07), these failures mainly occurred when transferring the objects. Sometimes the participants' fingers unconsciously pressed the button and triggered the teleport again, even though the first teleport had already let them reach the destination. The researchers believe this is also a representation of conflict between the locomotion method and the hand interaction.

## 6.2 Task-Complete Time

There was no significant difference in the overall task completion time for the three locomotion methods, proving the **H1**. However, the researchers found the efficiency of *ManiLoco* was a little worse when only one hand was needed to hold the object. In contrast, the efficiency was similar when holding the objects in both hands.

Compared to the other two methods, *ManiLoco*'s process is longer and more complex, and with the proficiency factor, a *ManiLoco* round should take longer. When holding an object in one hand, the participants with VR experience chose to hold the object in one hand and control the teleport with the other one, which did not cause conflict. Therefore, in these steps, the time performances were expected. However, when holding objects in both hands, *Point & Teleport* and *Gaze Teleport* was constrained, and because multiple rounds of teleport occurred, the time became similar.

Besides, the researchers found that the participants could finish the hand-only interaction tasks after each locomotion in a shorter time in the *ManiLoco* condition. The researchers argue that it may be because *ManiLoco* allows the participants to focus on their hand interaction better. Therefore, the participants can jump out of the locomotion operation and quickly return to the hand interaction.

## 6.3 Presence

For the presence of three methods, the results showed that *ManiLoco* was rated worse in Experience Realism. In addition, the researchers found that the participants gave lower scores to one of the questions in this category (How much did your experience in the virtual environment seem consistent with your real world experience?). Combining with the interview, the researchers infer that it may be because backward stepping is unnatural behavior, and the participants felt that such action was especially counter-intuitive in a locomotion method. So they did not think *ManiLoco* was consistent with the real-world experience.

## 6.4 Task Load

As a new locomotion method, it is understandable that the mental demand was higher when the participants were entirely new to *ManiLoco*. As a result, the overall effort demand of *ManiLoco* was also higher.

However, the researchers are surprised that, despite introducing a specific walking action, *ManiLoco* did not significantly differ in physical demand from the other two methods. The researchers believe that is because of two reasons. First, the speed required for backward and walking is the daily walking speed and therefore did not cause too much physical pressure on the participant. Second, performing *Point & Teleport* or *Gaze Teleport* while holding an object in both hands indeed caused tremendous pressure on hands, thus increasing the overall physical demand. The similarity of the physical demand also reveals that *ManiLoco* could successfully transfer the stress on the hands to the other body parts.

## 6.5 Subjective Measures

Most participants reported that *ManiLoco* was well suitable for such VR applications. These two subjective questions also indicate that *ManiLoco* caused the least stress on participants' hands, made them feel most comfortable and allowed them to focus most on the hand interaction in the application. It also validates **H2** of this research.

## 6.6 Trajectories in Tracking Space

*ManiLoco* is designed and implemented based on the teleport method. Therefore, it is important to ensure *ManiLoco* is also applicable to the room-scale tracking space, as the essential feature of teleport method. The participants' trajectory maps indicate not participants had been out of bounds, which means all the participants could explore the scene with *ManiLoco* in a $1.8\,\text{m} \times 1.8\,\text{m}$ room-scale tracking space, verifying **H3**, that *ManiLoco* can be a room-scale locomotion method.

# 7. LIMITATIONS AND FUTURE WORK

## 7.1 Appropriate Parameters

As a method based purely on VR HMD and software detecting, ManiLoco inevitably introduces a large number of parameters, e.g., the time and distance to detect backward and walk. These parameters may significantly affect the users' experience. If they are set too large, the users will have to rigger through strenuous physical movement, but if they are set too small, the users are likely to mistakenly trigger it when they do not want to. It can be a trade-off between sensitivity and body load.

## 7.2 Different Actions

From the experiment, the researchers found that users were not used to the backward stepping action in ManiLoco, especially when it appears as a component of the VR locomotion method. The action itself is uncommonly used, but also backing up is counter-intuitive with the goal of getting to the destination. Therefore, our future work will try to replace this component with other simple, easy-to-perform, and natural actions. Otherwise, ManiLoco need to come up with different solutions for the corresponding design challenge.

## 7.3 More Scenes

This research develops a simple chemistry lab to evaluate the performance of ManiLoco, which is only $3\,\mathrm{m} \times 8\,\mathrm{m}$. For future work, larger scenes will be tested. Furthermore, in the current virtual scene, the users' locomotions are in 1D, i.e., the targets are all in the horizontal direction. Therefore, more testing scenes need to be developed to explore its performance on 2D or 3D locomotion and verify whether ManiLoco can still be applied to room-scale tracking space.

## 7.4 Object-based Localization

The problem of distant localization has always been a drawback of using vision methods. In particular, ManiLocouses an object-based localization method, and introduces range search to reduce this problem. And because the VR scene in this research is not that large, this problem is not apparent. However, the extreme case of small distant objects has to be considered and it is necessary to develop solutions if larger VR scenes want to be tested in future work.

# 8. CONCLUSIONS

This research designs and develops a new hand-free VR locomotion method, ManiLoco, intended to transfer the hand pressure during locomotion and thus make it more suitable for VR applications where hand interaction is dominant.

A simple chemistry experiment is developed to compare ManiLoco with the other two locomotion method, Point & Teleport and Gaze Teleport. The results show that ManiLoco is less stressful and more comfortable for the users' hands by not relying on the controllers while maintaining efficiency and presence. Besides, ManiLoco allows users to focus more on their hand interaction and aids them on the object manipulation. However, the users may need to pay more mental demand as a trade-off. Meanwhile, ManiLoco introduces the walking, but with the help of an additional offset, it can be applied to room-scale tracking space. The experiment proves that users can explore the $3\,\mathrm{m} \times 8\,\mathrm{m}$ VR scene within a real space of $1.8\,\mathrm{m} \times 1.8\,\mathrm{m}$.

This research has demonstrated ManiLoco's feasibility and possibility. And with describing its design ideas and details, this research hopes to provide more research ideas for future VR locomotion methods.

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# A. RESEARCH CONSENT FORM

**RESEARCH PARTICIPANT CONSENT FORM**

Look-and-Walk: An Interactive Object-based Room-scale Locomotion Method in Virtual Reality

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Computer Graphics Technology

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**Key Information**

Please take time to review this information carefully. This is a research study. Your participation in this study is voluntary which means that you may choose not to participate at any time without penalty or loss of benefits to which you are otherwise entitled. You may ask questions to the researchers about the study whenever you would like. If you decide to take part in the study, you will be asked to sign this form, be sure you understand what you will do and any possible risks or benefits.

Point & Teleport, as one of the most popular locomotion techniques in Virtual Reality (VR), always needs users to use their hands to control the destination. However, users may also need their hands to grab items, etc.

**What is the purpose of this study?**

This research is to develop a new locomotion method without hands involved and to test its performance with another two popular methods. So, we would like to enroll 20~25 people in this user study.

The whole experiment will last about 1 hour.

**What will I do if I choose to be in this study?**

First, you will be introduced to a tutorial level, in which the program will instruct you how to interact with the items in the scene, as well as how to use the three locomotion methods. After you think you are familiar enough with all the content, you can have a rest for 2~3 minutes.

Then, there will be three rounds of testing. In each round of testing, you need to finish all the required steps using the knowledge you have learned in the tutorial level. There also will be audio, text, and user interface instruction to help you better understand what you need to do. After finishing all the steps, you need to answer 2 questionnaires, including 14 questions in total. Next, you can have a rest for 2~3 minutes.

After finishing all the rounds, you need to answer a post-technique questionnaire, including 4 questions in total. Then, there will be a short interview.

**How long will I be in the study?**

The whole experiment will last about 1 hour.

**What are the possible risks or discomforts?**

The motion sickness or vertigo is a typical risk in virtual reality. Specific symptoms include headache, eyestrain, sweating, nausea, etc. If you feel any symptoms in this experiment, please contact with the experiment assistant immediately. You can have a rest at any time. If the situation is not relieved, you can ask to stop the experiment.

Also, in any of the rest parts in this experiment, if you need more than 3 minutes of rest time, you can have the additional time.

Besides, breach of confidentiality is always a risk with data, but we will take precautions to minimize this risk as described in the confidentiality section.

**Are there any potential benefits?**

You may enjoy entertainment by trying VR applications.

You may learn more interaction and locomotion methods in virtual reality, which may let you have more interest in this area.

Also, this study may give you more ideas about your future research.

**Will I receive payment or other incentive?**

If you finish all the three rounds of testing, you can get a totally $15 gift card as compensation at the end of the experiment. If you quit the experiment for sickness reasons, you will receive an equivalent amount of $5 gift cards based on the number of rounds you have completed.

**Are there costs to me for participation?**

There are no anticipated costs to participate in this research.

**This section provides more information about the study**

**Will information about me and my participation be kept confidential?**

The project's research records may be reviewed by the study sponsor/funding agency, Food and Drug Administration (if FDA regulated), US DHHS Office for Human Research Protections, and by departments at Purdue University responsible for regulatory and research oversight.

Only the research team will access to the data, and all the data collected in this experiment will not be shared with the other person.

All the electronic data will be uploaded to the Box protected by Purdue University, and all data in paper format will be locked in this Purdue lab.

All data will be kept for three years, but no data will be used for the future study.

**What are my rights if I take part in this study?**

You do not have to participate in this research project.  If you agree to participate, you may withdraw your participation at any time without penalty.

**Who can I contact if I have questions about the study?**

If you have questions, comments or concerns about this research project, you can talk to one of the researchers. Please contact

**PI: Dr. Yingjie Chen (victorchen@purdue.edu)**

Researcher: Dayu Wan (graduate student) (wand@purdue.edu)

To report anonymously via Purdue's Hotline see www.purdue.edu/hotline

If you have questions about your rights while taking part in the study or have concerns about the treatment of research participants, please call the Human Research Protection Program at (765) 494-5942, email (irb@purdue.edu) or write to:

Human Research Protection Program - Purdue University
Ernest C. Young Hall, Room 1032
155 S. Grant St.
West Lafayette, IN 47907-2114

**Documentation of Informed Consent**

I have had the opportunity to read this consent form and have the research study explained. I have had the opportunity to ask questions about the research study, and my questions have been answered. I am prepared to participate in the research study described above. I will be offered a copy of this consent form after I sign it.

________________________________ ____________________

Participant's Signature Date

________________________________

Participant's Name

________________________________ ____________________

Researcher's Signature Date