How can I get there? Disorientation and motion sickness effects depending on the virtual reality navigation technique

Master thesis report

Marc Domenech Lopez

In this project Microsoft Visual Studio has been used as main integrated development environment. Additionally, the Aardvark Platform, developed by VRVis has also been used for the development of this project.

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Marc Domenech Lopez

Supervisor(s):
Martin Kraus

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Abstract:

Navigation in virtual reality is present in every application. Users need to move around the virtual environment in a user-friendly, intuitive and motion-sickness free way. Nonetheless, the diverse applications offered by this technology result in different virtual environments with different requirements in each case. To fulfill these requirements and give the user a better experience the selection of an appropriate technique is important in every case. For this reason, there is not a locomotion technique free of disorientation and motion sickness symptoms in different environments. With the aim of finding the appropriate navigation method in big virtual environments, three methods are compared against each other: teleportation, World in Miniature (WIM) and drone navigation. A task of navigating to a specified target and then finding another one suggested that the WIM technique could reduce motion sickness and disorientation in these kind of environments.

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Navigation in virtual reality is present in every application. Users need to move around the virtual environment in a user-friendly, intuitive and motion-sickness free way. Nonetheless, the diverse applications offered by this technology result in different virtual environments with different requirements in each case. To fulfill these requirements and give the user a better experience the selection of an appropriate technique is important in every case. For this reason, there is not a locomotion technique free of disorientation and motion sickness symptoms in different environments. With the aim of finding the appropriate navigation method in big virtual environments, three methods are compared against each other: teleportation, World in Miniature (WIM) and drone navigation. A task of navigating to a specified target and then finding another one suggested that the WIM technique could reduce motion sickness and disorientation in these kind of environments.

Contents

Chapter 1

Introduction

Virtual reality (VR) users have increased significantly over the last few years. This is, in fact, thanks to the introduction of low-cost head mounted displays, such as the Oculus Rift, the HTC Vive and the Google Cardboard [19], transforming VR into a widely-accessible and popular technology [2].

From a scientific point of view, VR has undergone a major technological revival, producing new interaction metaphors, design and tools [2]. Consequently, users' experiences have been affected, and the number of VR and Human-Computer Interaction (HCI) studies has drastically increased.

Among the common topics of investigation there is navigation, being also a common topic of discussion in VR-related forum threads and tech articles. Bloggers, tech journalists or forum users claim the best way to move around in VR is still not figured out [4].

VR navigation has suffered this technological revival. The navigation component is present in all VR applications; therefore, it has brought interest to scientists to develop and study user-friendly navigation techniques in virtual environments [9].

In pursuit of contributing to the VR community, this study compares three different navigation techniques in collaboration with the research company VRVis. The aim of the study is to discover an intuitive navigation method that reduces motion sickness and disorientation.

The research company VRVis (*VRVis Zentrum für Virtual Reality und Visualisierung Forschungs-GmbH*) conducts innovatice research and develops projects in cooperation with industries and universities [23]. The company covers a wide range of data types and applications all of them applied to the field of visual computing.

Chapter 2

State of the Art

VR navigation, also known as VR Locomotion, is one of the core tasks to be performed in a virtual environment. In order to navigate successfully, the spatial knowledge gained about the environment is used by users to plan the next movement [21]. However, some of the users often experience difficulties when traveling, which usually can lead to disorientation [7], because of the extra degrees of freedom within a virtual environment, or cybersickness [17] (also known as VR sickness), because they require a mismatch between the sensory information received by the visual system and the vestibular system of users.

Due to the challenges presented by the current navigation techniques, a definitive way of traveling that makes navigation lightweight so that users can focus on more important tasks is yet to be implemented [7]. There are several studies collecting the different techniques that have been studied so far [2, 7], dividing them into more general categories in order to select an appropriate technique depending on the real and virtual environment.

Bowman et al. [7] subdivided the navigation into the motor component called *travel* and the cognitive component called *wayfinding*. On top of this subdivision, Bowman et al. also divided the navigation tasks into the following three categories:

Exploration: navigation with no explicit target.

Search tasks: involve moving to a particular target location.

Maneuvering: characterized by short-range, high-precision movement that are used to place the viewpoint at a more advantageous location for performing a particular task.

Lastly, they also divided the travel interaction techniques into five different categories: physical movement, manual viewpoint manipulation, steering, target-based travel and route planning.

With all these categorizations, Bowman et al. were able to conduct different comparisons of techniques, that then served as a basis for design guidelines [5, 6, 7, 8]. Another group of scientists that compared among all the studied techniques were Boletsis et al. [2] that explored the VR locomotion techniques studied from 2014-2017 in order to identify research gaps and to construct new conceptual knowledge for future VR locomotion related work. The result of the 92 articles checked resulted in a different group formation described in Figure 2.1, which shows the different categories, from general to specific, in which each technique could be part of.
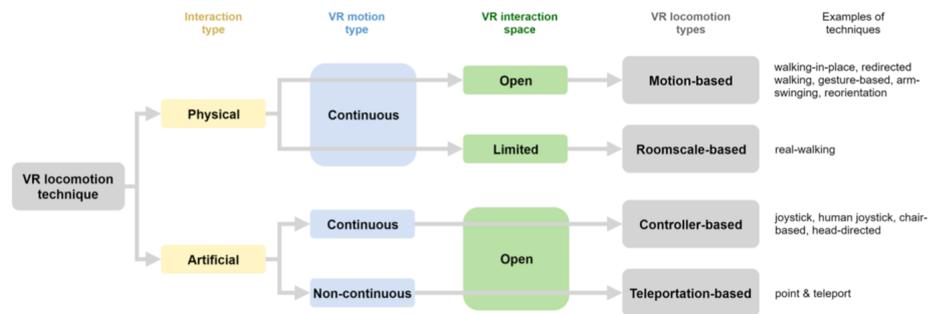

Figure 2.1: VR locomotion typology extracted from Boletsis et al. study

Boletsis et al. counted the number of instances each technique appeared in the studies analyzed. Walking-in-place and controller-based locomotion techniques resulted to be the most utilized techniques, each of them corresponding to two different interaction techniques: physical vs. artificial. For the sake of simplicity, the naming of controller-based locomotion technique used by Boletsis et al. will be replaced by steering technique, which was used by Bowman et al. The reason is that controller-based can be broad, and lead to confusion because, for example, teleportation also uses controllers.

Another observation is that teleportation is not studied or utilised as much. Interesting because teleportation is provided in many professional applications and public installations. For this reason, teleportation was expected to be studied in much more depth, representing a clear gap encouraging future studies to take teleportation into account.

Stoakley et al. [22] and Pausch et al. [20] presented the World-in-Miniature (WIM) concept in their studies, a graphical representation of the virtual environment that allows the user to change the viewpoint and location through moving a virtual representation of oneself in the WIM. Figure 2.2 corresponds to a representation of how the WIM was presented in Stoakley et al. study, in which users had to manipulate objects in the virtual environment.
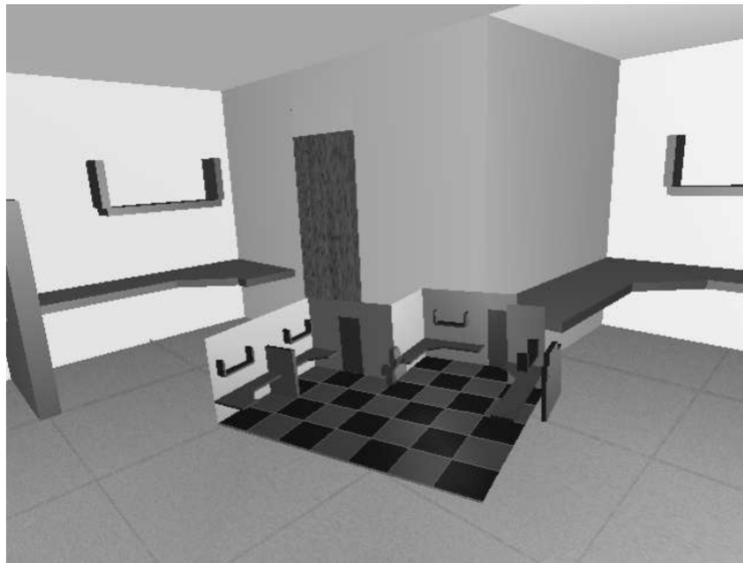
Figure 2.2: World in Miniature layout used in Stoakley et al. study

Berger et al. [1] then proved a gain of spatial knowledge by providing an overview of the environment and a clear understanding of the location of the landmarks versus the position of the user. In addition, motion sickness was also compared to continuous motion and teleportation in this paper.

Rating	Motion sickness	Spatial knowledge
Best	WIM	WIM
	Teleport	Teleport
Worst	Continuous motion	Continuous motion

Table 2.1: Results obtained in Berger et al. study

Table 2.1 shows the results obtained, proving that WIM can be a promising candidate to navigate in a virtual environment over continuous motion or teleportation, two common navigation techniques nowadays.

The three locomotion techniques were compared in three different environments to cover different levels of difficulty. Furthermore, three different distances between the start and end point were also studied to form paths. The largest distance covered was 45 metres, which is a smaller distance than our environment. This way, it is interesting to study if the same results apply in bigger virtual environments.

Steering locomotion techniques are one of the most studied techniques [1, 11, 12]. Despite the fact of the user being stationary and using a controller, these techniques can result cognitively intense and can also lead to VR sickness [2]. LaViola [16] described the two most important body parts that are associated with cybersickness before discussing the three main theories that cause this feeling of sickness in order to alleviate it. The most accepted theory is the sensory conflict theory and it is based on the discrepancies between the two senses involved in cybersickness (the vestibular sense and the visual sense). This sensory conflict arise when the sensory information is not the stimulus that the subject expected based on their experience. Figure 2.3 describes the possible conflict that can be generated if there is a mismatch between the vestibular and the visual system.
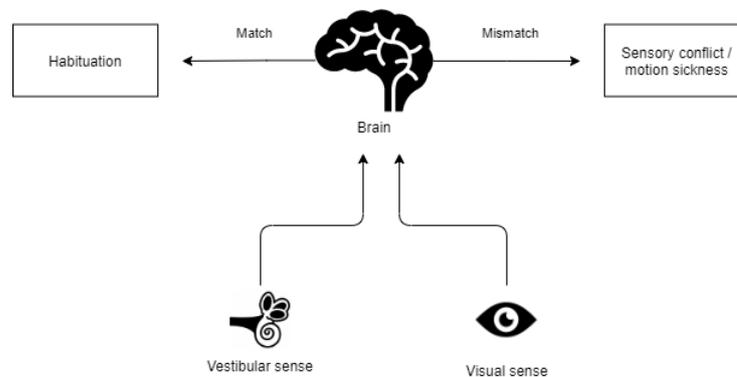

Figure 2.3: Sensory conflict between the vestibular and visual sense
Source: [18]

Other factors that can also contribute to cybersickness can be related to display and technology issues, like lagging or flickering, or individual factors such as gender, age or illness.

It is surprising, though, that even with all the studies proving that steering locomotion techniques tend to cause motion sickness, VR users prefer to use it anyway. Kraus et al. [14] discussed the possible factors that have lead over 90% of VR players of Rec Room, a multiplayer video game, moved over from teleportation to joystick-based navigation. Preference factors were the age of the average user (young users are less susceptible to cybersickness), immersion, physical ergonomics and pleasure.

Innovative techniques are continuously being studied against the most common ones due to the fact that a definitive locomotion technique is yet to be found. Jacob et al. [11] presented a new locomotion technique based on nodes placed 1 to 1.5 meters from each other and which users moves rapidly towards them if they are looking at them and trigger a button. This new technique offered better results as regards to motion sickness when comparing it to teleportation and continuous locomotion in a study which users had to move from one point to another using the three different techniques.

Chapter 3

Design

In this section the selection and design of the different locomotion techniques among all the possible ones is discussed. Three navigation techniques have been selected to be compared against each other.

The idea when deciding the techniques was that each had to be different between each other so that users do not get confused when using any of the techniques. Furthermore, the fact of using a big virtual environment had also to be taken into account when deciding. If a user is presented with a big virtual environment and the only navigation technique is Walking on Point, the experience might result negative because the user will have to walk long times to mover around.

Combination of different locomotion techniques has also been applied, in the extent possible. In addition, the interaction has to be intuitive, as it is valued by the users and created a better experience.

The second section of this chapter is related to the design of the evaluation. The main factors to measure in the study are disorientation and cybersickness. A part from that, the interaction with the interface should be intuitive and natural so that the user has a positive experience.

3.1 The navigation techniques

Limitations like not having enough physical space on site or working with a relatively big virtual environment lead to the rejection of physical interaction techniques. This way, steering and teleportation based techniques were left to be used in the study.

The hardware used during the evaluation is an important factor. In this study, an intuitive and natural way to navigate should be offered to the users so that they can focus on the main part of their measurements or studies. Ferreira et al. [21] compared a traditional desktop setup with a head mount set when carrying navigation search tasks. The results of the study were that users felt the head mount set application to be more intuitive and natural even though their performance was better using the desktop setup.

In order to have a helpful study for the virtual reality community, at least two or three different and innovative navigation techniques had to be compared. One of the techniques should be one of the most used currently to discover if users would rather use a different technique or not.

For this reason, teleportation is one of the locomotion techniques of the study. The point & teleport technique has been designed without innovations. Users use a laser to point a place in the scene and the intersection point between the laser and the surface will be the final destination when the user triggers a button. Figure 3.1 illustrates the point & teleport technique, which is one of the most common locomotion techniques in the virtual reality community.
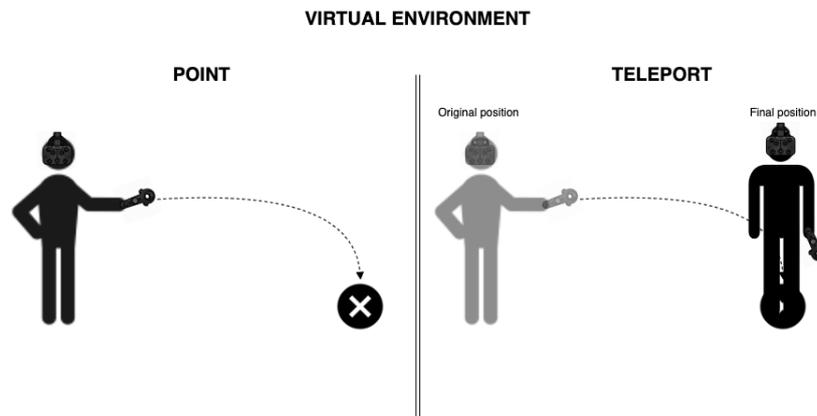
Figure 3.1: Point & teleport illustration

The second technique has not been tested in previous studies because it is an adaptation of remote-controlling a drone using a camera on the drone in real life. The idea is to bring this method of navigating to virtual reality and use the drone to explore the areas of interest through the screen that displays the drone's view.

This technique could be included in the steering-based technique group, referring to Figure 2.1. The fact of directing the drone using the orientation of the controller

can help users to easily learn how to use this technique. Furthermore, to avoid the conflict between the vestibular sense and the visual sense that causes cybersickness, users do not move. Instead, the drone moves for them and there is a screen close to the user that displays the drone's view. Figure 3.2 depicts a sketch of what the drone navigation technique would look like. In the figure, the user can see the drone's trajectory through the screen, which is attached to the controller's position.
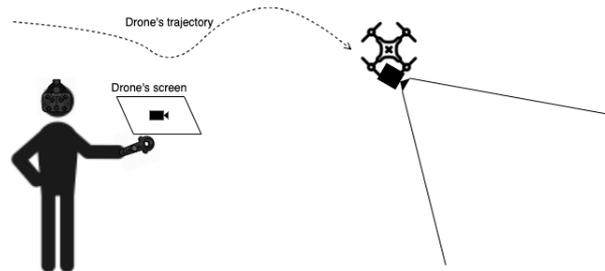
Figure 3.2: Sketch of the drone navigation idea

This idea emerged by trying to eliminate the continuous motion, factor that causes cybersickness, but still using a steering interaction, which is widely used in the virtual reality community and computer games in general. To eliminate continuous motion, navigation methods that use a non-moving environment around the user are the solution. In non-moving environment methods there is a virtual screen that displays the view from a moving camera. Another method in this regard is to make users think they are inside a vehicle so they have a similar feeling to when they are driving.

The last technique of the study is the World in Miniature (WIM) navigation method. This method was chosen due to the positive results that had proved in smaller environments in previous studies, encouraging further experiments in different conditions to see if they also apply. Boletsis et al. implemented a World-In-Miniature environment proving that this method of navigation reduces cybersickness and disorientation [22, 1].

Furthermore, having a mini-map of the whole virtual environment should help users gain spatial knowledge, specially in big virtual environments. The environment can be seen in a smaller scale and, therefore, more landmarks can be used to orient users. A sketch of the WIM idea is presented in Figure 3.3, in which different landmarks are shown in both the virtual world and the mini map overview.
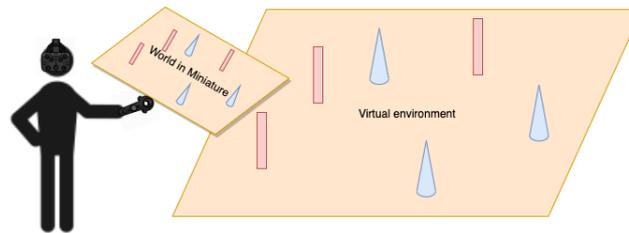
Figure 3.3: Sketch of the World in Miniature idea

Another aspect added in this technique is the indication of the user's current position in the real world. When changing position in the mini-map, users are able to see where in the real world they would go at any time. This indication helps users gain spatial knowledge of the scene and in consequence, feel more oriented.

3.2   The user evaluation

The two main constraints that have to be accomplished by the evaluation are to determine if users feel disoriented or suffer cybersickness while using the different techniques implemented as well as to discover which is the most effective technique in this regard.

For this reason, studies that measure these parameters have been taken account to explore what kind of evaluation the scientists conducted. Langbehn et al. [15] and Boletsis et al. [3] both compared different locomotion techniques between each other with the aim of documenting and guiding the design process of new distinguished locomotion techniques. Disorientation and motion sickness were some of the aspects that were measured in the studies.

Due to the similarity of the objectives of their studies and this one, the evaluation design is inspirational. Langbehn et al. participants had to navigate to several targets, visualized as color semi-transparent pillars. In addition to that, participants had to fulfill a pointing task that consisted of pointing at the position of the targets after reaching the last target, to analyze the effects of the different locomotion techniques on cognitive map building. Lastly, they had to draw a 2D map of the virtual environment and place the set of furniture and objects of the scene as they remembered.

Similarly to Langbehn et al.'s study, Boletsis et al. was based on a city with different assets and interesting locations that users had to navigate through whilst using the different navigation techniques. In this study, the task for the users was to locate four different locations in a 15 minute time frame.

To measure the feeling of motion sickness, participants answered a questionnaire in both studies.

Figure 3.4: Maps with landmarks of Langbehn et al.'s study (left) and Boletsis et al.'s study (right)

It is clear then, that using landmarks in the virtual environment to measure the orientation of the participants can be considered as a method. In order to measure the feeling of motion sickness, verbal feedback and questionnaires is a standard way to do so. There are standardized questionnaires that have been used in several studies.

Chapter 4

Implementation of the locomotion techniques

This section describes the implementation of the three different techniques used in the experiment: teleportation, drone navigation and World in Miniature (WIM), consisting of a mini map.

Before going into a technical point of view, requirements, real users and tools needed for the study, which apply equally for all the techniques.

4.1   Requirements

The main purpose of this study, as mentioned in previous sections, is to be able to move around the scene by means of different techniques, in order to discover which one is more convenient and comfortable in similar virtual environments.

The three techniques can be performed using one controller. With the main controller, the user will be able to change to a different position in the environment and to a different orientation.

One of the requirements is to find a technique that allows the user to travel short and long distances in a comfortable way. Having to use different techniques to travel short or long distances could lead to a worse experience at the end because users would have to change techniques often.

4.2   Real users

This application aims to support planetary scientists in order to measure and find significant data on Mars using high-resolution 3D surface reconstructions.

This way, studying what is the technique that they find most comfortable compared with other is an important aspect of this project. Using the adequate locomotion technique can result in letting the geologists focus in other aspects while traveling or moving more accurately through the scene.

4.3 Tools

The tools needed for the study are the HTC Vive controllers and the head mount device (HMD). The HMD is used to watch the virtual environment, while the controllers are used to perform the different actions. The follow-up figure illustrated the different names of the controller's buttons.

| 1 | Menu button |
2	Trackpad
3	System button
4	Status light
5	USB charging adapter
6	Tracking sensor
7	Trigger
8	Grip button
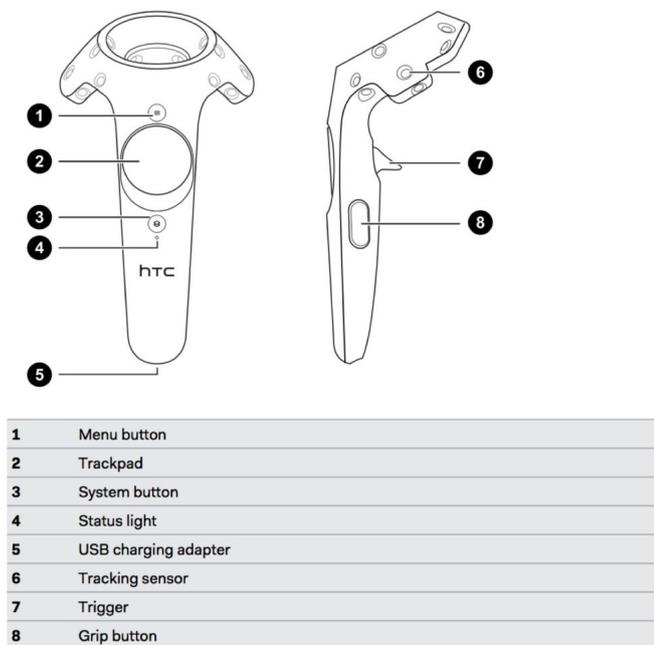
Figure 4.1: HTC Vive controller layout
Source: https://forums.unrealengine.com/development-discussion/vr-ar-development/103602-unreal-button-mapping-names-for-oculus-touch/page2

4.4 Implementation

This section describes in detail the more technical part of the study. For a better understanding, each navigation technique has a different section. Additionally, there is a more general section that explains the implementation that applies to all techniques, like the change to the final position of the user.

4.4.1 General implementation

There are two parts of the code that are applied equally in all the techniques: the part of changing user's position and the part of hovering the evaluation landmarks. The following sub sections describe each of them separately.

Changing user's position

During the implementation of this study, there have been three different coordinate systems that have been working concurrently but have not been defined yet. Therefore, an understanding of how the spaces are related between each other is needed, to have them all in the same origin and at the same scale. The three spaces used in the project are:

- *Opc Space*: this space is only used to translate the OPC from its original position to the origin, where all the other spaces have their origin as well. We call this spcace *opcSpace*.

- *Annotation Space*: space used to translate the items that we add to the scene like flags, lines or drawings to our world. We refer to this space as *annotationSpace*.

- *Working Space*: it is the space that describes the movements that the user does with the controller/s. This space is updated at every frame and stores all the changes applied in the scene by the controllers. We refer to this space as *workingSpace*.

To see the changes applied by the controller to the scene and objects added, it is necessary to combine the workingSpace with the two respective spaces separately. This space differentiation is important because all the objects that are in the scene (the opc and the annotation items) do not share the same origin and scale.

In addition to this, each coordinate system has two different variables: the initial and the current variable. For the opcSpace and the annotationSpace, the initial variable is static and it corresponds to the origin of their respective worlds. On the other hand, the initial variable of the workingSpace is updated every time that the trigger is unpressed, in order to update the variable with the latest movements of

the controller and then apply them the next time a change is done.

This explanation from above has been extracted from the report of my internship of Semester 9 [10]. This thesis could be considered as a continuation of the internship. For this reason, the basic part of the code works equally.

Changing the user's position is an aspect that had to be applied right after the user decided to move. To do so, the logic action would be to apply the changes to the current position of the head mount device (HMD), because it is the camera used by users to watch the virtual environment. Therefore, changing its position would mean changing what users see. However, the position of the HMD is related to the sensors that are in the room and most of the times when users change position, their position in the real world does not change.

To actually change the users' position, two steps have to be followed. First, get the new position where users want to move in the *annotationspace* and then apply the inverse of this transform and multiply it by the initial variable of the *workingspace*. This way, instead of users moving to the new position, the virtual environment moves to the users until the HMD's position is the same as the new position.

Hovering evaluation landmarks

To know when users were hovering or close enough to an evaluation landmark, meaning that they could proceed to move to the next one, the distance is computed.

The condition that had to be accomplished to compare the distance between the user's position and the evaluation landmarks is that they need to be in the same space. Once this is accomplished, it is only needed to decide how close we want users to get to the evaluation mark to consider that they have got close enough. In our case, 8 meters is considered close enough.

Figure 4.2 describes the storing of the variables needed to measure the distance between the controller and the corresponding landmark and the change of color to notice users that they are close enough to the landmark and so that they can proceed to the next task: finding the "look at" landmark and pressing the trigger button (see Figure 4.1) to change its color to green.

In addition to that, the evaluation landmarks change their color when users get close enough, so that they know they should proceed to the next landmark.

```
let mainControllerPos = Vector3(mainController)
let secondControllerPos = Vector3(secondController)
let landmarkPos = List(landmarks).getIndex(counter)

let controllerOnAnnotationSpace = mainControllerPos * workingSpace.Inverse // move the controller to the same space as the landmark
let distance = Vector3.Distance(landmarkPos, controllerOnAnnotationSpace

if distance <= 8.0 then
        landmark.Color = Green

        if secondController.triggerButtonIsPressed then
                counter = counter + 1
                landmarkLook.Color = Green
        else
                counter
                landmarkLook.Color = Blue
else
        landmark.Color = Red
```

Figure 4.2: Pseudo code for the hovering of evaluation landmarks

4.4.2 Teleportation

Teleportation is one of the most common used locomotion techniques within the virtual reality community. It consists of instantaneously moving the user to the point obtained from a ray that intersects with the plane and that starts in the controller.

To check an intersection two parameters are needed in our case: a k-d tree and a ray.

A k-d tree (k-dimensional tree) is a data structure used for organizing points in a k-dimensional space. In addition to that, a k-d tree helps speeding up ray intersections. The working virtual environment, called OPC, is composed of different patches and for each patch a k-d tree is loaded.

The other element needed to have an intersection is a ray. The ray will start at the controller's position and will go forward and will be constantly checking against each k-d tree until it hits a k-d tree. The hit point will be retrieved when there is a hit and therefore the intersection point will be provided. The pseudo code in Figure 4.3 describes how an intersection with a ray and the opcSpace is created. After finding an intersection, the pseudo code shows how to get the point of the opcSpace that has been intersected with the ray and where the final point of the ray is transformed at the intersection point.

```
let initialRay = Ray3d(controllerPos, controllerDir)
let ray = FastRay3d(initialRay)

let checkIntersection = Intersect.intersectiWithOpc (kdTree) (ray)

let getIntersectionVector =
        match checkIntersection with
        | Some intersection -> ray.getPointOnRay(intersection)
        | None -> ray.lastIntersection //if there is no intersection, then we do not update the intersection vector

let moveBox = box.updatePosition(getIntersectionVector)
```

Figure 4.3: Pseudo code of teleportation technique

Finally, for a better visual feedback, a line is created out of the controller's position and the intersection point. This way, the potential teleportation point is showed. Figure 4.4 represents how the teleportation method is seen in the application.
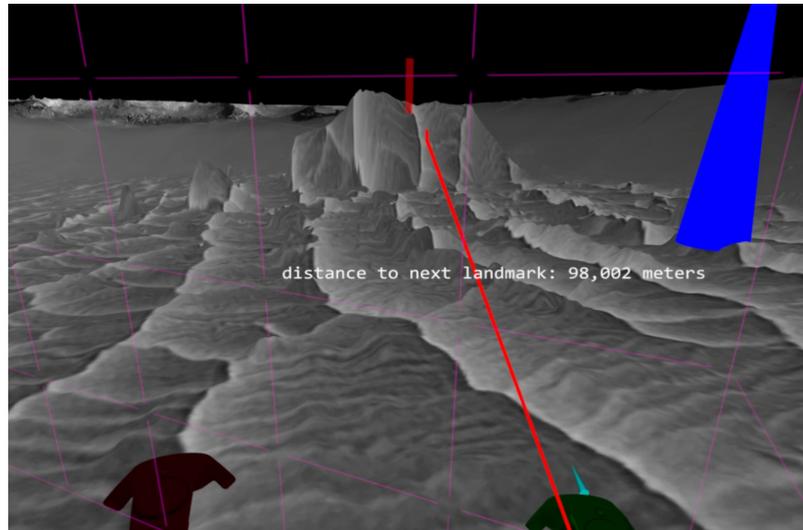
Figure 4.4: Teleportation navigation method

To move to the intersected point, the user has to press the trigger button. After that, Section 4.4.1 describes the change of the user's position.

4.4.3   Drone navigation

When selecting drone mode as a navigation tool, a box appears in front of the user's position, referring to the drone. This box is the movable object that acts like a drone and that users will control around the environment to decide the new position.

To move the drone, users have to press the trigger button. This action makes the drone move at a constant speed. The direction followed by the drone is indicated by the main controller. This way, when the user holds the trigger button and points the controller forward, the drone will move forward. On the other hand, if the user points to the right, the drone will then change its trajectory to the right. The pseudo code of the implementation of this action is shown in Figure 4.5.

```
let mainControllerPos = Vector3(mainController)

match mainController.backButtonIsPressed with
| true ->
        let mainControllerDir = mainControllerPos.DirectionColumn
        let moveDrone =
                dronePos * mainControllerDir * 0.05 // 0.05 corresponds to a constant speed
```

Figure 4.5: Pseudo code of drone movement

Lastly, a cylinder is also created in this mode. This object is attached to the drone and allows the user to spot where the drone is from a long distance. The cylinder is semitransparent so that the potentially occluded parts of the environment can still be seen.

This mode offers the user the possibility to see from the drone's position through a second camera that is attached to the second controller, as seen in Figure 4.6. This small camera follows the second controller's movements: position and orientation. The direction towards where the camera is pointing is controlled by the main controller. This way, users have the sensation that the drone is making a turn when they change the orientation of the controller.

Unlike the teleportation technique, in order to move to a new position users have to press the grip buttons. The reason for that change is that the trigger button is already used to move the drone around. When users presses the grip buttons, they will instantly move to the drone's position in the scene.

4.4.4 World in Miniature

The third and last navigation technique consists of displaying a small overview of the environment that allows users to travel from their current position to another one through a mini map. In addition to the change of position, users can change their current orientation as well. Changing position and orientation at the same time is useful in case they need to be facing a specific part of the scene that would need a change of position and, afterwards, a change of orientation.
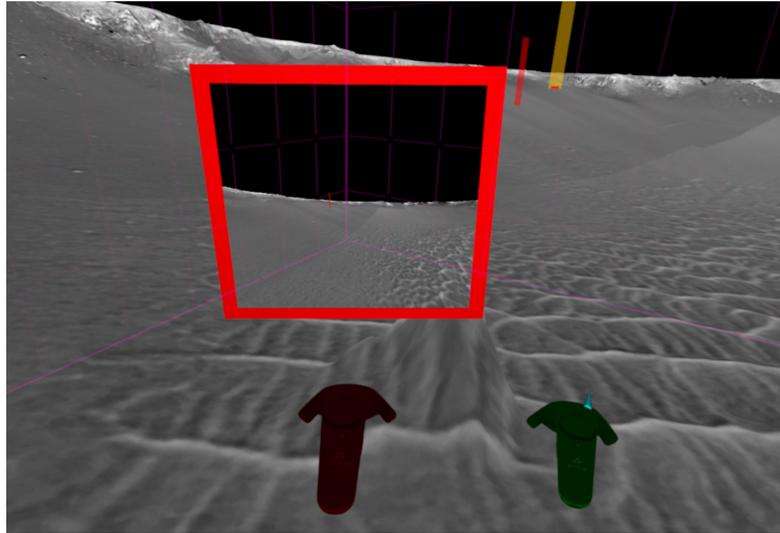
Figure 4.6: Drone navigation method

This technique can be divided in two different modes, which are represented differently in the menu: *WIM* and *WIM Place Landmarks*. First, the mode that shows the mini map and the different landmarks that are in the environment. Secondly, the mode where users can actually change their current position.

When selecting the World in Miniature (WIM) technique, a mini map of the environment appears attached to the main controller's position. A scale-down of the actual virtual environment is applied to create the mini map. Furthermore, no rotation is applied to the mini map. This way, users can actually walk around the map to orient themselves as they please.

The mini map shows three different features that are of great information for the user: the user's current position, the landmarks that they have to go and the landmarks that they have to look at, both represented with different colors. Figure 4.7 depicts the mini map with these three features. As regards to the user's current position, it is composed by two parts: a rectangle, representing the position, and a cone, representing the orientation of the head mount device (HMD) to help users know where they are currently oriented in respect with the scene.

As soon as users decide to fix the mini map in a specific position, they have to call the menu again and select the mode *WIM Place Landmarks*.
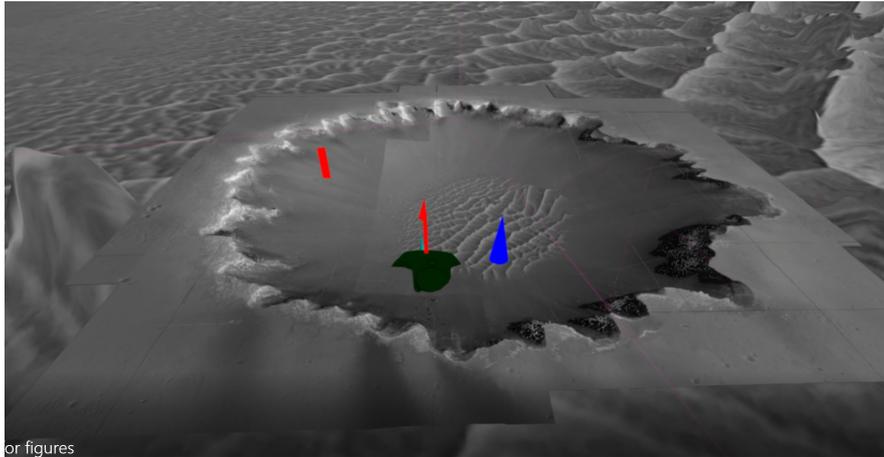
Figure 4.7: World in Miniature starting view, with the user position and evaluation landmarks

After fixing the mini map, users are now able to change their current position. To do so, they shall hover the object from the mini map representing themselves (a rectangle and a cone in red). Once the user's position object is hovered in the mini map a change of color will be applied to it, to give feedback to users.

To proceed with the change of position, users have to keep hovering and press the trigger button. At this point, a new figure appears in the mini map in a different color, representing the position and orientation that users had when pressing the button. After this, the red rectangle and cone are attached to the controller's position and they also follow its orientation. The two user position can be seen in Figure 4.8. It is at this point when users can decide where to move in the scene. To do so, they have to unpress the trigger button and they will immediately be transported to that position in the real environment.

As additional feedback feature, a yellow landmark appears in the real world representing where users would move if they unpress the trigger button. Figure 4.9 represents the mini map in the bottom right part of it as well as the potential user position in yellow.

Unlike the other two navigation techniques, there are two different "*worlds*": the world representing the mini map and the world representing the actual virtual environment. Therefore, changes that are applied in one world directly affect the other and the extrapolation between them has to be accurate. Otherwise, users could be easily confused if their actions did not match both worlds.
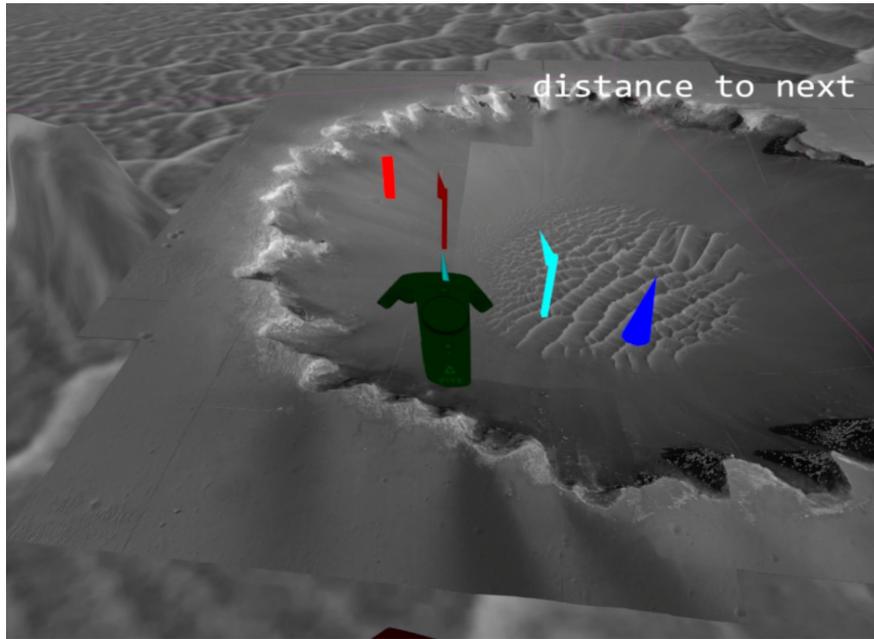
**Figure 4.8:** User's original position in cyan and current position in dark red
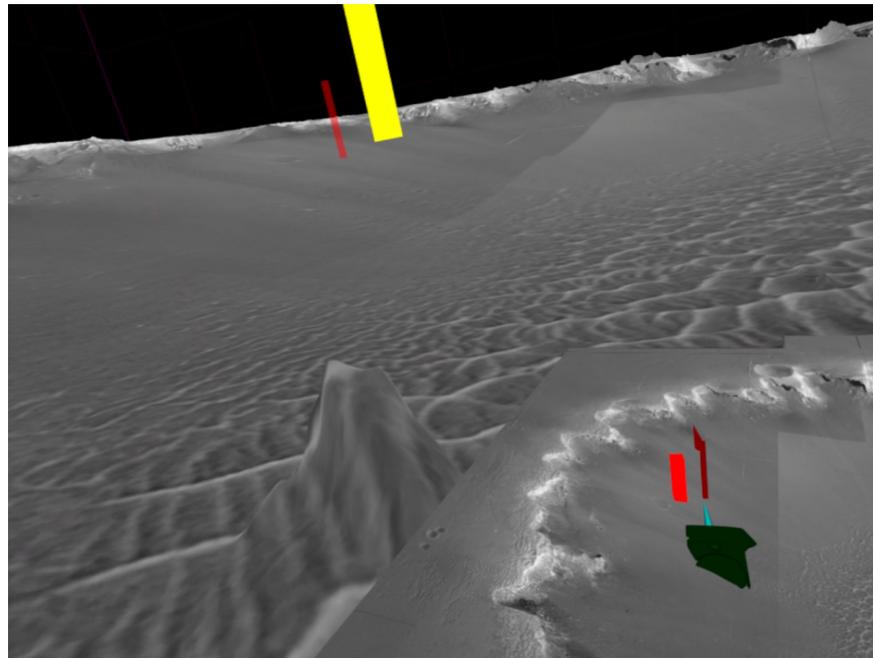
Figure 4.9: Mini map in the bottom right of the figure and yellow representation of future user position

Chapter 5

Evaluation

5.1 Participants

A total of five participants (4 female and 1 male) volunteered to test the three different locomotion techniques. The age of the participants varied from 27 to 35 years old (mean 30 years old). The majority of the participants (80%) work or use VR devices on a daily basis and had experience with video games, playing 2-7 times a week.

5.2 Environment

The virtual environment represents the Victoria Crater of Mars, created by reconstructed images obtained from orbiter images. This is one of the most famous datasets of the Mars missions.

Due to the high similarity between the different bays and capes, there are not enough distinguishable locations in the environment which the user could go without needing any extra help. This is the reason why we added landmarks in the evaluation.

Regarding the landmarks added, there are two types of landmarks, each of them distinguishable from each other with a different color and shape:

- *Go-to Landmark:* this type of landmarks, represented by a red rectangle in the environment are the objects which participants have to arrive by means of the different navigation techniques. As soon as they are close enough to the landmark, this will trigger a change of its color to green.

- *Look-at Landmark:* when participants arrive to the go-to landmarks, they have to spot the look-at landmark, represented with a blue cone. When users

find the look-at landmark a trigger action is performed, meaning the look-at landmark has been found, and changing its color to green.

With the use of these two different landmarks, users can use the different navigation techniques by getting to the go-to landmark and their spatial orientation can be tested by finding the look-at landmark.

To move to the next landmark, participants need to be close enough to the go-to landmark and find the corresponding look-at landmark. When this is done, the two landmarks will then turn green and two new landmarks (one of each type) will appear. A representation of this situation is shown in Figure 5.1, where there are completed landmarks in green as well as the next landmarks that the participant has to visit and look afterwards. Additionally, a message with the distance (in meters) to the next landmark can be seen constantly in the interface.
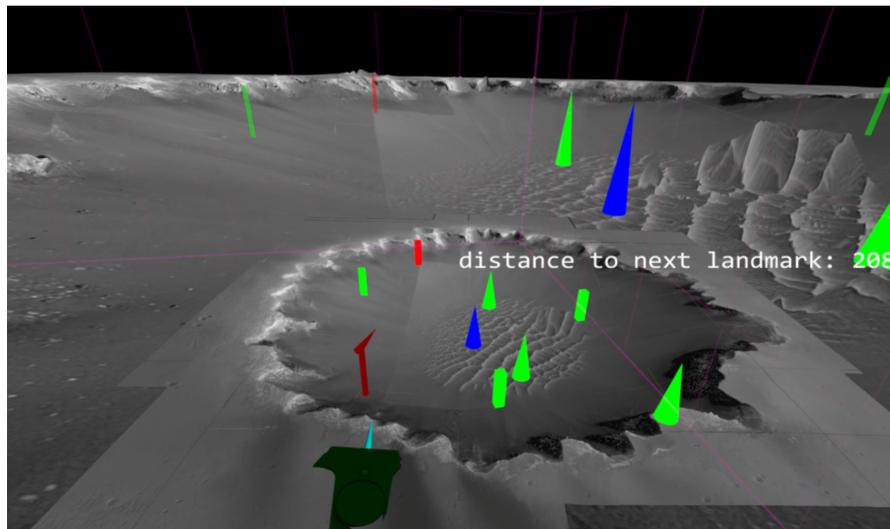

Figure 5.1: Completed landmarks (green) and next landmarks to go and look (red and blue)

5.3   Procedure

First, participants are introduced with a guide to the study. This introduction consists of teaching users how to use the three different techniques and to know what kind of tasks they will have to perform. The guide lasts around 3 minutes (one minute per technique).

After completing the guide, participants fill in a demographics and VR experience questionnaire and then they proceed with the testing of the first locomotion technique, randomly chosen. During each locomotion technique test, participants are presented with the two first landmarks of the environment. Getting to the go-to landmark and finding the look-at landmark means the completion of a task. The evaluation of the navigation technique is completed when ten tasks have been achieved.

After this, two different questionnaires are presented, consisting of the Kennedy-Lane simulator sickness questionnaire [13] (SSQ) and a likability questionnaire.

To conclude the experiment, when participants have used the three different locomotion techniques, they had to fill up a questionnaire gathering information regarding the preference over each techniques. Overall, the experiment lasts 20 - 30 minutes.

5.4 Results

Overall, the participants enjoyed the experience using the system. They considered that they were successful using the system as well as that they could control the three different locomotion techniques. Figure 5.2 shows the average scores obtained from the likability questionnaire that participants took after using each navigation method. The range from 1 (lowest score) to 5 (highest score) indicates that participants found the techniques easy to control and that the system was informative enough to complete all the tasks.
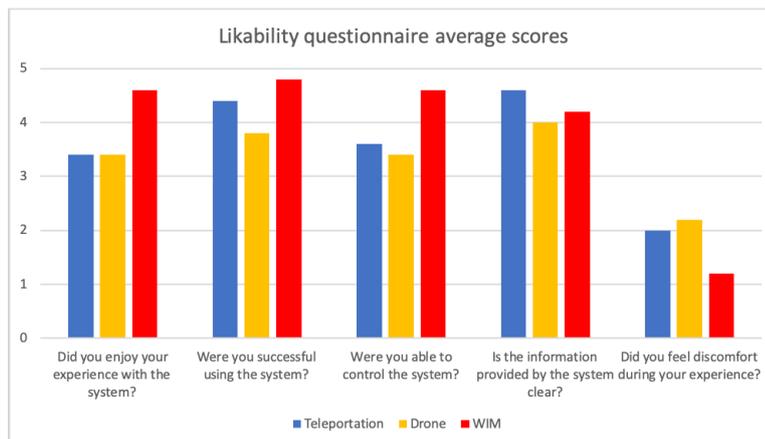

Figure 5.2: Scores of the likability questionnaire

As regards to the gathering of symptoms of motion sickness and disorientation participants took the SSQ after using each technique. A Friedman test comparing the results obtained from the three methods showed a statistically significant difference between the three techniques ($\chi^2(2)=8.49$, p=0.0144). Post-hoc Wilcoxon signed-rank tests with Bonferroni corrections applied yielded statistically significant differences between using the drone technique and the WIM technique (p = 0.0215).

This difference can also be appreciated in Figure 5.3, where it can be seen that results are worse when users were using the drone technique unlike when using the WIM technique.
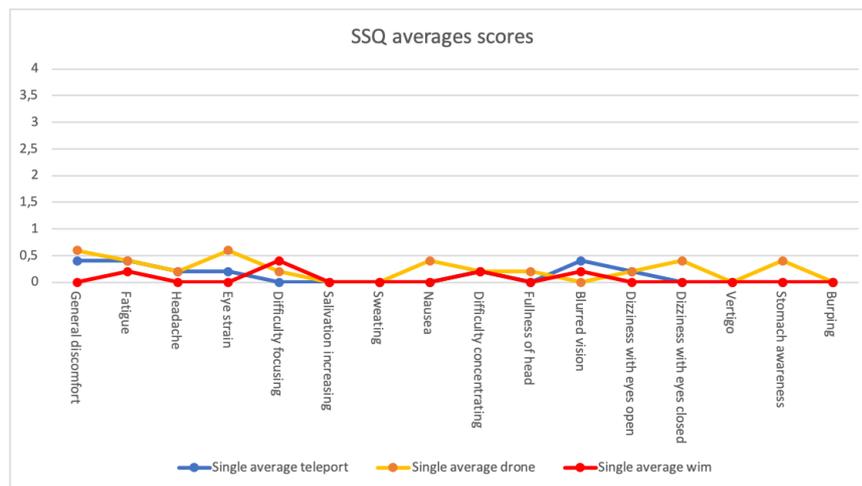
Figure 5.3: Simulator Sickness Questionnaire average scores

When it comes to finding a statistically significant difference between each variable the same post-hoc Wilcoxon signed rank test with Bonferroni correction is conducted. However, there is no statistically significant difference in this regard in any of the different variables. Despite not finding any significant difference, variables like general discomfort, eye strain, nausea, blurred vision, dizziness with eyes closed or stomach awareness could be possible candidates of showing a statistically significant difference if more participants were evaluated.

Kennedy et al. divided the symptoms of the SSQ in three groups: nausea, oculomotor and disorientation as well as a total score. The groups are formed by different variables of the SSQ, that can be part of more than one group.
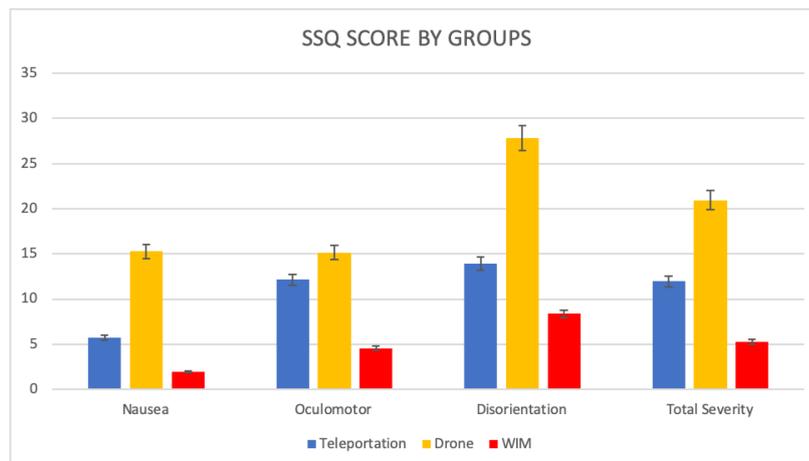
Figure 5.4: SSQ scores in the three groups and total score

As it can be seen in Figure 5.4 the drone technique out-performs in all the groups, specially in the disorientation group. However, according to the users' comments teleportation was the technique causing more disorientation or confusion of their position after teleporting multiple times.

In addition to that, this navigation technique also stands out when it comes to the feeling of nausea. On the other hand, the WIM technique has the lowest scores in all the groups, confirming it was the most preferred technique by the users and the most comfortable one, offering low levels of disorientation as well as cyber sickness.

Users were asked in relation to their preferences over techniques at the end of the evaluation. In this regard, all the participants agreed that the WIM technique was the best to find the target because of the mini map representation, same for the understanding of the user's position. On the contrary, the worst navigation technique and the worst one to understand the user's position was dominated by teleportation with a 60% and a 40% of drone technique according to participants in a questionnaire about preference over techniques that taken at the end of the evaluation.

The WIM technique also dominates the comfort of use, with a 60% of the answers from the users, and a shared 20% of the answers to the remaining techniques.

Video recordings of the users using each technique suggest that WIM could possibly be the most efficient technique. Having the overview as interaction board and

having information such as the position of the go-to and look-at landmarks as well as the user's position and orientation helped users to quickly locate the look-at landmark as soon as they reached the go-to landmark. Some users even changed their orientation in order to face the look-at landmark. In fact, users that noticed this mentioned the positive impact it had compared to the other two techniques. Users that did not take advantage of this, did not have any problems in finding the look-at landmark quickly, since they already knew their final orientation and where they had to look in order to find the blue cone.

During navigation, using the drone technique, participants also focused on other parts of the environment during the process of getting to the target. For this reason, it was easy for them to orient and find the look-at landmark once they were close enough to the go-to landmark.

On the other hand, a slight difference can be seen when users used teleportation. They sometimes had to look around the scene to find the blue cone because they were more focused on pointing and teleporting towards the go-to landmark and after that they focused on finding the look-at landmark.

In other words, WIM and drone techniques potentially take the same time when it comes to finding the look-at landmark. On the other hand, teleportation is slower because users had to first orient themselves and then find the look-at landmark.

Chapter 6

Discussion

Having an environment with no significant landmarks in it leaded to having to add landmarks so that users could navigate to them without any help. Two different landmarks have been added, as explained in Section 5.2: the go-to landmark (red rectangle) and the look-at landmark (blue cone).

A task consisted of first going to the go-to landmark and then finding the look-at landmark. The intention behind this procedure is to discover if users have to focus mostly to using the navigation technique to get to the go-to landmark or either they can focus on the environment and the look-at landmark while navigating.

During the drone technique, users commented it was the most entertaining one even though it was the one that took them the most to complete due to the size of the environment and the fact that the speed was constant. For this reason, providing different drone speeds to the user could be a solution. However, the interaction on how to change from one speed to another intuitively can be challenging. Another option could be to not having a constant speed and changing the drone's speed depending on how pressed the trigger button was.

The fact that the drone technique got the worst scores in Figure 5.4 could possibly be related to the amount of time it took the participants to complete the tasks. Users completed the tasks using the WIM and teleportation way faster than when using the drone technique. This could explain why the nausea group is significantly higher in the drone technique than the two others. The nausea group has variables like general discomfort, nausea, difficulty concentrating or stomach awareness, which their averages were all the highest compared to the other techniques.

The disorientation group in Figure 5.4 shows a big difference between the drone technique, which obtained worse scores than the two others. An explanation to this could be related to the type of participants. Note that 80% of the users work or use VR on a daily basis, meaning that they could be used to the teleportation technique, being one of the most common locomotion techniques in professional applications and public installations, while the drone technique has not been implemented anywhere before.

The differences reflected in Figure 5.4 can also be seen separated by each symptom in Figure 5.3. It would be interesting then, to discover exactly what symptoms have a statistical significant difference between the different techniques. However, that is hard to get with only five participants and we can only get a trend of what symptoms could possibly have a statistically significant difference.

With 30 participants, more robust statistics could be generated. Perhaps, a statistically significant difference could be found using a Friedman test and, if the p-value was lower than 0.05, a post-hoc Wilcoxon signed-rank test could tell us what techniques have a statistically significant difference.

Another topic of discussion is the scenario that has been used in the evaluation. As mentioned before, the similarity of the bays and caves of this scenario is high, which could also lead to a higher disorientation. Testing the navigation techniques in a scenario with canyons or craters could lead to different results. In a scenario with a lot of canyons, the drone technique could be a potential candidate to be the most efficient, enabling the users to move between the canyons freely and easily unlike the two other techniques.

The scale of the environment is something to take into consideration when selecting the locomotion technique. In our case, where the environment is about one kilometer diagonally, results suggest that WIM works properly. Nevertheless, WIM might not be as good in a way smaller environment, where walking can be the most efficient and natural option to move around. This is why it is interesting to test these techniques in environments of different scales.

Chapter 7

Conclusion and Future Work

There is no such definitive virtual reality navigation technique that works perfectly in all the environments. Nonetheless, disorientation and motion sickness are aspects to take into account when selecting a navigation technique regardless of the scenario.

In this study, three different locomotion techniques have been compared in a big and similar virtual environment. Symptoms of orientation and motion sickness have been analysed in detail, discovering that the World in Miniature technique turns out to be the most efficient technique in such environments.

This study could also be the start of a continuation of Berger et al.'s study, that found out that the WIM technique reduced the feeling of motion sickness and disorientation in small environments. With the results obtained in this study, the same findings might apply for bigger environments.
Nonetheless, users felt comfortable using the two other techniques (teleportation and drone navigation), suggesting they could be useful in different scenarios.

Important factors to take into consideration for the selection of the appropriate locomotion technique and for future studies are the scale of the environment and the type of environment.

As part of a future work, more participants should conduct this study. A total number of five participants only gives a trend of what could possibly be the final outcome of this study, but with this number of participants the results can not be considered statistically significant.

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Appendix A

Appendix

A.1 Logs of the implementation

A.1.1 Week 1(10th - 14th February)

- Research state of the art: what kind of techniques are rellevant to study, specially in evironments similar like ours.

- Think of innovative navigation methods

- Navigation methods to consider: WIM, Drone control center, walking, Google Earth method, Landmarks & Fix-Scale, Waltz of Wizard (game) teleportation method

A.1.2 Week 2(17th - 21st February)

- Refactor internship code in order to reuse parts of it.

- Annotation part of the internship code removed.

- Menu is re used as well.

- Implementation of adding landmarks in the scene

- Implementation of World in Miniature technique - display a smaller mini map in the screen

- Start implementation of placing landmarks in mini map

A.1.3 Week 3(24th - 28th February)

- Implementation of adding landmarks in mini map done.

- Implementation of user's position in mini map

- Landmarks are positioned in the mini map and the real world

- mini map orientation on controller started to be implemented

A.1.4   Week 4(2nd - 6th March)

- Implementation of laser pointer without intersection

- Landmarks move together in the mini map and the real world with the controller according to controller's position

- Drone control center implementation: drone moves according to controller's orientation

- Start implementation of second camera that will show what the drone is seeing

- Drone center updates user position when finished: user will go to the drone's position if the grip button is pressed

- Camera follows the drone

A.1.5   Week 5(9th - 13th March)

- Drone cyllinder implemented

- Addition of cone in the mini map that displays the user's HMD orientation

- Implementation of change of user's position in the mini map when hovering it in the mini map.

- Translation of user's position from mini map to real world implemented. When user changes its own position in the mini map, the changes are applied in the real world as well.

- Implementation of showing the initial position of the user in the mini map when changing its position.

A.1.6   Week 6(16th - 20th March)

- new user orientation in the mini map is taken into account

- drone camera orientation is now according to hmd orientation

- OPC and landmarks displayed together in the second camera

- New cylinder transportation technique started to implement

- when in cylinder mode, opc disappears so that the user thinks he is in a room.

- add landmarks in cylinder mode

- Basic teleportation technique implemented. To teleport the user presses the back button.

- Border applied in the second camera when in drone mode to differentiate from the background

A.1.7   Week 7(23rd - 27th March)

- move second camera when hovering and pressing back button

- Implementation of changing user position in mini map with main controller (it was done with second controller before) so that it is more intuitive for users

- Rotation to drone controller by the HMD implemented

- initial user position and orientation in mini map implemented

- hover and move position of second screen improved

- drone mode with second screen attached to controller

A.1.8   Week 8(30th March - 3rd April)

- code refactoring

- second screen shift trafo implemented

- drone improvements from first round of user feedback

A.1.9   Week 9(6th - 10th April)

- Landmarks orientation fixed to be vertical

- Change orientation of HMD to controller's when changing user position in wim

- Evaluation task started: target appears one by one and the user has to hover them so that next one appears

A.1.10   Week 10(13th - 17th April)

- Set position of evaluation landmarks

- Landmarks appear one at a time

- Change color when user is hovering the landmarks or is close enough

- Wim and drone evaluation landmarks working

- wim evaluation done

- First pilot study package created

- Orientation teleportation in wim working

A.1.11   Week 11(20th - 24th April)

- fix wim opc position

- drone is bigger now

- second screen attached to second controller

- visual feedback when hovering in wim

- border of second camera attached to controller

- rudimentary teleportation implemented

- distance to landmark set as text in the application

- kd-tree loading and saving implemented

- implementation of intersection of ray and opc working

- orientation in teleportation mode working

- line controller to intersection in teleportation mode working

A.1.12   Week 12(27th - 30th April)

- second camera rotation same as controller

- look evaluation landmark when pressing trigger button of second controller

- mark main controller

A.1.13 Week 13(4th - 8th May)

- screen in second controller smaller

- position of second screen further from controller

- order of appearance of landmarks is randomized

- distance properly computed to landmark. Instead of euclidean distance, the minimum distance to the surface

- cones instead of rectangles for the look at landmarks

- main controller cone (pointer) used as an arrow to change the user position in wim

- evaluation landmarks are semi transparent

- user study program

A.1.14 Week 14(11th - 13th May)

- workaround for cosmos vive

A.2 Demographics Survey

- How old are you?

- What is your sex?

  - Female
  - Male
  - Prefer not to say

- How much experience do you have with VR?

  - I have worked with it before
  - I work with, or use, VR on a daily basis
  - I have tried it multiple times before
  - I have tried it a couple of times before
  - I have tried it once before
  - I have no experience in VR

- How often do you play video games?

- – Once a year or less
- – Once a month
- – Once a week
- – 2-3 times a week
- – 4-5 times a week
- – Daily

- How often do you use mapping and location services (for example, Google Maps)?

  - – Once a year or less
  - – Once a month
  - – Once a week
  - – 2-3 times a week
  - – 4-5 times a week
  - – Daily

A.3   Likert Questionnaire

The questions in this questionnaire had a scale from 1 (not at all) to 5 (very much).

- Navigation technique used

  - – Teleportation
  - – Drone navigation
  - – WIM (mini map)

- Did you enjoy your experience with the system?

- Were you successful using the system?

- Were you able to control the system?

- Is the information provided by the system clear?

- Did you feel discomfort during your experience with the system?

A.4 Simulator Sickness Questionnaire

The questions in this questionnaire had all the same answers. Users had to choose between none, slight, moderate and severe according to what they experienced in the evaluation.

- Navigation technique used
    - Teleportation
    - Drone navigation
    - WIM (mini map)
- General discomfort
- Fatigue
- Headache
- Eye strain
- Difficulty focusing
- Salivation increasing
- Sweating
- Nausea
- Difficulty concentrating
- Fullness of head
- Blurred vision
- Dizziness with eyes open
- Dizziness with eyes closed
- Vertigo
- Stomach awareness
- Burping

A.5   Preference over techniques questionnaire

- Which navigation technique was best to find the target?

    – Teleportation
    – Drone navigation
    – WIM (mini map)

- Why?

- Which navigation technique was worst to find the target?

    – Teleportation
    – Drone navigation
    – WIM (mini map)

- Why?

- Which navigation technique was best to move to the target?

    – Teleportation
    – Drone navigation
    – WIM (mini map)

- Why?

- Which navigation technique was worst to move to the target?

    – Teleportation
    – Drone navigation
    – WIM (mini map)

- Why?

- Which navigation technique felt most comfortable?

    – Teleportation
    – Drone navigation
    – WIM (mini map)

- Why?

- Which navigation technique felt least comfortable?

    – Teleportation

- – Drone navigation
- – WIM (mini map)

- Why?

- Which navigation technique was best to understand your own?

  - – Teleportation
  - – Drone navigation
  - – WIM (mini map)

- Why?

- Which navigation technique was worst to understand your own?

  - – Teleportation
  - – Drone navigation
  - – WIM (mini map)

- Why?