# Interaction Challenges in the Development of a Fire Warden VR Training System using a HMD


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Abstract: This paper presents challenges encountered when interacting with 3D environments by means of Virtual Reality devices in a seated position. A use case has been devised and developed to support this work: a fire warden virtual training system. The users interact with the virtual environment with a combination of a Head-Mounted Display and other assisting devices to complement the virtual experience (keyboard, gamepad, leap motion). This work points out the benefits achieved using virtual reality in this environment and it exposes the limitations experimented by humans in such situations. With the knowledge gathered with these experiments this paper proposes interaction techniques to overcome them.


## 1 INTRODUCTION

In the last years, the new generation of Head-Mounted Displays (HMDs) have become popular devices to provide highly immersive experiences which are very difficult to achieve by other means. They are excellent tools to view virtual environments (VEs) in a realistic way but, by themselves, they do not offer interactive capabilities with the objects in the VE. Additional devices are attached to the HMD setup to overcome this situation.

When wearing a HMD, users cannot see the real world surrounding them, so it is difficult to locate and use the mouse, the keyboard, the gamepad or any other interaction device at their disposal. Additionally, even wireless devices, they are normally placed at physical location, breaking the virtual experience of the user. New interaction devices have been developed to solve this issue, such as, walking platforms, specific hand input devices, haptic gloves, etc. These solutions may be a good choice for gaming purposes, in which a higher level of activity is necessary or recommendable. However, depending on the application or final user these devices may not be suitable. For example, for educational purposes, with school students, it seems more likely for them to use their own computer screen and keyboard.

This work studies some interaction possibilities of HMDs in a natural seated position. To analyse the challenges of interacting with HMDs we consider three universal interaction tasks within 3D or VE applications (Hand, 1997), (Bowman et al., 2001), (Bowman et al., 2004) which Jankowski, J. and Hachet, M. (Jankowski and Hachet, 2013) defined as:

- Navigation: Related to the motor task of moving the viewpoint through an environment. If it includes a cognitive component, it is referred to as Wayfinding
- Selection and Manipulation: Related to the techniques of choosing and picking an object and specifying its position, orientation, and scale.
- System Control: Related to the communication between user and system which is not part of the VE.

For the use case presented in this work, we will study the methodology followed when planning the experiments and the decisions taken regarding these three tasks according to our work experience.

This paper is organized as follows. Section 2 analyses the related work regarding interaction in VEs and hand gesture recognition. Section 3 explains the interaction devices selected for the Setup of this work. Section 4 describes the fire warden use case developed and analyses each of the interaction tasks. The final section is about conclusions and future work.

# 2 RELATED WORK

Jankowski, J. and Hachet, M. (Jankowski and Hachet, 2013) presented a state of the art of non-immersive interaction techniques for Navigation, Selection and Manipulation, and System Control. This work also summarizes the main 3D Web design guidelines.

Moya, S. et al. (Moya et al., 2014) analysed the influence of different factors in locomotion control in 3D VEs. They designed an automatic locomotion system and concluded that, for non-casual gamers, automatic locomotion is preferred, whereas gamers prefer to control locomotion themselves.

Regarding hand gesture recognition for HCI, (Sharma and Verma, 2015) proposed the tracking of six static hand gestures. They used images extracted from recorded video streams at different distances and positions. They are able to use their system to control applications such as power point, media player, windows picture manager, etc.

Manresa, C. et al. (Manresa et al., 2005) present a real-time algorithm to track and recognise hand gestures for interacting with the videogame. This algorithm is based on three main steps: hand segmentation, hand tracking and gesture recognition from hand features. The results of this work show that users can substitute traditional interaction metaphors with their low-cost interface.

Segura, I. et al. (Segura et al., 2007) developed a simulator of construction machinery for safety training. In this work the visualization was implemented as a chroma-key-based mixed reality system, combining a 3D VE, a real cabin interior, and some superimposed messages to the user. The overall impressions from the testers were positive.

Goenetxea, J. et al. (Goenetxea et al., 2010) presented an interactive and stereoscopic hybrid 3D viewer. In this work they used Nintendo Wii control and developed a dynamic gesture recognition procedure used for interacting with the weather animations.

Regarding fire simulation, it has also been a research topic in VR applications (Moreno et al., 2011), (Moreno et al., 2012). The simulation of real-time interactive fire is a challenging topic that has not been solved yet.

In this work we propose to use a HMD combined with usual interaction devices such as keyboards and gamepads. Leap Motion Controller is used for hand recognition. The following sections explain the setup we have developed for a fire warden virtual training use case.

# 3 Use Case Setup

In our use case, the tests are carried out autonomously by a fire warden trainee. Therefore, it is not a collaborative learning experience, as each user must be aware of their own actions and decisions.

The setup used in these experiments is composed of the following items:

- Chair. One goal of our work is to keep the setup as simple as possible. This is why we tried to limit the amount of extra devices needed. The users will interact in a seated position, needing no other devices.
- Computer. The recommended system requirements are: Windows 7 or newer, Compatible HDMI video output, Intel i5, NVIDIA GTX 770 or greater.
- Monitor. The final goal is for the user to visualize the 3D VE with the HMD, but it is necessary to have a monitor to make the first steps until the virtual experience is launched and to get some additional information after the training session.
- HMD. We have used Oculus Rift DK2. The Oculus CV version or any other HMD brand could be used, but the specifications of the computer might require modifications to match the HMD requirements.
- Keyboard. Anyone used to dealing with computers is familiarized to keyboards and there is no extra effort needed. Wireless or not is irrelevant, but it should be placed in a known and fixed place before the VR training session. Bare in mind that the user will not be able to see the real world with the HMD on.
- Gamepad. It is also a familiar device in video games and it is intuitive for navigation purposes. We have used the Logitech Rumblepad2.
- Leap Motion Controller. This device provides means for tracking the hand gestures performed by the user. It was attached to the Oculus Rift with the universal bundle. The latest Orion beta software has been used (Orion, 2016).

## 3.1 Interaction Devices

This section discusses the interaction devices selected for the use case presented in this work.

### 3.1.1 Keyboard

The keyboard is used to navigate through the VE using the up, down, left and right arrow keys. In traditional computers, they are a group of isolated keys, easily distinguishable from others. In more compact devices such as laptops, the arrow keys despite being closer to other keys are still easy to locate. The advantage with laptops is that the keyboard is attached to the screen so it cannot change position. Sometimes, WASD keys are also used for navigating. Normally, this keys are used with the left hand leaving the right hand free to interact with the mouse. This setup is typical used in gaming (see Figure 1).

Both arrow keys and WASD keys can be used with only three fingers of one hand, leaving the other hand free. In this use case, the free hand is used to perform the gestures defined to select and manipulate objects in the scene. This gestures are captured by the Leap Motion Controller.

#### 3.1.2 Gamepad

Instead of using the keyboard to navigate, we have experimented with a gamepad. In this case both hands are needed to hold the gamepad and the user has to let go of one hand to perform the hand gestures for selecting and manipulating objects of the VE.

In most applications, the right stick is used for navigating (forward, backward, left and right) and the left stick for turning the camera view. This left stick is not necessary as the user can look around by moving the head with the 360 tracking system offered by the HMD. So, in the gamepad the user only has to use the right stick, none of the other buttons are needed. This makes it simple for the user, despite wearing the HMD.

#### 3.1.3 Leap Motion

HMDs offer a really immersive experience. Users feel they are actually in the VE they are watching through the HMD device. This experience is so realistic and convincing that users try to interact with objects from the virtual world with their own hands. However, regular interaction devices as the ones described above do not allow this sort of interaction. This is why we have chosen Leap Motion Controller for our work. This device allows users to integrate their hands into the virtual world and unlike other devices, they require no practice or previous knowledge from the user.

The Leap Motion Controller is mounted on the front of the Oculus Rift glasses, as seen in Figure 2, and whenever the users lift their hands to grab an object from the virtual world, the virtual hands appear in the virtual world, performing exactly the same movements as the real hands.

This setup is more compact than other alternatives using external trackers for gesture recognition.

# 4 USE CASE: FIRE WARDEN TRAINING

This use case has been designed to train experts on occupational hazard prevention and more precisely in fire safety in buildings. The fire warden trainee has to perform the tasks described below:

- Locate the possible fires in the building.
- Extinguish these fires.
- Alert other people in the building.
- Evacuate the building.

These tasks imply different levels of interaction with the VE. In the next subsections we will explain the methodology followed to decide which kind of interaction devices to use, and we will explain the trial and error process carried out for each of the classical VR interaction categories.

## 4.1 Navigation

One of the tasks that the user has to perform is the location of the possible fires throughout the building, to discover these fires the user has to navigate through a two-floored warehouse. The floors are connected by two staircases which the user can use as many times as needed.

Another task that implies navigation is the evacuation of the building. For these tasks the user has to know the exits available in the building. Moreover, the users are asked to put the fire out, to do that the location of the extinguishers has to be found. The user has to select them and head towards the fire.

These tasks imply wayfinding, as the user has to have a cognitive overview of the building and has to be able to make decisions. To ease this job, the application displays some messages (images or text) on the screen of the HMD. These messages are explained in section4.4.

## 4.2 Selection

One of the goals of our fire safety training is to allow wardens to learn how to use fire extinguishers in a safe and efficient way. In real life a fire extinguisher must be manipulated in a precise way and fires must be put out following the PASS method (Safety and Administration, 2016):

- Pull the pin in the handle.
- Aim the nozzle at the base of the fire.
- Squeeze the lever slowly.
- Sweep from side to side.

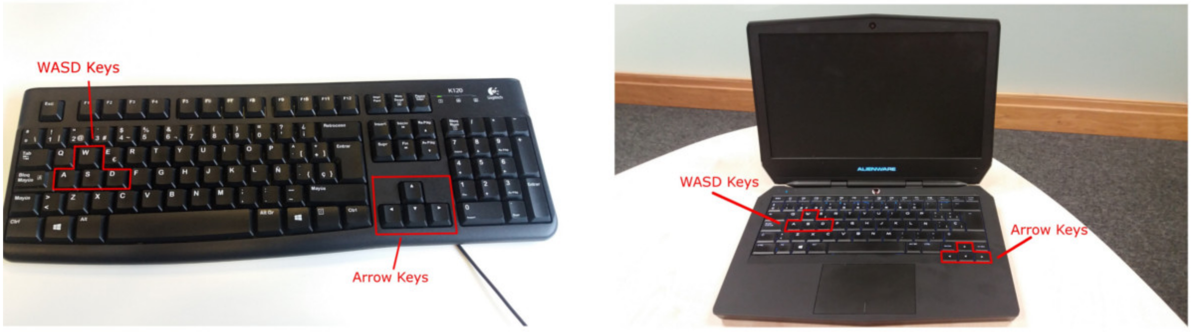


Figure 1: Arrow Keys and WASD Keys in a Traditional Keyboard (left) and a Laptop (right).

Figure 2: Leap Motion Controller attached to Oculus Rift DK2.

Figure 3: Setup #1: Interaction with Keyboard and Leap Motion Controller.

We have made several tests to see which hand gestures are most appropriate to simulate these actions in virtual life and we have used the Leap Motion Controller (LM) to track them.

In the first place, the warden has to grab a fire extinguisher. To allow this action in the fire safety training application, first the user has to navigate to one of the extinguishers, and get close to it to a certain distance. We have set 60 cm as the maximum distance to allow the user to grab the extinguisher. We have chosen that distance as it is the standard length of an adult's arm (McDowell et al., 2008),(NASA, 2016). Once the users are placed at reaching distance from the extinguisher they have to extend their arm towards it and grab it.

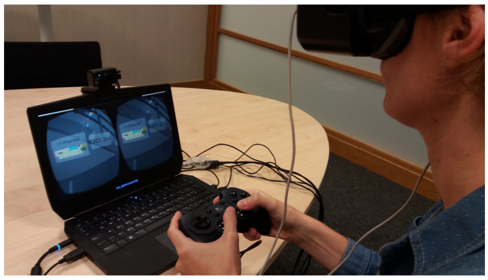

Figure 4: Setup #2: Interaction with Gamepad and Leap Motion Controller.

To represent this gesture, the first idea we thought of was a "palm closing" gesture. This gesture is easily trackable by the LM and it is easy to perform and understand by anyone: "I want to grab the extinguisher". However, we dismissed this gesture for two main reasons. First, the PASS method indicates the user has to pin in the handle. This action implies a more precise movement of the fingers and we wanted to force the user to do so. Second, as explained later, we selected the "palm closing" gesture for opening and closing doors or windows.

We want to enhance the interaction degree and the learning experience. For that we designed independent gestures for different actions. This way, the user can easily internalize the meaning and consequences of each virtual gesture in the real world. This is why we decided to define the "pinch" gesture for grabbing objects in the scene, in this case the fire extinguisher (see Figure 5).

So, summarizing the full action process, the user has to get close to the extinguisher, reach an arm towards it and pinch it by holding the index and thumb fingers together. The platform must detect a collision between the extinguisher and the virtual representation of the user's hand. If this happens, the extinguisher is moved towards the user and it is placed in the right side of the visual field, representing that the extinguisher has been grabbed and it is ready to be

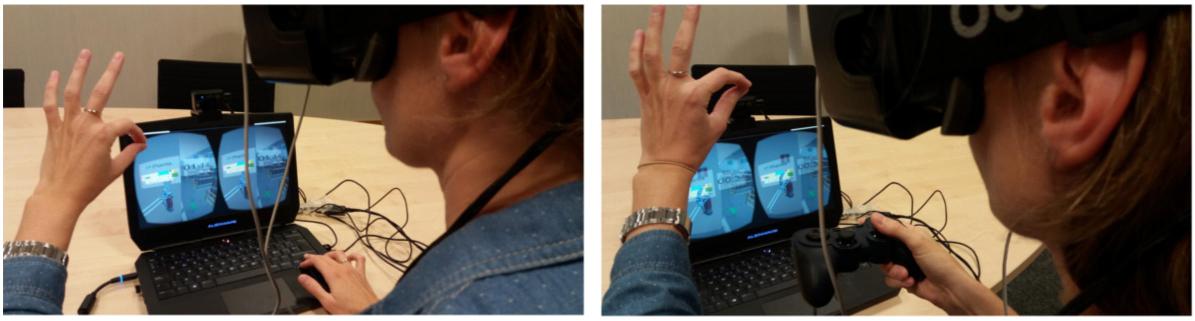

Figure 5: “Pinch” gesture with Setup #1 (left) and Setup #2 (right).

used. The actions that the user can do with the extinguisher are discussed in the next subsection 4.3.

Another goal, is to teach the warden how to evacuate the building safely. In this work, to do this, the warden has to navigate to the closest exit and open the door. We have chosen the “palm closing” gesture for this action as it is the one we perform in real life to grab door handles. The user has to approach a door in the virtual scene and reach out the arm towards it. As with the extinguisher selection, the user has to be placed at least 60 cm. from the door.

At first, we thought on detecting the collision between the virtual hand and the door handle. We also thought it would be recommendable to track the hand turning down a certain angle as if turning a door handle to open it. But these actions resulted confusing and tedious. In the virtual scene, to detect a collision between the hand and the handle, the warden had to get very close to the door, which implied correcting their position and performing the “palm closing” gesture several times. Moreover, depending on the angle degree the hand was turned, this gesture could be confused with the “thumbs up” gesture. Finally, we decided to simplify this action by allowing the door to open by performing the “palm closing” gesture at the right distance from an exit (see Figure 6).

Additionally, we have the same action to represent a door by pulling it or by pushing it. Even if pulling or pushing would affect in the cognitive process of opening a door, we decided to omit this feature for the sake of simplicity. Furthermore, it is expected that the doors should be correctly designed, promoting “pushing” mode over “pulling”, as it may be required for safety regulations.

## 4.3 Manipulation

In this use case, the fire warden must learn to manipulate fire extinguishers. First, the user has to navigate with the fire extinguisher towards the fire and manipulate it following the PASS method. The correct distance to put out a fire safely is between three to one meters. So if the user is further than 3 meters or closer than 1 meter from the fire an alert text is displayed as a HUD. Once the user is at the right distance, the user has to aim at the fire, squeeze the nozzle and sweep from side to side.

In real life, we would need both hands to manipulate the extinguisher. However, in this virtual scenario the user also has to interact with the keyboard or gamepad. When using the keyboard, it is not convenient for the user to lift the fingers from the arrow keys and with the gamepad, the user needs one hand to keep holding it. To simulate the squeezing of the nozzle, we decided to track one hand of the user performing a “thumbs up” gesture (Figure 7), closing the hand with the thumb heading up. We chose this gesture because it is similar to the one users should perform in real life and to differentiate it from the “closing palm” gesture, in which the thumb is not visible.

Then, if the user is in possession of an extinguisher and performs the “thumbs up” gesture at the right distance from a fire, a graphical particle system representing the extinguishing jet will blast out from the user’s hand position. If the user stops performing the gesture, the particle jet stops. To increase the realism, the noise of a real extinguisher is played through the audio systems (integrated in the HMD or external).

While performing this gesture the user also has to move the hand from left to right to perform a sweeping gesture.

Our Unity-based 3D engine (Unity3D, 2016) detects whether a collision between the particle jet and the fire has taken place. This way we check if the user is aiming at the fire and sweeping the hand correctly. If there is a collision the fire is put out. We define each fire as a collection of particle systems, so they are put out gradually. If the user does not sweep from side to side, the fire will not put out correctly. Fire extinguishers contain around 10 seconds of extinguishing power. If the warden spends more than

Figure 6: “Palm closing” gesture with Setup #1 (left) and Setup #2 (right).

Figure 7: “Thumbs up” gesture with Setup #1 (left) and Setup #2 (right).

that time trying to extinguish the fire it will probably mean the sweeping is not being performed correctly. In this case an alert HUD appears to remind the warden the PASS method.

### 4.4 System Control

This section explains the input messages we have defined to communicate the user and the system. These messages appear as HUDs (Heads-Up displays) on the screen.

Where to place each HUD is also important, as far as possible they should be integrated in the virtual scene (Yao et al., 2014).

The user can begin the simulation in training mode or in simulation mode (see Figure 8). The user selects between these options with the LM.

During the simulation the user can visualize a semi-transparent and non-intrusive 2D mini-map. This map has been designed as an egocentric map. The map shows the following signs to help the user:

- “You are here” marker.
- Exit location signs.
- Extinguisher location signs.

A timer is also visible at all times, so the user knows how long it is taking to perform the exercise. These HUDs are shown in Figure 9.

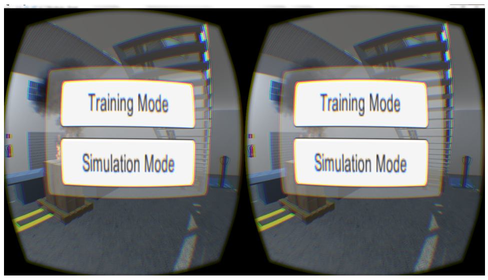


Figure 8: Mode Selection.

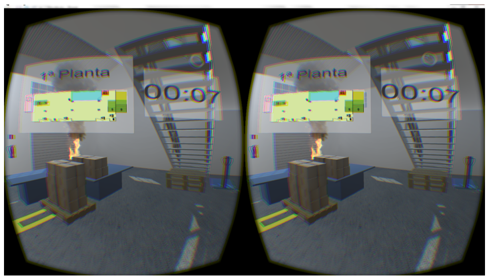


Figure 9: Upper Left: 2D mini-map. Upper Right: Timer.

In the training mode, some green arrows are displayed on the 3D environment to show the user the path to the closest extinguisher, once the user has selected the extinguisher and put out the fire, again some arrows are displayed to show the path to the closest exit (see Figure 10). These signs are not shown

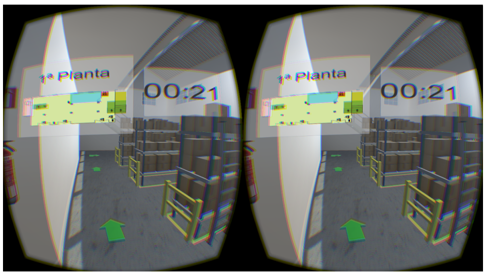


Figure 10: Training Mode. Green arrows placed on the floor guide the user to the exit.

in the simulation mode, as the user should have acquired knowledge about the environment in the training mode.

# 5 CONCLUSIONS

In this work, a VR fire warden training system has been presented. Its main objective is to provide VR experiences to fire wardens in order to internalize and comprehend the concepts behind the standardized procedures that have to be followed when a fire emergency arises in a building. In our preliminary developments, a few actions have been tested as they target the main interactions within VR environments: Navigation for evacuation routes and fire finding; Selection and Manipulation to interact with the extinguishers and doors; and System Control interaction to display non intrusive 2D information as a HUD. All the actions have been developed as a combination of gestures recognized with the aid of Leap Motion Controller and keyboard/gamepad to navigate the 3D environment.

The seated position has been defined as a requirement from the very beginning as it is the most comfortable way of interacting with the VR environment. The stand-up position poses additional problems like i) problems with the cabling, ii) collisions with the real-world furniture and iii) anxiety regarding the cognitive disassociation of the virtual position and the real position, specially when stairs are included in the scenarios. The seated position is also recommendable if the interaction is going to last a long period of time.

More trials and validation of the VR setup is needed. However, we have found that the election of the keyboard or the gamepad is a matter of personal preferences. In any case, we have reports about the necessity to adapt the keys of the keyboard or buttons of the gamepad to each personal preference.

Some users found some limitations in the VR navigation. They report that turning commands conflict with looking to the sides in the VR environment. Nevertheless, it is a matter of time to get the users acquainted with the navigation system.

As future work, the following prototype will experiment alternatives to solve the problems reported by the users. A more extensive evaluation will be carried out.

The extension of the prototype to other users and purposes is also under consideration. The presented use case could be adapted easily to children in order to show them basic information about what they have to do when a fire emergency arises.

After the preliminary implementation, we are planning to introduce a different use case, oriented to the visualization of 3D models on the Web. This use case is very different from the one presented in this work and therefore, it will provide complimentary information about the VR techniques in a different VR environment.

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