

UTILIZATION OF VIEWER LOCATION BASED
PROJECTION EFFECTS ON ODV VIDEO DISPLAY
IN CAVE LIKE ENVIRONMENTS

Saqib Saghir

University of Tampere
Faculty of Communication
Sciences (COMS)
Human-Technology Interaction
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UNIVERSITY OF TAMPERE

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The thesis work provides an overview of the CAVE-like virtual environments by describing and comparing different kinds of virtual environments and the technologies behind them. It provides through information about presence, immersion and user experience of a virtual environment. It also explains the concept of omni directional videos, which are used in CAVE virtual environment. The study involves a CAVE-like virtual environment hardware setup situated at University of Tampere. The system is evaluated by conducting an experiment where the participants are viewing objects in omni directional (360-degree) videos (ODV). The participants were asked to perform certain tasks within virtual environments.

The study objective is to understand how adjusting virtual camera parameters based on the user's physical head location effects the user experience of viewing 360-degree videos in a CAVE-like environment. Three conditions are tested which are termed as scaling conditions. In each scaling condition, the virtual camera moved differently based on the user's head movements. The results are collected through questionnaires, observations and interviews. The questionnaire data is compiled using statistical analysis. The results describe the overall user experience of CAVE-like virtual environment, the level of immersion and presence felt by the user and any possible cyber-sickness. The study conducted paves way to explore different dimensions of CAVE-based ODV viewing and how to improve it.

Keywords: Virtual Environment, Virtual Reality, CAVE Automatic Virtual Environment, User Experience, Omni-directional Videos, Immersion, Presence

Preface

First, I would like to thank all mighty God, who blessed me to write the thesis work. During the course of my thesis work, I endured a huge loss. I lost my father a couple of months ago. I am writing this preface with a heavy heart. My father would have been so proud of me on finishing my thesis work and eventually earning the masters' degree. I would like to dedicate my thesis work and masters' studies to my late father. May the departed soul rest in peace. Amen.

I would also like to thank my mother who was always there to support me and pray for me, my sisters and the addition of a new person in my life, my wife.

I would also like to thank my supervisor Mr. Jaakko Hakulinen, who has been guiding me all through this thesis writing process and appreciated my work. I learned many things working under his supervision.

Tampere, 25 April 2018

Saqib Saghir

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ABBREVIATIONS AND NOTATIONS

| | |
|-------------------|------------------------------------|
| CAVE | CAVE automatic virtual environment |
| VR | Virtual Reality |
| I/O Devices | Input Output Devices |
| FOR | Field of Regard |
| FOV | Field of View |
| FR | Frame Rate |
| ODV | Omni Directional Video |
| PQ | Presence Questionnaire |
| SUS Questionnaire | Slater-Usch-Steed Questionnaire |
| UX | User Experience |
| HCD | Head Coupled Display |
| HMD | Head Mounted Display |
| BOOM | Binocular Omni-Orientation Monitor |

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1 INTRODUCTION

“Virtual reality is the ultimate empathy machine. These experiences are more than documentaries. They’re opportunities to walk a mile in someone else’s shoes” - (Chris Milk, 2015)

Decades ago computers were sacred objects which could only be operated by certain professionals. In the recent past the relation of human beings and computing devices have become quite close. Nowadays, these computing devices are found everywhere and have become an essential part of the daily lives of human beings. The advent of mobile devices has made sure that every single moment of our lives is being dealt with the technology. The new era of computing has allowed the creation of immersive environments known as virtual environments to create a whole new set of experiences providing new places and interaction possibilities.

Virtual reality (VR) is a term used for computer-generated 3D environments that allow the user to enter and interact with alternate realities. In modern age, the users can immerse themselves to varying degrees of immersion which may either be a simulation of some form of virtual reality or the simulation of complex data [Giraldi, Silva and de Oliveira, 2003].

In recent years, virtual environments have been of growing interest in the computing and scientific world. Computer scientists are exploring different ways to utilize and take advantage of them in their respective fields. Human beings learn through visual and spatial cues. Virtual environments provide visual and audio feedback. Creating a sense of presence through visual and spatial cues makes it possible to retrieve and remember information. Research has been done to create solutions for different contexts of use.

With the modern headset and motion tracking equipment, it’s far easier than a few years back, to take advantage of the new VR technologies and experience its benefits. There have been a lot solutions which provide immersive experiences starting with the cheapest of all the Google Cardboard, and a relatively expensive solution such as Oculus Rift, Samsung Gear VR etc. The technology has been there for a while but still has several limitations regarding its effectiveness, user experience and immersion.

Virtual reality is rapidly growing thus creating great expectations and anticipation for more to come. Limited amount of researches has been done on CAVE (Cave Automatic Virtual Environment) virtual environment (VE) to create professional solutions. This is mainly because the setup requires a lot of investment upfront making it one of the most expensive technologies to implement and with complex hardware requirements. CAVEs are a work in progress [Manjrekar et al., 2014]. 3D graphics software APIs are quite limited for CAVE VE.

However, the community is quite active in exploring new avenues regarding this platform. For example, Sebastian et al., of Virtually Reality Group at RWTH Aachen, University [Sebastian Pick et al., 2015] have developed an application to create and design art work in the immersive and interactive world of CAVE VE. On the other hand, there are applications such as simulators to train fighter pilots. Other commercial products include BARCO [70] and VRCO [71].

CAVE VEs are one of the best platforms available to experience the virtual environment. There has been a strong interest in CAVEs since the rise of the technology. Other immersive systems include heavy head mounted displays providing limited resolution and field of view. CAVE VE environment features a fictional world which allows interactivity and visualization of objects with high quality resolution of 3D spatial datasets. CAVE VEs differ in size, dimensions and characteristics and are used for both study and public exhibitions [Manjrekar et al., 2014].

The purpose of the study is to measure the aspects of changing virtual camera parameters based on user's physical head location. How these parameters are affecting the user's perspective for viewing objects in a virtual environment where 360-degree Omnidirectional videos are used to render the scene? The study consists of an evaluation to understand the user experience of the developed solution. The study will help to improve number of parameters that specify the effects of the movement of the virtual camera to enhance the user experience of such an environment. The environment uses projectors for the playback of omnidirectional videos. The experimental environment setup consists of three projectors covering 3 out of 4 walls of a laboratory room. HTML based technologies are used for playing back ODVs and special cameras are used for tracking the user movements. A web based application framework has been created by the thesis supervisor to implement a basic form of interaction within the environment. The evaluation results

consist of usage data, interviews and observations. The results shall also be compiled to draw an understanding of these effects on the user experience, immersion and presence.

An introduction to the virtual environments is given in Chapter 2. It explains the concepts of virtual environments while Chapter 3 describes the concepts of immersion and presence in VR and Chapter 4 discusses user experience regarding VR. Chapters 5 and 6 describes CAVE environments and ODVs respectively. Chapter 7 discusses the design and its implementation of the system used in the evaluations while Chapter 8 reports the evaluation and finally Chapter 9 draws the conclusion of the thesis work and proposes future work related to the topic.

2 VIRTUAL ENVIRONMENTS

“make that (virtual) world in the window look real, sound real, feel real, and respond realistically to the viewer’s actions” - Ivan Sutherland, 1965 [3].

Computer graphics are prevalent in every walk of life these days, thanks to the more powerful microprocessors and faster graphical processing units (GPUs). With the introduction of three-dimensional (3D) graphics the technology allows us to simulate a virtual environment with which an average user can also communicate and interact. VR gives the ability to view such details which cannot be examined via a naked eye [Ioannis Giannopoulos et al., 2007]. It is a simple, engaging and (near to) natural method for human-computer interaction.

2.1 Introduction to VR

The term VR is also known by Artificial Reality (AR), Cyber Space (CS), Virtual Worlds (VW) and Virtual Environments (VE) interchangeably [Ioannis Giannopoulos et al., 2007]. VR systems require some extra input and output equipment and gadgets which are coupled with a standard desktop computer to run the environment setup.

As in every computer system, VR is composed of some basic hardware and software with the addition of a VR engine and I/O devices and application software and databases respectively. Figure 2-1 describes the building blocks of a VR system.

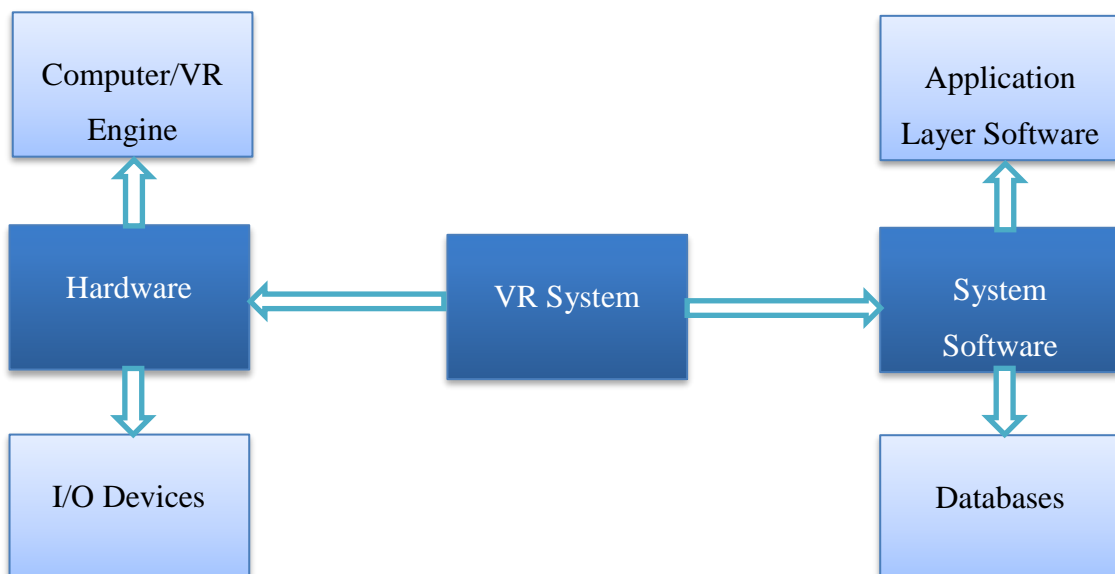


Figure 2-1 A basic VR System [Oluleke Bamodu et al., 2013]

In most VR systems, the user wears a HMD (head mounted display) or just a simple position tracker. A tracker provides position and orientation to the host computer. The host computer generates the virtual environment images to be displayed. The quality of the virtual environment experienced by the users depends on the performance of the position trackers. The four major categories of position trackers are acoustic, optical, magnetic and mechanical [Devesh Kumar Bhatnagar, 1993].

There are different types of VR environments which are discussed in the subsequent sections of this chapter. In some cases, the user can interact with the system by means of different body gestures and actions. The input devices share this information with the system. The VR system generates the output in real time through the output display units.

There are many types of virtual reality [31].

1. Immersive Virtual Reality
2. Desktop Virtual Reality
3. Projection Virtual Reality
4. Simulation Virtual Reality

Considering the above discussion, we can determine that a VR framework is defined by certain elements. VR heavily relies on immersion, interaction and presence in computer-generated environments [Oluleke Bamodu et al., 2013]. The system acts as a stimulator for certain human senses, e.g., visual, auditory and haptic.

2.2 VR Engine

The creation of a 3D environment requires a lot of processing power from a computer. The general graphics software for a VR system requires a fair amount of computer hardware to render 3D graphics on screen. Every VR system has its own set of hardware and software requirements. Thus, the specification of any VR engine depends mainly on the type of application to be executed, since it is solely responsible for graphical modelling, object creation and its rendering, complex calculations for simulation purposes, the amount of light and texture and finally mapping it accordingly to create an

immersive experience for the user to interact with the system through the input devices on real-time basis [Oluleke Bamodu et al., 2013].

For a VR engine to create a flawless virtual experience, it must create a VR environment that recalculates its values approximately every 33ms and create simulation patterns of more than 24fps on real time basis [G.C Burdea and C. Philippe, 2003]. Any computer system that possess a fast CPU unit and powerful graphics, can act as a VE engine.

2.3 Input Devices

Through input devices the user interacts with the VR environment. Input devices communicate the user's actions and activity to the VR framework resulting in appropriate output signals by the system. All this activity takes place in real time causing an immersive experience for the user. Different kinds of input devices are used e.g., tracking devices, pointing input devices and voice input devices. Tracking devices use position sensors to track the user's position.

2.4 Output Devices

VR engine feeds the required information to the respective output devices creating a respective VR effect which engages its users by stimulating their senses. There are different kinds of output devices in a VR system mainly auditory, visual, haptic and some relatively uncommon such as smell and taste. Commonly used graphics output devices are stereoscopic displays which provides high level of immersion [Gibaldi, Silva and de Oliveira, 2003]. 3D sound techniques are used to generate a natural immersive experience. Haptic feedback is used to achieve a realistic feeling of touching the virtual objects in VR environment.

2.5 Types of VR Devices (I/O Devices)

Traditionally we interact with a computer's virtual world using a viewing device such as a monitor display, a pointing device and a keyboard. This does not really meet the requirement of impression that only a VR environment can provide. The major

characteristic of VR is immersion [Giraldi, Silva and de Oliveira, 2003]. Users experience the feeling of being surrounded by the environment [F. Balaguer and A. Mangili, 1991].

There are different types of input and output devices available for a VR system. Following are the devices which are integral part of modern VR environments.

2.5.1 Tracking Devices

VR systems use tracking devices. A tracking device measures 3D position and orientation of its subject. Tracking is usually done using one of different types of position sensors [T.H. Dani, G. Rajit, 1998], electromagnetic, ultrasonic, optical, mechanical and gyroscopic sensors [Oluleke Bamodu et al., 2013].

2.5.2 Head Coupled Displays

Head coupled displays (HCDs) render 3D imagery on 2D devices. The perspective of the visual scene which is displayed on the screen changes with respect to the position of the user's eyes, hence simulating a 3D environment accordingly. The perspective of the visual scene changes as the user's head position changes, resulting in an effect of glancing at the scene through a window as compared to the one created of a flat projection scene [Giraldi, Silva and de Oliveira, 2003].

2.5.3 Head Mounted Displays

A head-mounted (HMD) is a type of HCD, which consists of a pair of goggles that are worn on the head often referred as a helmet. The head gear offers two small display devices in front of the users' eyes resulting in a stereoscopic vision thus offering a perception of 3D environment. HMDs comes equipped with a tracker to respond to the head movements [Giraldi, Silva and de Oliveira, 2003]. There are 3DoF (Degree of Freedom) and 6DoF trackers. Degree of Freedom refers to the number of different directions in which an object can move in a three-dimensional (3D) space. 3DoF VR headsets can track head orientation only, i.e. three rotational motions, pitch, yaw and roll. However, 6DoF can track orientation and position i.e. both rotational motions and linear translations of an object. Samsung Gear VR has 3DoF tracking while Oculus Rift has full 6DoF tracking.



Figure 2-2 Man wearing HMD



Figure 2-3 Dlodlo V1 VR Glasses [14]

2.5.4 Data Gloves

A data glove is an intuitive gadget, which resembles a glove worn on hand, providing tactile feedback and motion control in VR environment setup. These electromagnetic devices report hand and fingers positioning by making use of several sensors that are embedded to the gloves [F. Balaguer and A. Mangili, 1991].



Figure 2-4 Data Glove

2.6 Types of VR Systems

VR systems can be ordered into three noteworthy classes. These are, non-immersive, fully immersive and semi-immersive, in view of the different kinds of interfaces and/or parts used in the framework.

Non-Immersive VR framework, additionally called Desktop VR framework or Window on World frameworks is the most common of all the VR frameworks and provides minimal level of immersion. It enables the users to interact with a 3D environment through a stereo monitor and glasses, other regular parts incorporate space ball, console and information gloves. It is useful in simulating computer aided design (CAD) tasks [Oluleke Bamodu et al., 2013]. Immersive VR framework creates maximally immersive experience, its segments incorporate HMD, position tracking devices, information gloves and other devices, which link the user with 3D environment. Semi-Immersive VR framework, additionally called hybrid systems [T.H. Dani, G. Rajit, 1998], gives high level of immersion experience, while providing simplicity similar to that of a desktop VR. Cave automatic virtual environment (CAVE) is one such example of semi immersive VR.

2.6.1 Non-Immersive VR

Desktop computer are mainly categorized as devices which provide the least immersive experience when talking about VR systems. A desktop computer generates a virtual environment with the use of a high-resolution monitor alongside different interaction devices such as mouse, keyboard and gamepads, data gloves etc.

Non-immersive frameworks have their own advantages as these systems do not require the largest amount of graphical resources and processing power thus, making them a low-cost VR solution, meeting the minimal requirements to run many basic applications [Oluleke Bamodu et al., 2013].

The disadvantage to this system is that the interaction is limited to 2D devices which means no real sense of immersion where a user could isolate him/herself from the real world to experience the virtual world. General computer peripherals i.e. keyboard/mouse are not the ideal set of interaction devices which can be used to navigate through a 3D VE system. Being a low-cost system, it has performance limitations.

2.6.2 Semi-Immersive VR

The term semi-immersive VR is a new concept in the technological world. These systems fall in line with those used for flight simulation field and are often called projection based VR systems. It consists of a fixed wide-angle display with FOR of more than 60° and is backed by a considerably high performance graphic engine. The display is constructed using one large screen monitor or single/multiple projectors.

Semi-Immersive VR provides a wider FOV, hence gives a higher level of immersion as compared to the desktop VR systems. However, an important factor to consider is the quality of the projected image. The higher the resolution of the images the better the experience. In case of higher resolutions, the system can use many projections each displaying a part of a picture to construct the whole scene. This kind of projection based VR systems allows shared use of the environment [Oluleke Bamodu et al., 2013].

Semi immersive systems are very costly compared to desktop systems. When applying these system, things to consider are projection geometry and screen curvature as these effects the display quality of the system. It is a challenge to effectively use such a wide screen VR space for multi-user/shared interaction

2.6.3 Fully-Immersive VR

A fully immersive VR system is the one which provides a 360° FOR. This is achieved using a HMDs. It is thought of to provide the most immersive experience. Since the HMDs are used to create a fully immersive experience, it must be noted that the quality of immersion shall depend upon the quality of the display unit of the HMD. The variables

effecting the quality of any HMD are its resolution, FOV and frequency with which the images gets updated in the view.

A fully immersive VR system provides the best immersive experience in a VR environment. This is possible because it provides a 360° field of regard, which gives this technology precedence over others as it allows to display the information in every direction the user tends to look and feel. HMDs usually block out the real world which makes them more immersive as an experience.

Fully immersive VR systems are the most demanding systems when it comes to processing power and making use of the modern technology. Thanks to the advancement in technology, the prices of the electronic components have reduced. Nowadays a basic VR system can be purchased in approximately 3000€. However, CAVE VEs can easily cross 20000€ mark, mainly due to expensive hardware components required by the system. Research and development is still being carried out to achieve maximum level of realism. Significant areas of improvements include the relationship between the FOV and the resolution of a display, contrast, illumination, making HMDs more compact by reducing the size and weight and how to overcome system lags [Oluleke Bamodu et al., 2013].

2.6.4 Comparison Between Immersive VR Systems

Table 1, shows the comparison between different types of immersive VR systems in terms of their qualitative performance.

Table 1 Summary of different parameters effecting the quality of an immersive system [37].

| Main Features | Non-Immersive VR | Semi-Immersive VR | Fully-Immersive VR |
|---|-------------------------|--------------------------|---------------------------|
| Resolution | High | High | Low-Medium |
| Scale (perception) | Low | Medium-High | High |
| Sense of situational awareness (navigation skills) | Low | Medium | High |

| | | | |
|-----------------------|-----------|---------------|-------------|
| Field of Regard (FOR) | Low (50°) | Medium (150°) | High (360°) |
| Lag | Low | Low | Medium-High |
| Sense of Immersion | None-Low | Medium-High | Medium-High |

2.7 Examples of VR Systems

2.7.1 CAVE

The CAVE [Cruz-Neira et al., 1992], provides enhanced experience over HMDs for the applications of scientific nature. It provides better resolution, a large depth of field and a stable display for both single and multi-users. The viewer is surrounded by projection videos which come from multiple projectors placed at six different angles in a room along with head tracking to track the user's position.

CAVE provides its own graphics library to generate graphics to the display devices, control the displays, and react to user tracking and input devices. It uses a user-centered approach to create nearly seamless virtual display. The system is also equipped with a sound system to provide auditory feedback [Giraldi, Silva and de Oliveira, 2003].



Figure 2-5 CAVE Virtual Environment

In this thesis work, CAVE is used to study VR systems. Chapter 3 discusses CAVEs in detail.

2.7.2 Immerse Desk

Immerse Desk [Bhatnagar, 1993], is a drafting table configuration VR display. It is made up of 67*50-inch rear projected screen which is at an angle of 45 degrees. Users wear shutter glasses to view head track images of high resolution. The images are stereoscopic in nature. It makes use of the head marker of the user to generate accurate perspective, enabling the users to look forward and down. Immerse Desk is also equipped with a sound system to provide auditory feedback [Giraldi, Silva and de Oliveira, 2003]. Immerse Desk VR system is easy to carry and move around as the system holds its ground on wheels. It can also be folded up to move through the doors. Immerse Desk uses the same graphic library that is incorporated with the CAVE. Therefore, CAVE applications can also run on Immerse Desk.



Figure 2-6 Immerse Desk

2.7.3 Infinity Wall

Infinity Wall is a larger scale system. It is constructed around the same resources as that of CAVE environment. It is intended to large group of audience for presentation purposes. It has a single 9*12 feet screen with four projectors at different positions to project the environment to the audience. SGI Onyxes drive the display and also perform user tracking [Marek et al., 1997]. Like CAVE and Immerse Desk, Infinity Wall also make use of

shutter glasses to create the immersive effect. It uses CAVE graphics library to create projections and synchronization of displays [Giraldi, Silva and de Oliveira, 2003].



Figure 2-7 Infinity Wall

3 IMMERSION AND PRESENCE

“We modern, civilized, indoors adults are so accustomed to looking at a page or a picture, or through a window, that we often lose the feeling of being surrounded by the environment, our sense of the ambient array of light... We live boxed up lives.” - (Gibson, 1986).

The goal of any VE is to provide an immersive and engaging experience. Immersion alongside presence are the most important factors that gives its users a compelling experience with which they can isolate themselves from the real world.

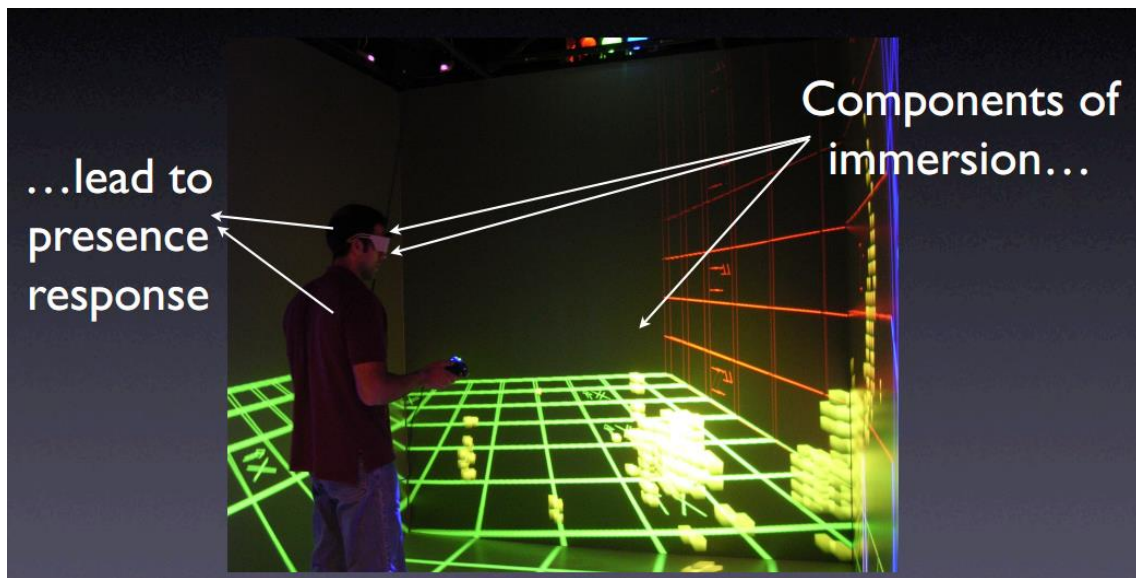


Figure 3-1 A user in a Virtual Environment wearing VR glasses and interacting using controllers

3.1 Immersion

Immersion refers to the experience of being physically present in a non-physical world [Sharma et al., 2015]. VR environment allows its users to immerse into this non-existent world. Immersion depends upon the overall quality of any VR system, i.e. technology used in a VR system. It is an objective measure of a VR system [James et al., 2012]. This objective measurement provides fidelity of the sensory stimulation produced by a VR system [Ragan, 2010]. Higher fidelity of the sensory stimulation achieves greater level of immersion. Therefore, the greater a VR system immerses its users in stimuli with relation to their assumptions and intentions of the virtual world, the more fascinating their VE experience is [Bowman et al., 2007]. Emotional, motivational and cognitive processes

also, effect the level of immersion alongside the technological aspects in a VE framework. [Kim et al., 2014].

The level of immersion is determined by how effectively a VE system can stimulate human senses i.e. visual, auditory and touch. The stimulation by the system must be persistent and should react realistically to the user actions avoiding predictability.

A typical VE system enables its users to immerse into virtual world using either physical immersion or head-coupled rendering. Head-coupled rendering is discussed in chapter 2.5.2. Following are some of the definitions for the basic terms related to VE system.

3.1.1 Field of Regard (FOR)

The visual angle surrounding the user within which the virtual world is displayed to the user is called FOR [Ragan, 2010].

3.1.2 Field of View (FOV)

The FOV is the area within which the user sees the virtual world at any instant of time and is measured in terms of degree of angle [Ragan, 2010].

A higher FOV and a higher FOR leads to higher level of immersion.

3.1.3 Frame Rate (FR)

Frame rate (FR) of an interactive graphics system is defined as the rate at which new frames of the displayed scene can be rendered and shown [Bryson, 1993]. Higher FR leads to higher level of immersion [Mazuryk et al., 1999].

3.1.4 Resolution

Resolution for computer systems are defined as the number of horizontal and vertical pixels that is contained by the display device [Ed et al., 1997]. The image sharpness for a display is dependent upon the resolution and the size of the display device. Therefore, the higher the resolution, the higher the sharpness [Mazuryk et al., 1999].

3.2 Components of Immersion

Following are the components to take care of while designing an immersive environment.

3.2.1 Visual Components

Visual components relate to FOV, image rendering capabilities, display size and resolution, stereoscopy, frame rate, refresh rate and realism of lighting [Sherman et al., 2003].

3.2.2 Auditory Components

Spatial audio components provide the necessary sound output to achieve immersion [Sherman et al., 2003].

3.2.3 Haptic Components

Haptic relates to the field of touch. VE systems include motion platforms and active and passive haptic devices, enabling the user to touch and feel the objects [Sherman et al., 2003].

3.2.4 Kinesthetic Components

Kinesthesia relates to the field of sensation of movement for muscles. [35]. Kinesthetic components respond to head or limb movements of the user, recording the information of how the individual body parts are moving in a VE system.

3.2.5 Vestibular Components

Vestibular relates the perception of position of the body [36]. Vestibular things are basically what the user feels when in an interaction with the virtual environment. These are non-visual cues which can have a powerful influence on the user's perceptual experience [Harris et al., 1999].

3.3 Presence

The sense of presence is an important feature and is the highlight of any VE system [Steuer, 1992]. In general understanding, it is a mental state “of the sense of being there” and is called the subjective response of a user to a VE system [Sheridan, 1992].

Presence is a measurable component of a VE system. However, it is not guaranteed that the system shall produce the same level of presence for all the users. Therefore, we can say that different VE systems with same level of immersion may produce different levels of presence for the same user. Users can feel greater level of presence if a VE is more engaging. To achieve higher level of presence, VE performance should be persistent and should provide experiences comparable with those occurring in everyday life.

Per Sheridan [Sheridan, 1992], there are three measurable physical variables that determine presence:

3.3.1 Extent of Sensory Information

Extent of sensory information means the amount of information provided to the user in terms of sensory information, including multiple senses.

3.3.2 User Control over the Virtual Environment

The control a user has over VE using controller can greatly affect the feeling of presence. For example, a system should be able to provide the user the facility to change the viewpoint or reposition his head.

3.3.3 Modifying the Virtual Environment

The extent to change objects in the virtual environment and their relation to one another.

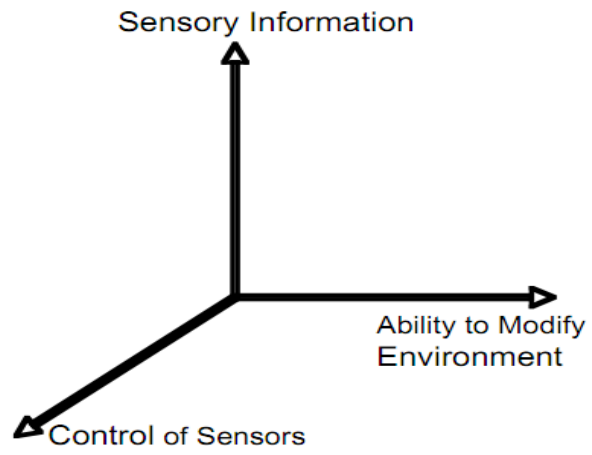


Figure 3-2 Sheridan's three measurable physical variables [Sheridan, 1992]

4 USER EXPERIENCE IN VR

User experience (UX) signifies a thorough understanding of the abilities and limitations of the users with respect to interaction with any product. The rise of interactive technology products especially in the field of VR in the recent years have brought special attention to UX. Even though UX is of great importance in the field of VR systems, however it still needs a clear universal definition [Rebelo et al., 2012]. Most of the definitions refers to the qualitative experience with a product [McCarthy et al., 2004]. The ISO 9241-210 defines it to be the user's responses during interaction with a product and the resulting reactions [29].

Following figure shows some of the characteristics of useful user experience.



Figure 4-1 User Experience Honeycomb [38]

The rest of the chapter layouts the possible guidelines for best possible user experience for a VR system.

4.1 Interactive and Reactive

There are various interaction methods for using a VE system. Therefore, different kind of inputs are required to interact with the system compared to traditional inputs (keyboards and mice etc.) (VR Inputs are discussed in Chapter 1). This creates a situation where there is a need to stress upon the specifications for the input devices. Input devices come in

different shapes, sizes and features. Different inputs require different design decisions. While wearing VR headsets, the input devices are invisible to the user's eyes. These devices must be suitable for the "invisible/blind mode" use.

VR experience is both interactive and reactive at the same time, and is always changing w.r.t the user's behaviour and movements. Therefore, designing a user experience would require a great deal of anticipation for user's movement and point of view.

4.2 Comfort

VE can cause simulator motion sickness [Brooks et al., 2010]. A comfortable UX design is the most critical quality for creating a successful VR experience. Users can compare a VE to the real world and anticipate to it to act the same way. A slight mismatch may result in to motion sickness. A user might feel distress about the inconsistent design specifications related to relative scales, heights, spaces, objects, brightness and darkness. Hence a careful thought process is required while designing the layout for VE space [Costello et al., 1999].

The reason for the user to experience motion sickness is when physical and visual motion signals give the user incompatible or conflicting data. This can be overcome by keeping few objects in a static position irrespective of the user's movement and maintaining high frame rates. The user can be provided with a point of reference e.g., a horizontal line, that moves as the user moves in the space. This technique helps reduce nausea.

4.3 Ease of Use

Developing easy to use controls are a challenging as navigation and menu placement is entirely different from a flat screen monitors and mobile screens. It requires intuitive design process to make the controls easily accessible for the user. In many cases the menus are drawn in the space and head tracking is used to navigate.

4.4 Ergonomics

Because the virtual environment usually expands to all directions across the user, the user often tries to use the space in 360° area thus creating a potential risk for neck strain by

performing different kind of gestures, walking, standing or holding an input device. Following diagrams shows the ergonomically comfortable head movement zones in terms of degree of movement in horizontal and vertical direction respectively [Gibaldi, Silva and de Oliveira, 2003], [Costello et al., 2017].

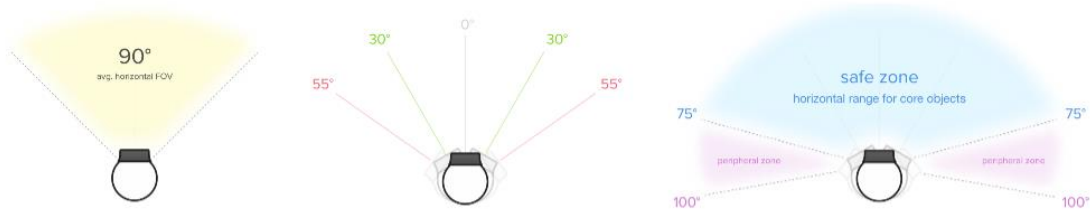


Figure 4-2 Ergonomic Horizontal Range FOV [39]

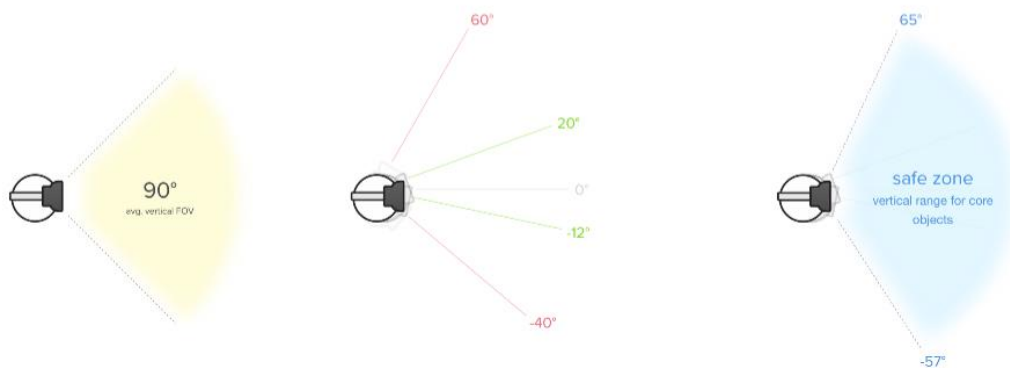


Figure 4-3 Ergonomic Vertical Range FOV [39]

VR environment can easily make a user prone to wrong body postures especially while looking down at something as in the case of looking at the mobile phones. It can create up to 60 pounds of pressure on the user’s spinal cord which in some cases can lead to permanent damage to neck and spine [Lanman et al., 2017].

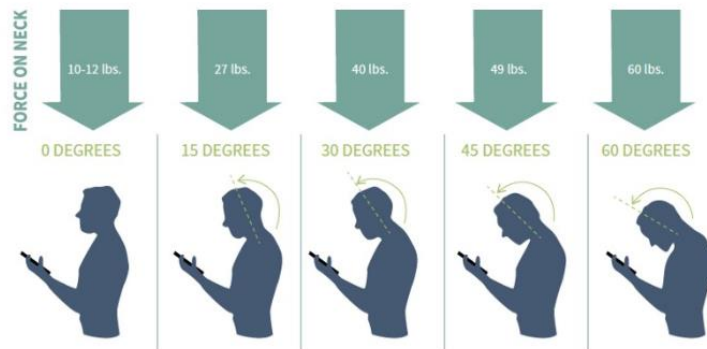


Figure 4-4 Force on Neck vs Degree of Head Movement [40], [Lanman et al., 2017]

Therefore, it is essential to build ergonomically feasible movement standards that govern the interaction design process for a VR system making it as natural and intuitive as possible [Costello et al., 1999].

4.5 Sound

Applying different audio techniques such as 3D audio, positional and directional sound effects, can enhance the user experience of a VR environment, creating an illusion of being in a virtual environment. High quality sound effects are vital for great user experience in VR.

4.6 User Safety

User safety is an important aspect so that the user can experience the space fearlessly. To provide the best possible user experience, the system should provide mechanism to inform the user if he/she is about to hit something in the physical space that could damage his/her VR experience. It is important to consider the varying heights and sizes of the users also consider differently abled people (handicapped). Necessary VR elements should be equally accessible for all [Costello et al., 1999].

5 CAVE ENVIRONMENTS

CAVE stands for CAVE automatic virtual environment which is a form of immersive VR environment. The environment is a cube like space where multiple projectors are used to display images. The first CAVE was invented by Cruz et al. in 1992 [Cruz-Neira et al., 1992].

The CAVE has turned out to be a viable and persuading VR framework that expands the application areas and equally increasing the overall experience of virtual reality [Carolina et al., 1993].

The CAVE accomplishes the objectives of delivering a large FOR, high resolution images, permitting multi user experiences, and allowing utilization of progressive refinement.

5.1 Design

Per Cruz et al. [1992], the CAVE environment which they presented was a built like a theatre of 10'x10'x10' with projection screens to show images on the walls and a separate projection screen pointing down to the floor. One or more sophisticated workstations connected to the four projectors which made use of the high-end graphics provided the workstations.

The original CAVE could show up to 1024*768 resolution stereoscopic images at the rate of 96Hz. Users wore shutter glasses to enable stereoscopic image viewing of view the environment. Tracking was done using a head tracker. The system consisted of a 6 degree-of-freedom tracking system and thus the system generated images by tracking the view point of the user. The system also allowed its user to interact with the environment. The users could use a pressure sensitive joystick to interact with the system. The system is also equipped with a sound system to provide auditory feedback [Giraldi, Silva and de Oliveira, 2003].

5.2 Software and Graphics

CAVE provides its own graphics library to build upon the graphical segments of the environment, that controls the display, user tracking and input devices. It creates nearly seamless virtual display. Software programming libraries particularly for CAVE applications have been developed. There are a few procedures for rendering the scene. There are 3 mainstream scene charts being used: OpenSG [48], OpenSceneGraph [Ruas, A. & Gold, C, 2008], and OpenGL Performer [50]. OpenSG and OpenSceneGraph are open source; while OpenGL Performer is free.

CAVELib was the first application developer's interface (API) produced for the CAVE framework made at the Electronic Visualization Lab at University of Illinois Chicago [45]. The product was marketed in 1996 and additionally improved by Mechdyne Corporation [46]. The CAVELib was a low-level VR programming toolset in that abstracted for a designer window and viewport creation, watcher focused point of view computations, rendering to numerous illustrations channels, multi-handling and multi-threading, group synchronization and information sharing, and stereoscopic survey. Designers made the greater part of the illustrations and the CAVELib rendered it according to the user position and display configuration. The CAVELib API is self-sufficient programming interface, empowering designers to make top of the line virtual reality applications on Windows and Linux. CAVELib-based applications are remotely configurable at run-time, making an application executable autonomous of the framework.

There are many APIs which have been developed by several companies' other than the Mechdyne Corporation e.g., EON Icube [51], VR Juggler [52] and CaveUT [J. Jacobson and M. Lewis, 2005] to name a few.

5.3 Field of Applications

CAVE VR has been used in different fields of science for both research and practical purposes such as art, architecture, physics, medicine and healthcare, biology, geology and archaeology. Engineering companies make use of CAVE to exercise product develop to next level [Ottosson, Stig, 2002].

CAVE provides 3D stereo images having low distortion. The monitor based, head mounted displays and Binocular Omni-Orientation Monitor (BOOM) [43] VR systems on the other hand are not capable of achieving the same results. As CAVE analyzes user's head position to track down the view point, it provides tracking information that is less error prone, as compared to HMDs and BOOM VR, which can have rotational tracking noise and latency issues [Carolina et al., 1993].

6 OMNIDIRECTIONAL VIDEOS

Omni directional video (ODV) provides a 360° panoramic experience [Michiels et al., 2014]. It is also called immersive video or spherical video. 360° video provides rich immersive experience as well as a large sum of information to the viewers [Neng, L. A., and Chambel, 2012]. The video comprises of views covering all the six directions at the same time. The user has full control of viewing the video while playback, such that the format gives the possibility to the user to choose the viewing directions freely of the audio-visual scenes [Alface et al., 2012].

6.1 Creation

The video is recorded using special kind of camera consisting of multiple cameras or through a special collection of cameras. The video footage captured by all the camera lenses are joined using a special video technique called video stitching [Xu and Mulligan, 2013], to make spherical video. Color and contrast is calibrated accordingly to keep it consistent throughout the video [Nielsen, Frank, 2005]. Some advanced and sophisticated cameras are able to perform this operation while filming. Dedicated software solutions are also available to create ODVs, which are intelligent enough to analyze visual and audio streams and synchronize the video feed generated by separate cameras.

The format of a typical ODV is an equirectangular projection [Neng, L. A., and Chambel, 2012] and can be categorized into two types; monoscopic and stereoscopic.

6.1.1 Monoscopic ODV

Monoscopic ODV consists of only one image which is directed towards both user's eyes.

6.1.2 Stereoscopic ODV

Stereoscopic ODV consists of two distinct images which are directed towards each eye individually thus creating a 3D effect.

In the modern era well known hardware equipment which can record an ODV are Nokia OZO, Samsung Gear, Garmin VIRB 360 and GoPro Omni etc.

6.2 Playback of an ODV

ODV is generally shown as a classical two-dimensional (2D) rectangular panorama video which is projected on to a spherical or cylindrical geometry before rendering it to the user's screen [Alface et al., 2012]. Normally ODVs can be viewed on any personal computer and mobile devices, but to get the maximum immersive experience, the videos are suggested to be viewed via a HMD or a 3D environment such as CAVE.

7 EVALUATED SYSTEM

The four key elements to design a VR are, virtual world, immersion, sensory feedback and interactivity [Sherman et al., 2003]. VR has inputs and outputs which are discussed in chapter 1 section 2.3 and 2.4 respectively.

In this study, my supervisor has designed a CAVE-like VR experience in Sim lab at University of Tampere. The virtual camera used to render the 360-degree video is coupled to user's head location. We have different scaling conditions that change the visual angle of the objects and thus altering user's perspective for the objects. We are trying to evaluate aspects of changing scaling conditions on user's perspective for objects in a 360-degree video rendering virtual environment.

7.1 Hardware Setup

The setup consists of three projectors (XGA panel, 1800 ANSI lumen) that are projecting an ODV on each of the three screens (walls) of the CAVE-like environment. The environment is called CAVE-like because the original CAVE has six screens as compared to our system which has three screens. The projection surface consists of five segments and there are three projectors. In order to make a continuous image, a projection corrections software called Immersive Display Pro [57] is used. Because of this, the actual resolution of the display is smaller than the projector resolution. The corrected picture has effective resolution of approximately 5500*900 pixels. The physical size of the picture is 1083cm x 190cm.

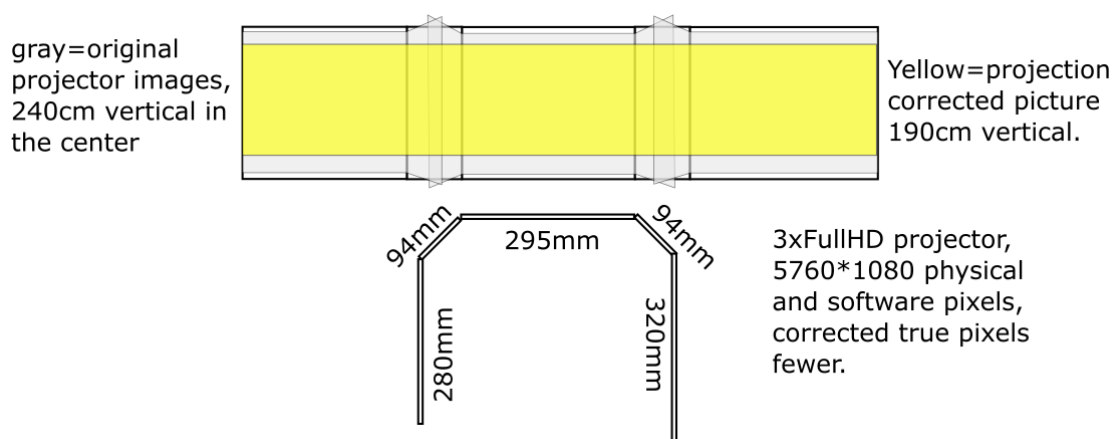


Figure 7-7-1 Simlab CAVE-like VE, University of Tampere

There are 10 OptiTrack [55] cameras to track the position of the user. The computer hardware specifications to run the system are as follows:

Processor Intel Core i7 4770K, 3.5GHz with 16GB of RAM and the graphic chip is from Nvidia with model number GeForce GTX 1080 and 1 GB of graphics memory. Operating system is Windows 10 64bit.

7.2 Software Setup

The software runs in any compatible web browser that has support for WebGL [56] (Web graphics Library) API (Application Programmable Interface). A 3D JavaScript library called ThreeJS [58] is used which provides WebGL API for rendering 2D and 3D graphics. Opti-Track Motive is the software that reads and processes the Opti-Track cameras data and perform calculations. A Python based server starts the Motive software, which continuously reads rigid body marker information from Motive and serves the information over WebSocket connection. HTML (Hyper Text Markup Language) and JavaScript based application connects to the server and reads the marker information via the WebSocket and renders the videos.

7.3 Inputs

Inputs for the VE are as follows.

7.3.1 User Location Monitoring

A regular OptiTrack rigid body marker is used to track user location. The marker is attached to a cap. The silver spheres reflect infrared light from cameras and are clearly visible in the camera images. The fixed layout of the three spheres is used to identify the marker and to calculate the marker orientation

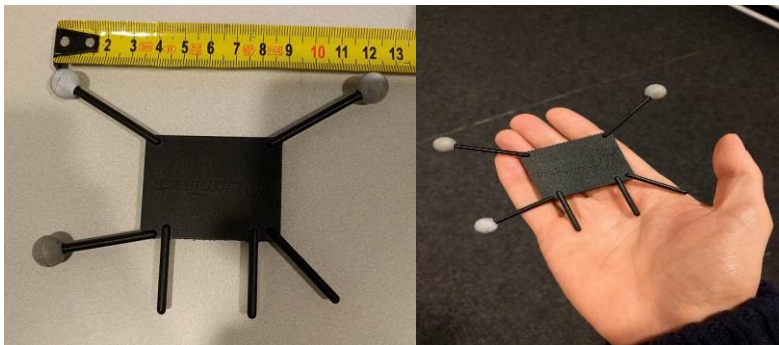


Figure 7-2 Opti-Track Rigid Body Marker

7.4 Outputs

Outputs for the VE are as follows.

7.4.1 Visual Outputs

We are using CAVE-like environment where we are having three projectors that are projecting an ODV on the three walls. The projectors are Full HD with a resolution of 1920*1080/1920*1200. So, the total resolution is 5760 pixels. The resolution of ODVs is Ultra High Definition (UHD) in 2*1 ratio, i.e. 3840*1920 pixels.

The visual outputs are provided based on the user's head movements. The size of the objects depends on the visual angle while seeing through the eyes. A near object has larger visual angle as compared to an object that is far away. Thus, size of an object is proportional to the visual angle [75]. We have implemented a system to manipulate the visual angle of the objects into three different scaling conditions. The details of which are presented in chapter 8.1.

7.4.2 Aural Outputs

Our CAVE-like setup includes ambient sounds. It will help to provide better presence and immersion levels within the VE.

8 EXPERIMENTAL PROCEDURE

As discussed in section 3.4, presence is a significant part of the user experience of any VE. The greater the presence factor for a VE, the greater it simulates to that of a real world. The factors that influence the experience of presence in a VE are [Usoh et al., 2000]:

1. High resolution displays
2. Consistency of the displayed information
3. Navigation and interaction within the environment
4. The actions performed through interaction within the VE and the resulting outcomes should have consistency and flow

We are interested to explore the effects of virtual camera parameters based on user's physical head location while viewing 360-degree videos to interact within a CAVE like environment. Therefore, we have created two questionnaires to measure the presence.

The first questionnaire is a composition of Presence Questionnaire (PQ) [Witmer et al., 2005] and Temple Presence Inventory (TPI) [Lombard et al., 2009]. Each question has a scale from 1 to 7. Both the questionnaires are composed of questions that are related to presence w.r.t different factors such as interactive factors, sensory factors, realism, and distraction factors [Slater, 1999]. Since in our CAVE-like environment we are focused to measure the presence of the user, the questions related to other factors were left out. The revised version of the questionnaire is attached to the appendix 1.

The second questionnaire that we are using is constructed by Slater et.al. [62], which measures the subjective presence of body movement in VE. It is composed of seven questions that measures presence in a VE, to what extent a VE can become a dominant reality and to what extent a user can remember VE as a 'place' [Usoh et al., 2000]. This questionnaire is used as published in the research paper and is referred as Slater-Usoh-Steed Questionnaire (SUS) in this study. The questionnaire is attached to the appendix 2.

Both questionnaires consist of a 7-point Likert scale where the participants could agree or disagree to the statements. A value of 1 indicated full disagreement while a value of 7 indicated full agreement.

8.1 Study Objectives

The study objective is to understand how adjusting virtual camera parameters based on user's physical head location affects user experience of viewing 360 videos in CAVE like environments. For this few conditions and criterion were setup.

We tested three conditions which we termed as scaling conditions. In each scaling condition, the virtual camera moved differently based on the user's head movements. The conditions we tested are as follows:

1. Scaling 0, which emphasizes the effect of user's movement: as the user moves to any direction things get bigger in that direction (actual projected size)
2. Scaling 1, which removes the effect of user movement: things appear roughly the same size (when measured as degrees of the view) when the user moves
3. Scaling 2: there is a little movement similar to condition 2. This makes the view seem similarly "alive" as in the other two conditions but the actual change in object sizes is close to insignificant

For all cases, user's physical location controls the position of the virtual camera inside the virtual sphere where the 360-degree video is projected into. The camera moves in all three dimensions. In scaling 0, the camera moves to the same direction as that of the user, which means that the object size will be drawn bigger in terms of pixel size as the user walks or move towards them in the VE. At the same time, the user moves close to the relevant projection surface. Objects on the sides of the user follow the user, i.e., the sideways movement is smaller than normal. In scaling 1, the virtual camera moves to the opposite direction than the user movement. This means that the objects the user moves towards will be drawn smaller in pixel size. As the user moves to view the objects closely, they appear roughly the same size. On the side walls of the VE, the objects appear to move to the opposite direction, i.e., movement on side walls is emphasized. Scaling 2 has only a small amount of movement. The movement is so small that the objects' pixel sizes do not change significantly. However, even the minor changes make the user feel that the system reacts to his/her movements.

We are also interested to gather data regarding the overall user experience and immersion about our CAVE-like environment. We are particularly interested about motion sickness

(if any) and the level of immersion the user experienced. The related questions are included both in the questionnaires and interview.

8.2 Participants

The tests/evaluations took place in the Sim lab, situated in School of Communication Sciences, University of Tampere. Before the actual test, a test plan was developed and tested in pilot phase. Based on the pilot test, the test plan was revised to ensure the success of the final tests conducted afterwards.

The recruitment of participants was done through personal communication by asking the acquaintances to volunteer for the study and also through social media communication. A total of 12 participants were taken to perform user study.

The average age of the participants that participated in the experiment was 27.92 and belonged to Asia, with 11 males and only 1 female participant. Four of the 12 participants had no experience of any kind of virtual reality prior to this experiment but they were fascinated to experience it for the experiment. Six of the remaining participants were aware and two were only slightly aware of any VR. Those who had tried VR before had used devices like Gear VR, Oculus Rift and Google Card Board etc. The participants were interested to watch 360-degree videos for home, school, cinema and sports. As expected, none of the participants had any CAVE like experience before.

Table 2 Participants background data

| | Age | Gender | Experience with VR | Tools for experiencing VR | CAVE VR experience |
|---------------|------------|---------------|---------------------------|----------------------------------|---------------------------|
| Participant 1 | 28 | Male | Yes | Samsung Gear VR | No |
| Participant 2 | 28 | Male | Yes | Samsung Gear VR, Oculus Rift | No |

| | | | | | |
|----------------|----|--------|-----|-----------------|----|
| Participant 3 | 29 | Male | Yes | Samsung Gear VR | No |
| Participant 4 | 27 | Male | No | N/A | No |
| Participant 5 | 27 | Male | Yes | Oculus Rift | No |
| Participant 6 | 31 | Male | No | N/A | No |
| Participant 7 | 23 | Male | Yes | Samsung Gear VR | No |
| Participant 8 | 34 | Male | Yes | Samsung Gear VR | No |
| Participant 9 | 32 | Male | No | N/A | No |
| Participant 10 | 40 | Female | No | N/A | No |
| Participant 11 | 26 | Male | Yes | Samsung Gear VR | No |
| Participant 12 | 25 | Male | Yes | Oculus Rift | No |

8.3 Video Contents

The videos were shot in a cruise ship. The videos contain different areas within the ship such as duty-free shop, engine room, restaurant, dance club and ship decks.

8.4 Test Tasks

It required a lot of thought process to design test tasks. As explained above the videos were shot in a cruise ship, the tasks and the environment were similar to a real-life situation, depicting a scenario that the participants would be ‘moving’ around the cruise ship. The test tasks required the user to think out aloud while looking for certain

information and try to find and memorise objects and places. At first, we decided to show ODV videos without any interaction, but doing so could have made a boring and confusing experience for the participants. Therefore, we decided to implement some basic interaction also where the participants were required to navigate between different videos (scenarios) by moving close towards an icon marker in the video. The tasks were designed so that the participants had to perform enough movements to cause significant changes in the video projection.

As described in section 8.1, we tested three scaling conditions. Six tasks were designed which were divided equally among the three conditions i.e. two tasks for each scaling condition. After every two tasks, the scaling condition was changed. Counter balancing was used to reduce learning effects and to remove the effects of individual tasks. While the tasks were always presented in the same order, the scaling conditions were randomized as follows:

Table 3 Counter balancing scaling conditions

| | Scaling | | |
|--------------------|----------------|---|---|
| | 0 | 1 | 2 |
| Participant | 0 | 2 | 1 |
| | 1 | 0 | 2 |
| | 1 | 2 | 0 |
| | 2 | 0 | 1 |
| | 2 | 1 | 0 |
| | 0 | 1 | 2 |

Table 4, shows the order of the scaling conditions. The order was followed for first 6 participants and repeated for the next 6.

The tasks required the participants to navigate within the cruise ship ODVs and find out information about objects and places. The participant was provided with the test tasks on a piece of paper and was made sure that the order of the questions on the paper is followed. The same set of videos was used across the tasks and scaling conditions. The test tasks are attached to the appendix 3.

8.5 Methods and Procedure

The test procedure was divided into three parts. In the first part, an introduction was given to the participants about the purpose of the evaluation and he/she was introduced to the CAVE-like VE and was provided with the background questionnaire to fill in.

Provided the introduction and familiarization with the VE to the participants was very important since they may be experiencing the environment for the first time and the use of technology might dominate the participants' attention [Tiainen et al., 2006]. The participant's behavior in the environment was observed closely during the test.

The second part included the actual user test. Earlier it was decided that the participants shall be given the one set of questionnaires after they would have completed all the tasks. After conducting the pilot test, we concluded that the participants will be asked to fill the questionnaires after every two tasks, i.e., after each scaling condition to gather comparable results immediately after experiencing each condition.

The third part was to an interview. After all the tasks were completed and forms filled, the participants were interviewed about their experience. The audio for the interview session was recorded of which the participants were informed in the beginning.

8.5.1 Script

To keep the consistency for each test, a script was developed. It included a short background and purpose of the test and order of the different tasks to be executed during the test procedure by the observer/evaluator. It is a paper which lets the observer/evaluator keep track of different tasks during the experiment.

8.5.2 Consent Form and Background Questionnaire

The participants were requested to fill out the consent form to take in writing the permission from them to record the interview audio for evaluation purposes. Background information questionnaire was provided to the participants to collect the necessary information. Consent form and background question is attached to the appendix 4.

8.5.3 Questionnaires and Interview of the Participants

Interviews are individual conversations with the test participants. Interviews give insights regarding user's opinions, their attitudes towards a product and their preferences [Unger and Chandler, 2012]. According to Goodman et al, interviews are necessary to have a real understanding of user's experiences [Goodman et al., 2012]. In a semi-structured interview approach the interviewer asks prepared questions from the user but also has the opportunity to explore interesting responses and commentaries from the participants [Unger and Chandler, 2012]. The questions in the interview should be flexible and open-ended so that the participants can introduce related topics and questions which the interviewer would not have been able to anticipate [Hartson, 2003]. Our study included open-ended interview questions.

After the test, the participants were interviewed using a semi-structured interview process in which the questions were mainly related to user's experience and presence in the VE and if they felt any cyber sickness.

The duration of the interview was on average five to seven minutes. The interview questions are attached to appendix 5.

9 STUDY RESULTS AND ANALYSIS

9.1 Tasks Completion Results

The average task time for the first two tasks was about eight to ten minutes and for the rest of the tasks the average time was around four to five minutes (in a pair of two tasks under one condition). Five of the total of twelve participants were not able to perform one or more of the tasks for corresponding scaling conditions. Others could perform all the tasks with varying level of difficulties under each scaling condition. One test session lasted for about 40 minutes. Table 3 shows the time taken and tasks performed by the participants

Table 4 Tasks performed and average time taken by the participants

| Participants | Tasks performed | Task 1-2 (mins) | Task 3-4 (mins) | Task 5-6 (mins) |
|---------------------|--------------------------------------|----------------------------|----------------------------|----------------------------|
| Participant 1 | Was not able to perform task 2 and 3 | 10 | 6 | 4 |
| Participant 2 | Was not able to perform task 3 | 7 | 7 | 5 |
| Participant 3 | Was not able to perform task 3 | 7 | 7 | 3 |
| Participant 4 | All tasks performed | 8 | 4 | 5 |
| Participant 5 | Was not able to perform task 1 and 3 | 9 | 5 | 4 |
| Participant 6 | All tasks performed | 7 | 3 | 5 |
| Participant 7 | All tasks performed | 8 | 4 | 5 |
| Participant 8 | All tasks performed | 8 | 5 | 3 |

| | | | | |
|----------------|--------------------------------|---|---|---|
| Participant 9 | Was not able to perform task 4 | 9 | 5 | 5 |
| Participant 10 | All tasks performed | 7 | 4 | 5 |
| Participant 11 | All tasks performed | 8 | 5 | 4 |
| Participant 12 | All tasks performed | 9 | 5 | 3 |

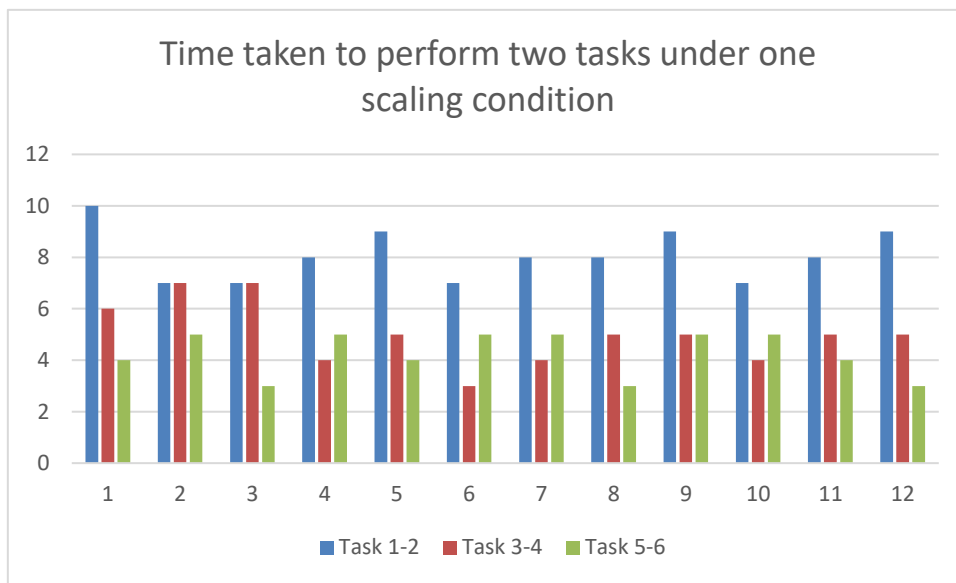


Figure 9-1 Time taken to perform two tasks under one scaling condition

9.2 Questionnaire Results

This sub chapter will report the questionnaires results for the three conditions which were tested during the experiment. The questionnaire responses were analyzed using pairwise two-tailed t-test (alpha value 0.05) using Bonferroni correction (corrected alpha 0.0009). Medians and Averages are collected for each of the questionnaires for statistical analysis.

9.2.1 Presence Questionnaire (PQ):

The averages for each scaling for Presence Questionnaire (PQ) are described in Table 5.

Table 5 PQ questionnaire results for averages

| Statements | Scaling 0 | Scaling 1 | Scaling 2 |
|--|------------------|------------------|------------------|
| <i>1. To what extent did you experience a sense of being there inside the environment you saw?</i> | 4.17 | 4.58 | 5.25 |
| <i>2. How much did it seem as if the objects and people you saw/heard had come to the place you were?</i> | 4.416 | 4.33 | 4.41 |
| <i>3. How much did it seem as if you could reach out and touch the objects or people you saw/heard?</i> | 3.66 | 3.08 | 4.41 |
| <i>4. How much did your experiences in the virtual environment seem consistent with your real-world experiences?</i> | 3.66 | 4.08 | 4.08 |
| <i>5. How completely were you able to actively survey or search the environment?</i> | 4.08 | 5.00 | 4.41 |
| <i>6. I felt nauseous?</i> | 1.25 | 2.5 | 1.91 |
| <i>7. How closely were you able to examine objects?</i> | 4.50 | 4.91 | 5.00 |
| <i>8. How involved were you in the virtual environment experience?</i> | 5.00 | 5.66 | 4.91 |
| <i>9. How quickly did you adjust to the virtual environment experience?</i> | 4.58 | 4.58 | 4.83 |
| <i>10. How proficient within the virtual environment did you feel at the end of the experience?</i> | 4.58 | 4.58 | 5.00 |
| <i>11. How well could you identify sounds?</i> | 5.08 | 5.41 | 5.41 |
| <i>12. How well could you examine objects from multiple viewpoints?</i> | 4.08 | 4.08 | 4.16 |

Participants felt somewhat present in the virtual environment having a feeling for the surrounding objects and people, and rated the overall experience with an average score of above 4.16 in each scaling with scaling 2 recording the highest average value for statement number one. However, the participants did not feel to be reaching out for the objects but only slightly (statement 3) as the environment felt to be only somewhat consistent with the real world (statement 4 and 5) but they still felt involved. They were able to adjust to the VE. Cyber-sickness did not seem to be a problem in any scaling. The

sounds appeared to received rather good response as well. Responses concerning the examination of objects were mixed since they did not feel to reach out for the objects. According to the data for PQ, scaling 2 is the best among the scaling and scaling 0 performing the worst but the difference is not so statistically significant.

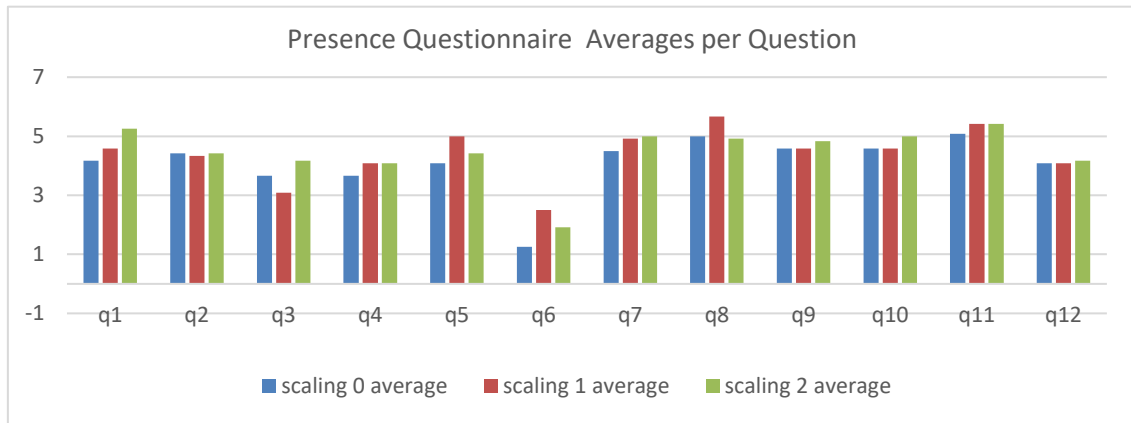


Figure 9-2 Presence Questionnaire, Averages per Question

9.2.2 Slater-Usuh-Steed Questionnaire (SUS):

The average results for Slater-Usuh-Steed Questionnaire (SUS) are described in Table 6.

Table 6 SUS questionnaire results for averages

| Statements | Scaling 0 | Scaling 1 | Scaling 2 |
|--|-----------|-----------|-----------|
| <i>1. Please rate your sense of being in the virtual environment, on a scale of 1 to 7, where 7 represents your normal experience of being in a place.</i> | 3.91 | 4.66 | 4.25 |
| <i>2. To what extent were there times during the experience when the virtual environment was the reality for you?</i> | 3.25 | 4.08 | 3.91 |
| <i>3. When you think back to the experience, do you think of the virtual environment more as images that you saw or more as somewhere that you visited? (lower scale being the images and higher scale being as somewhere you visited)</i> | 3.83 | 4.08 | 4.41 |
| <i>4. During the time of the experience, which was the strongest on the whole, your sense of being in the virtual environment or of being elsewhere? (lower scale being in the virtual environment and higher scale being elsewhere)</i> | 3.75 | 4.25 | 3.75 |
| <i>5. Consider your memory of being in the virtual environment. How similar in terms of the structure of the memory is this to the structure of the memory of other places you have been today? By</i> | 4.16 | 4.41 | 4.50 |

| | | | |
|---|------|------|------|
| <i>'structure of the memory' consider things like the extent to which you have a visual memory of the virtual environment, whether that memory is in color, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other such structural elements.</i> | | | |
| 6. During the time of your experience, did you often think to yourself that you were actually in the virtual environment? | 3.66 | 4.00 | 3.91 |

According to the average values of SUS questionnaire, the participants somewhat had a sense of being in the VE with an average score of around 4. They did not feel it to be close to reality with feeling of having a movie like experience. The results are consistent from the findings of PQ. According to the data for SUS, scaling 1 is the best and again scaling 0 performing the worst.

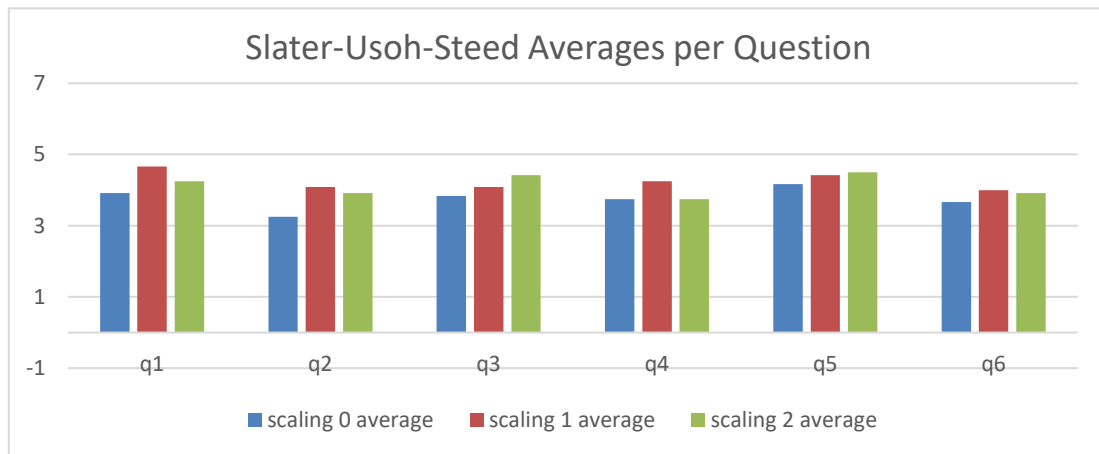


Figure 9-3 Slater-Usuh-Steed Averages per Question

9.3 Observations

The participant's actions, reactions and performance behaviors were being closely observed during each test session and notes were made for analysis and compilation of results. The participants were asked to use think aloud strategy while performing the tasks so that their verbal expressions and resulting impressions could be observed and analyzed. The purpose of this was to get better understanding of how the participants worked through their tasks while navigating in the VE, the possible hurdles and unwanted situations they faced during the test process and how they tried to overcome these.

All the participants were able to understand the given tasks. However, few of the participants were not able to comprehend some questions in the questionnaires at first.

However, after a bit of explanation they were able to understand those questions quite well. This may be because the questionnaires were composed of some technical terms and the participants might have lacked knowledge about those terms due to their background.

For the first two tasks for each condition/scaling, the participants took more time as compared to the last four tasks as described in the performance section of this chapter. This could be because all the users were using CAVE like VE for the first time. They were trying to get acquainted with the environment at first. As the user got acquainted with the environment, there was a considerable reduction in time taken by the participants to perform the remaining tasks.

During the test, the participants sometimes moved too close to the marker or too far away, subsequently getting out of the range of the motion trackers. The observer helped the participants whenever this unwanted situation arose and they could not realize that they were out of the range of the motion trackers. This may have happened because the participants were so involved in the VE that they anticipated they could interact with it at any given distance. Other possibility could be that they were not aware of the location of the motion trackers which was detecting their motion.

An interesting observation during the test was found that almost all the users started to use their hand gestures to interact with the environment as soon as the experiment began. This could be because as soon the experiment started and the ODV projection was changing with the user's head movement, the participants might have been anticipating that the environment could react to gestures as well. Being an observer, I had to remind of the limitations of the system for this particular experiment.

Another very important observation was about configuration of the user tracking. During the evaluations it was configured according to certain average height of a person. One of the participant was significantly shorter than average. He was finding it extremely difficult to navigate through the environment because the navigation markers were not visible on screen to him as he was not tall enough for the configuration of markers placed in ODV.

9.4 Interviews

The section reports and analyzes the interviews which took place at the end of each test session. The results are described as aggregated interpretations about the overall experience of the participant in the CAVE like VE, the one or multiple scaling(s) under which the participants felt easy to navigate through the VE, level of immersion and presence, observing different objects in VE and dizziness.

The participants were quite excited to experience the CAVE VE as none of them had experience it before and reported the overall experience to be quite good. However, they were not able to clearly differentiate between the three conditions and the associated changes. Only one of them experienced mild cyber-sickness. They had mixed feelings of being involved in the VE. At some point, they felt completely involved and at other times the feeling was only slightly involved. They were able to hear and recognize the sounds quite well.

Every participant wanted to interact with the environment using gestures or controllers. They wanted to have more interactivity within the environment. They suggested to improve the video quality (resolution) of the 360-degree videos used in the experiment. They also reported some bugs while navigating due to which they had problems in accomplishing the tasks. All the participants wanted to experience more CAVE VEs in future and suggested improvements.

10 CONCLUSION AND FUTURE WORK

This thesis measured the implementation of viewer location-based projection effects for ODV content in CAVE like VE. The process included literature review to understand the basics of VE subsequently leading up to evaluating the VE. The system is an excellent platform for testing and developing applications for CAVE VE. A browser based web application was developed and implemented targeting Windows 10 platform. The application served as the mechanism to create an environment where the users could move around from one location to another while performing different tasks.

In conclusion, the study conducted paves way to explore different dimensions of CAVE VE-based ODV viewing. Three types of virtual camera scaling effects were evaluated with users and the results analyzed. The results showed no significant differences in terms of the scaling conditions and their effects. However, scaling 0 was ranked worst among the three. The participants showed no sign of simulator sickness. They somewhat felt 'presence' in the VE but felt limited interactivity within the VE. Observation and interview data showed that the participants were quite excited to use this kind of VE in the future.

The current version of CAVE-like VE requires a lot of modifications and a new set of features to provide a more immersive and engaging experience for the users which may include the implementation of High Definition (HD) ODV playback, better calibration of head mounted marker w.r.t the user's height, structured navigation, and information modules behaving as the instructions booklet to use the environment. In addition, the interaction with the VE should be improved to give more control the users.

The practical potential of application areas of CAVE VEs are limitless, they could be used as a remote sightseeing tool in tourism industry. The environment can be used for educational purposes to create virtual classrooms. Companies can use it to create prototypes in a shared environment for co-creation of products. The environment facilitates to overcome limitations of head mounted displays. CAVE VEs can pay way to a new era of scientific research, experimentation and entertainment.

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APPENDIX 1. Presence Questionnaire (PQ)

1. To what extent did you experience a sense of being there inside the environment you saw?

NOT AT ALL SOMEWHAT COMPLETELY

2. How much did it seem as if the objects and people you saw/heard had come to the place you were?

NOT AT ALL SOMEWHAT COMPLETELY

3. How much did it seem as if you could reach out and touch the objects or people you saw/heard?

NOT AT ALL SOMEWHAT COMPLETELY

4. How much did your experiences in the virtual environment seem consistent with your real world experiences?

NOT AT ALL SOMEWHAT COMPLETELY

5. How completely were you able to actively survey or search the environment?

NOT AT ALL SOMEWHAT COMPLETELY

6. I felt nauseous?

NOT AT ALL SOMEWHAT COMPLETELY

7. How closely were you able to examine objects?

|_____|_____|_____|_____|_____|_____|_____|
NOT AT ALL SOMEWHAT COMPLETELY

8. How involved were you in the virtual environment experience?

|_____|_____|_____|_____|_____|_____|_____|
NOT AT ALL SOMEWHAT COMPLETELY

9. How quickly did you adjust to the virtual environment experience?

|_____|_____|_____|_____|_____|_____|_____|
NOT AT ALL SOMEWHAT COMPLETELY

10. How proficient within the virtual environment did you feel at the end of the experience?

|_____|_____|_____|_____|_____|_____|_____|
NOT AT ALL SOMEWHAT COMPLETELY

11. How well could you identify sounds?

|_____|_____|_____|_____|_____|_____|_____|
NOT AT ALL SOMEWHAT COMPLETELY

12. How well could you examine objects from multiple viewpoints?

|_____|_____|_____|_____|_____|_____|_____|
NOT AT ALL SOMEWHAT COMPLETELY

APPENDIX 2. Slater-Usoh-Steed Questionnaire (SUS)

SLATER-USOH-STEED QUESTIONNAIRE (SUS)

1. Please rate your *sense of being in the* virtual environment, on a scale of 1 to 7, where 7 represents your *normal experience of being in a place*.

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|

2. To what extent were there times during the experience when the virtual environment was the reality for you?

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|

3. When you think back to the experience, do you think of the virtual environment more as *images that you saw* or more as *somewhere that you visited*? (lower scale being the images and higher scale being as somewhere you visited)

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|

4. During the time of the experience, which was the strongest on the whole, your sense of being in the virtual environment or of being elsewhere? (lower scale being in the virtual environment and higher scale being elsewhere)

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|

5. Consider your memory of being in the virtual environment. How similar in terms of _____ the *structure of the memory* is this to the structure of the memory of other *places* you have been today? By 'structure of the memory' consider things like the extent to which you have a visual memory of the virtual environment, whether that memory is in color, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other such *structural* elements.

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|

6. During the time of your experience, did you often think to yourself that you were actually in the virtual environment?

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|

APPENDIX 3. Test Task

Starting point could be stairway and the front of deck 10 (the club is in the back, there are two scenes between the stairway and the club)

1. Go to the night club on decks 10 and 11. What is the name of the club being animated on the stage screen? Answer: club Vogue

2. Go to the tax-free shop on deck 9. What champagne brands are advertised on the champagne shelf? Answer: Krug and Dom Pérignon

3. Go to the buffer on deck 10. What kinds of sweets can be found in bowls on the counter? Answer: English liquorice (aka Liquorice allsorts)

4. Go to the spa entrance on deck 11. What items are displayed on the window next to the door? Answer: slippers.

5. Go to the bar area on deck 10. Which instrument is a man playing on the small stage? Answer: guitar.

6. Go to the corridor on deck 9. What symbols can be seen on the side of the reception desk? Answer: paw marks (and an arrow)

APPENDIX 4. Consent Form and Background Questionnaire

CONSENT TO RECORD A TEST

We ask you to participate in a user study that is part of my thesis work at the University of Tampere. By participating in the user study, you will help us to evaluate the CAVE-like virtual environment.

You will be asked to watch a number of omni directional videos in a CAVE-like virtual environment. In addition, we will ask you to fill in questionnaires and we will interview you about your experience in a CAVE-like environment. The user study activity will be recorded.

At the end of the experiment we will ask you some interview questions related to the experiment. We will record your audio during the interview session. The audio recordings will be used to evaluate the effects of viewer location based projection effects on ODV video display in CAVE like environments in the thesis work. In addition to the thesis writer, the supervisor of the thesis will also have the access to the audios and other materials from the study. The recordings will be destroyed after the thesis work is completed and accepted by the faculty.

The results of the user study will be reported anonymously. A summary of the main results will be analyzed and discussed in the thesis work. Audio recordings or participants' personal data will not be revealed.

You can stop participating in the test at any point.

We are happy to answer, if you have any questions.

By signing this form, you will accept the above terms.

Date and place: _____

Signature: _____

Name clarification: _____

Background questionnaire

Please take a few minutes to answer the following questions to help us better understand your background. We will use this information only to provide background and usage context in which to interpret the input and feedback you'll give us in the user study. We will keep your name confidential, and anonymously report the information you provide today.

| | |
|-------------|--|
| Name | |
| Age | |
| Gender | |
| Nationality | |

- Please select one option which describes your VR experience:
 - a. How familiar are you with the concept of Virtual Reality (VR)?
 - a. I am not at all aware of VR
 - b. I am only slightly aware of VR
 - c. I am aware of VR and are beginning to investigate the topic

 - b. Have you experienced a VR environment before?
 - a. Yes, I have tested/tried VR
 - b. No, I have not tested/tried VR

 - c. If yes then what kind of experience it was?
 - a. VR Head set such as Oculus Rift, Samsung Gear VR, Google Card Board
 - b. CAVE-like VR

 - d. How do you feel about watching video in virtual reality?
 - a. Fascinating
 - b. Boring
 - c. Somewhat ok
 - d. I do not want to watch a video in Virtual Reality

 - e. Where (if at all) do you think you would like to use virtual reality to watch video?
 - a. Home
 - b. School

- c. Cinema
- d. No where
- f. What kind of videos would you like to watch in Virtual Reality?
 - a. TV Shows
 - b. Movies
 - c. Sports
 - d. Cartoons

APPENDIX 5. Interview Questions

1. How could you describe your experience in the CAVE-like environment?
2. Which condition did you like the best and why? a. How easy or difficult was it to perform the tasks under these conditions?
3. Under which condition was it easy or difficult to navigate around the CAVE VE?
4. How did you find observing different objects under different conditions in the VE?
5. Did the experience seem more like looking at the events/people on a movie screen or more like looking at the events/people through a window (as if you experience in a real-world)?
6. How often when an object seemed to be headed toward you did you want to move to get out of its way?
7. What was the most fascinating/least fascinating thing about the VE?
8. What kind of feelings did you experience during the use of VE? (a) Why do you think you were experiencing them?
9. How would you describe this experience compared to your expectations?
10. If you compare watching a 360-degree video in a CAVE-like environment and how you normally watch video, which do you think give the best experience? a) Why?
11. Was there anything that was hard to understand?
12. Was there anything that you felt was easy to understand?
13. Was there any functionality you felt was missing?
14. Was there anything that annoyed you?
15. What do you think would have made the experience better?
16. Did you at any point felt dizzy or nausea? If yes, then please describe that moment?
17. How would you rate your over-all experience of CAVE-like VE and would you like to experience more about CAVE-like VE?