REALM

THE STUDY OF NATURAL HAND GESTURAL COMMANDS TO NAVIGATE AND INTERACT WITH IMMERSIVE 3D INTERFACES AND WIDGETS

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HONOURS THESIS

2015

BACHELOR OF DESIGN COMPUTING (HONS)

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Design Lab Faculty of
Architecture, Design and Planning
The University of Sydney

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ABSTRACT

For many years, the main form of digital interaction has been with desktop computers, portable devices like mobile phones and touchscreen tablets. As the new generation of Head Mounted Displays (HMDs) are beginning to make the much-anticipated arrival of augmented reality (AR) and virtual reality (VR). A large body of research from the last three decades has laid the foundation for the concepts now emerging in the market. There has been little focus on the analysis of consumer user interfaces being produced for these new platforms. As technology is progressing, there is an increasing need to study current trends in user and developer communities, and to contextualise them within the ongoing evolution of human-computer interfaces.

As these trends in user interfaces (UIs) start to appear, it is also crucial to understand the user interaction behaviours and further analyse what the current flaws are. In this study, we specifically focus on mixed reality (MR) within immersed simulations enabled through combining VR headsets with vision sensors. We present complementing guidelines through an analysis of apps on the *Leap Motion* market and outline further suggestions for developers and designers to assist with creating more natural user interface experiences. These suggestions further present the understanding of ergonomics in an immersive space through five zones of interaction, UI compositions through minimal graphical buttons, object manipulation through intuitive gestural interactions with consideration of actual size and reinforcing stronger interaction feedback.

ACKNOWLEDGEMENTS

This study has been a long journey with many obstacles that has shaped my way of thinking, working and collaborating with others. My passion and consideration for pursuing my honours research all began thanks to Dr Rob Saunders, for recommending further studies with devices such as the *Oculus Rift*. Rob has provided me with many opportunities throughout my time in the Design Lab and I am highly grateful.

I would like to immensely thank all the developers and designers in the *Leap Motion* and *Oculus Rift* communities for providing their apps/materials to analyse and find trends and guidelines to further build a stronger foundation for mixed reality experiences.

In addition to all the existing work by other academics and innovators, this research would still not have been possible if not for the constant support, supervision and positive encouragement from my supervisors, Dr Oliver Bown and Dr Martin Tomitsch. Very few students get the opportunity to have such great supervisors like them. To add to this league of legends, I would like to thank my Honours coordinator, Dr Somwrita Sarkar for being there throughout this journey and pushing me to strive for the best that I could achieve. I am most grateful and consider myself as a very fortunate student.

I would like to thank the staff at the Design Lab for providing me with such positive support throughout my four years in the faculty. Throughout my time in the Design Lab I have been fortunate to receive a lot of support and encouragement towards my studies. I would like to thank Dr Lian Loke for her advice and for providing me the opportunity to experience the *Oculus Rift* for the very first time when visiting the engineering faculty. Also, I would like to thank Dr Caitiln De Berigny, for all her support and always guiding me towards positive outcomes for my assessments throughout my degree!

Since this study has required much technical support and use of powerful devices, I would like to thank Leslie George for providing me with the best facilities a student could ask for. If not for his help in providing me with a workspace and a powerful computer, there was no chance of being able to analyse the applications and experiment with various prototypes. I would also like to thank Julius Dimataga for always being around to help troubleshoot and provide me with equipment to set up for the user study and graduation show.

Furthermore, I would like to thank Giulio Lues for being supportive throughout my study. As a designer, I always tend to struggle to understand code, and he has always been there to answer any of my questions in regards to technical issues. Also, I would like to thank Nikash Singh for always being there to provide advice in conducting a useful study. I would like to thank Callum Parker for helping me sort out the errors that were discovered during the pilot study! Also, I would like to thank all the participants who took part in this study.

Last and most importantly, I would like to give a big hug and thank my family and loved one for all their support and always being there to make me smile after a long day of battling within virtual worlds. Your love and support has encouraged me to come this far, and I am extremely grateful.

MOTIVATION

“With great power comes great responsibility” - Benjamin Parker

This quote clearly expressed my feelings during my honours presentation. Knowing that I have been given the opportunity to work with great supervisors and having a good topic put many responsibilities to present a good work.

My passion for 3D modelling and animation drove my focus in looking into all the possibilities with wearable devices and ways of designing intuitive menu systems that could benefit a range of interactive visualisations.

Despite previous headsets being an expensive flop, there is still much potential for wearable technology in the near future. With the upcoming releases of Head Mounted Displays like *Microsoft HoloLens*, *Sony’s Project Morpheus*, and *Oculus Rift* there is a much more promising future for virtual and augmented realities. Since these devices are no longer being used for just gaming purpose, it reinforced a much stronger motive to study gestural interactions that can be utilised across many disciplines.

Furthermore, I wanted to see how I could experiment with the current tools and analyse current applications that may present opportunities for future guidelines for designers and developers. The main motive of this study has been to find gaps and present results about the interaction of users in virtual and physical spaces that can be presented to the community of virtual and augmented reality to expand our knowledge and understanding of upcoming head mounted displays.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

2D – Two Dimensional

3D – Three-dimensional

AR – Augmented Reality

API – Application Programming interface

CLI – Command-line Interface

DK2 – Development Kit 2

FOV – Field of View

GUI – Graphical User Interface

HCI – Human Computer Interaction

HMD – Head-Mounted Display

MR – Mixed Reality

NUI – Natural User Interface

OUI – Organic User Interface

SAR – Spatial Augmented Reality

UI – User Interface

VE – Virtual Environment

VR – Virtual Reality

LIST OF FIGURES

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1. INTRODUCTION

This chapter describes the topic and structure of this thesis. The focus of this research looks into the design and use of menu systems within immersive environments and how hand gestural behaviours can affect the interaction and experience in mixed reality.

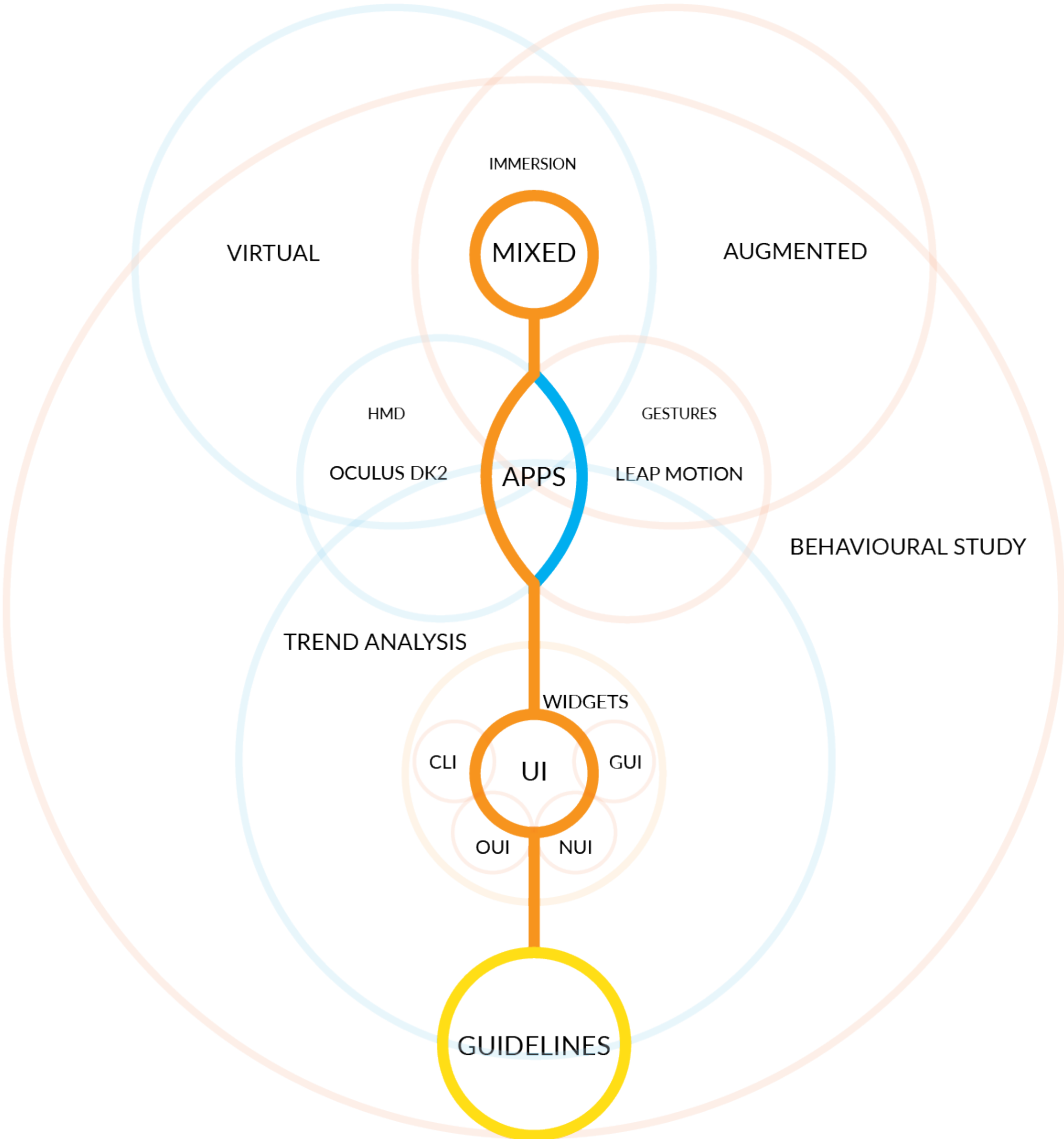

Figure 1. Study diagram, an overview structure of the thesis

"I believe we will look back on 2010 as the year we expanded beyond the mouse and keyboard and started incorporating more natural forms of interaction such as touch, speech, gestures, handwriting, and vision—what computer scientists call the 'NUI' or natural user interface."

—Steve Ballmer, CEO Microsoft

Numerous researchers emphasise the idea of how technology is advancing quicker than we can adapt to it. Today digital consumers all over the world use desktop computers, laptops and mobile devices to complete everyday activities. For example, these activities could involve a person navigating through multiple tabs on their browser, interpreting various data visualisations, interacting with widgets or just simply reading text on a document. However, would these devices be the only form of digital interaction available for consumers ten years from now? Would we still be using flat screens to get the job done? These questions brought on my curiosity into researching current menu systems in immersive applications and the possibilities of interaction techniques for such activities.

The majority of physical computing requires the use of hand interaction with devices. For example, devices provide interaction with physical touch screens, or typing on a keyboard and moving a mouse. However, how would such hand gestural behaviours change within an immersive virtual space? This notion of interaction in new spaces provides an intriguing possibility of looking at other methods of interaction, such as in-air interaction instead of direct interaction. Based on the current development of interactive technologies within digital computing, there are possibilities within an immersive virtual environment that can support direct manipulation by the use of hand gestures, which could offer novice consumer a much more recognisable way to manipulate spatial virtual object or interfaces. Would this give a user a new way to navigate and manipulate widgets? For example, to change the position of a 3D object through hand manipulation in an immersive space is similar to moving an actual object in the real world.

1.1 AIM

The aim of this research is to explore, analyse and evaluate menu interfaces and 3D widgets/objects in immersive user interfaces. These menu systems will focus on the interaction of using natural hand gestural commands. This study will look at existing applications on the *Leap Motion* market that are compatible with the *Oculus Rift* Development Kit 2 (DK2).

1.2 RESEARCH QUESTION

The focus of this study will be directed by the following questions that will lead the investigation and analysis of this topic:

- How effective are natural hand gestural commands when using menu systems in virtual or mixed reality?

- How can the use of three-dimensional widgets and interfaces create a more informative understanding of spatial interaction?

- What are the issues with head mounted displays that stop users from experiencing natural and organic user interfaces?

1.3 OBJECTIVES

The following objectives for this research look into existing content that are currently developed for the *Leap Motion* market that supports the use of the *Oculus Rift*. This convergence of devices presents the ability of hand gestural interaction and provides the experience of how it may influence menu systems for future applications. There are three phases in this study; the first phase involves an independent study that looks at the top 10 mixed reality (MR) applications. These applications are analysed against the characteristics of the four types of user interfaces by Wixon (2008). Further developing this concept, Phase two consists of conducting a user study on five apps from the list. The participants will experience three different kinds of app categories that present

(a) navigation and interaction in 3D environments (b) exploring and understanding various data visualisations, and (c) interaction with the legibility of text on augmented interfaces. The third and final phase include the implementations of the guidelines to present further new possibilities that can be achieved.

This project aims to accomplish the following objectives:

1. **Background research:** The first stage of this research is to investigate current topics that support this study. These main topics look into interaction experiences in virtual, augmented and mixed reality. These topics are further supported by understanding the devices like the *Oculus Rift* DK2 and the *Leap Motion* sensor, which are used in this study. Further research looks into the evolution of user interfaces which relate to object manipulation, visual compositions and task interactions.

2. **Trend Analysis:** Conducting a study on existing applications that present gestural navigation/interactions with virtual widgets and interfaces. In the case of this study, we will be looking at the top 10 demo apps on the *Leap Motion* market and analyse them with the four types of user interfaces (command line interface, graphical user interface, natural user interface and organic user interface).

3. **User behavioural study and observations:** Further narrowing down to analysing 5 existing apps that present menu/widget interfaces where participants will experience through each app. This user study will further present data on the problem areas that can be addressed and present themes that present guidelines.

4. **Evaluate data findings:** Analysing the data that from observing participants and transcribing their interview responses to further structure and find patterns of behavioural preferences and identification of problem areas.

5. **Guidelines and future work:** Presenting the findings and supporting and adding to existing principles that give guidance for current and future menu systems and user interfaces for immersive applications to be more intuitive, responsive and provide users with positive experiences.

1.4 CONTRIBUTIONS OF RESEARCH

The contributions of this research present an in-depth analysis that gathers themes and guidelines from observing characteristics in user interface trends and observing user behaviours within existing applications. These applications are built for the use of the *Oculus Rift* and *Leap Motion* sensor which provide users with VR and MR experiences. The *Leap Motion* has provided many fixed guidelines for developers and designers. However, few guidelines and themes have been discovered in this research which can be considered when developing UIs in immersive apps. The results of this study offer new and current themes that may benefit future immersive experiences by reflecting on the proposed guideline principles. By further building on existing principles provided by the *Leap Motion* community which focus on desktop interaction, it allows this research to get a much deeper insight into user behaviour when interacting with user interfaces with in-air gestures within an immersive state.

Furthermore, there are many significant aspects of this study that present alternatives and preferred commands for more immediate results, providing a clear idea of what kind of gestural navigational commands would be most appropriate when interacting in the new digital era. With the upcoming release of the virtual head-mounted displays such as the *Microsoft HoloLens*, the *Oculus Rift*, *Sony's Project Morpheus* and many others, this research could potentially provide a better understanding what are the key attributes that developers and designers should consider when building new immersive experiences. To further evaluate the findings, the app from this research will be submitted to the Leap Motion community as an open-source project for others to develop further towards positive immersive experiences.

2. BACKGROUND

Some theories explain the implementation and studies of natural hand gestural behaviours (Manresa, Varona, Mas, & Perales, 2005). In parallel, recent research also looks at human interaction experiments with virtual reality (Boas, 2013). However, there are very few research theories that explore the convergence of both domains. This convergence is becoming fundamentally important because new emerging virtual and augmented reality technologies are going beyond traditional modes of interaction with input devices like the mouse and the keyboard and are increasingly incorporating the use of natural gestures. This literature review will look into relevant materials that are associated with virtual and augmented reality interactions that predominantly connect to the study of ergonomics and natural hand gestures. Although the literature may present a variety of contexts, this paper will primarily focus on how hand gestural behaviours can affect, manipulate and navigate through interfaces and three-dimensional objects within immersive spaces.

2.1 VIRTUAL REALITY (VR) AND AUGMENTED REALITY (AR)

The idea of experiencing a dynamic world has been a subliminal vision for both digital and non-digital users. Virtual Reality is defined to have the objective of creating a virtual world where an individual is immersed while interacting with a portable or workspace device to simulate an environment. Such devices provide feedback to enhance the experience as real as possible (Boas, 2013). A classic example of virtual reality novelty is Morton Heilig's device called the Sensorama, which was built in 1962. It provided the user with 3D visuals, audio, haptic, and even physical wind simulations to provide an immersive experience. However such computers and devices were not affordable or accessible to general computer users until the development and release of a recent successful kick-starter project called the *Oculus Rift*.

Figure 2. Virtual reality CAVE experiences, Self-administer health care at home (Right) and a driving simulation with head-mounted displays (Left)

There are many differences and similarities between virtual reality (VR) and augmented reality (AR). The primary goal of VR is to present the illusion of experiencing another world i.e. an artificial world. VR is commonly known to be used for gaming and virtual worlds like *Second Life* and *IMVU* (Dede, 2009). Compared to VR, AR is much more commonly used with devices such as mobile phones or any other portable screen that has the capability to present graphical elements in real spaces. AR can provide users with a mixed reality experienced, where one is aware of their physical surrounding and can see virtual elements.

Due to recent advancements in processing power, AR and VR are no longer utilised for just gaming purposes but are also being integrated into many applications. These applications vary across a broad range of fields, such as medical, military training simulations, and educational. Thanks to the availability of Application Programming Interfaces (APIs), developers have created a range of different types of content, which present VR or AR experiences through commercially available portable and wearable devices. The upcoming release of Head Mounted Displays (HMDs) such as the Oculus Rift and Microsoft's HoloLens, will likely lead to the release of a growing number of AR and VR apps. HMDs are wearable devices in the form of goggles that provide users with fully immersive and or semi-immersive experiences. There are two categories of HMDs: video see-through and optical see-through. Optical see-through displays provide users with real world vision with an overlay of graphics, giving a holographic element. Video see-through displays, on the other hand, present the real world through videos on a screen (Zhou, Dun, & Billinghurst, 2008). In conclusion, both VR and AR share the main focus, which is on extending the human-computer interface (HCI) through sophisticated 3D graphics.

2.2 HEAD MOUNTED DISPLAYS – DEFINING IMMERSION

There are a few different ways for consumers to experience VR in various locations. One of the most common forms of experiencing a full immersion can be seen in the example of the "cave" (Figure 2), which is simply a projection on walls that simulate an environment around the user. Another form of experiencing VR is by the use of head mounted displays (HMD). Researchers and engineers mainly used these headset systems at institutes and very rarely were given to users outside the institutes for testing. The lack of public use of HMDs is due to the price factor and availability of these devices. However, with the upcoming release of the *Oculus Rift*, *Samsung Gear VR*, and other devices will soon be available for users at a reasonable price and provides developers to push further the evolution of immersive experiences.

Figure 3. (Left) Head tracking device (right) Oculus Rift Development Kit 2 (DK2)

The *Oculus Rift* supports another external device, which is called the Positional tracker (Figure 3), which gives the freedom to control their movement in a more realistic setting (Rubin, 2014). By having this freedom of control, it creates this intuitive behavioural change in immersive virtual worlds that inform programmers and researchers about what components of a user's experience create the highest levels of immersion (Takatalo, Nyman, & Laaksonen, 2008).

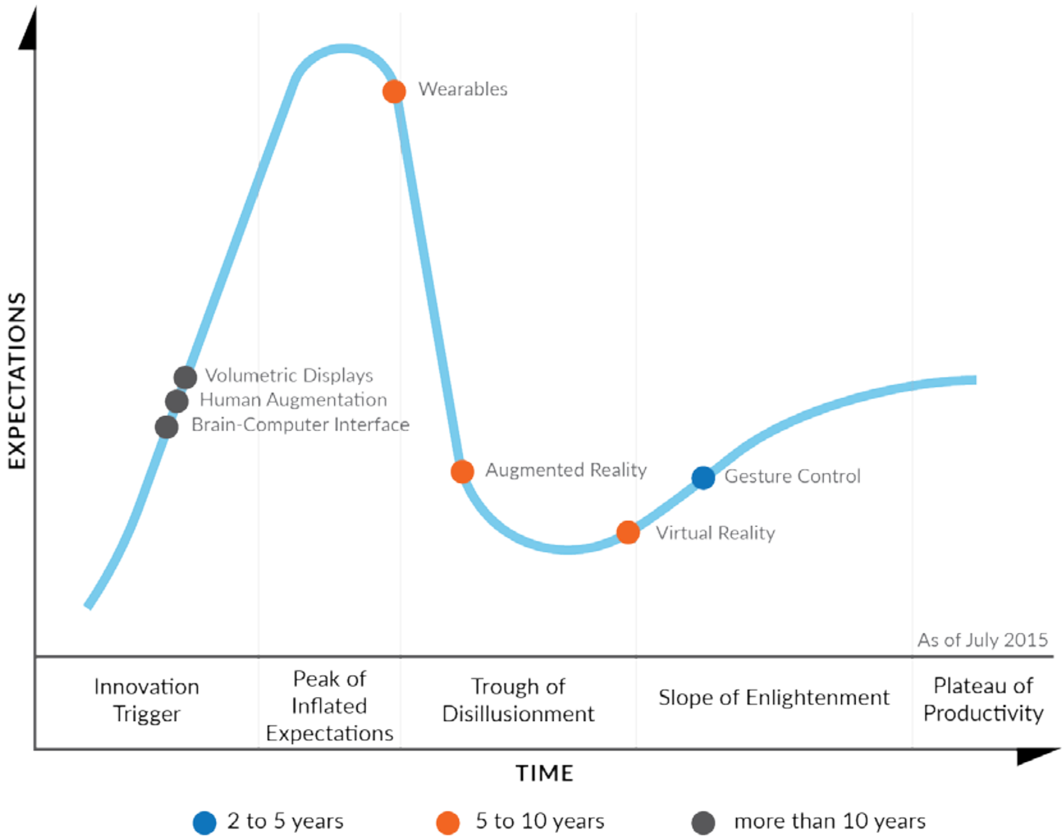

Figure 4. Gartner's (2015) Hype Cycle on emerging technologies

This current interest in HMDs can be explained with Gartner's (2015) Hype Cycle. Based on Gartner's methodology on emerging technologies (Figure 4), it is important to point the high expectations for wearables. Gartner has made several predictions regarding the HMD market, one of which is that "by 2018, more than 25 million HMDs will have been sold as immersive devices and virtual worlds will have transitioned from the fringe to the mainstream" (Gartner, 2015). This forecast emphasises what the potential market for VR and AR apps would be within the next 5 to 10 years. As seen in popular media and movies, such as Iron Man, Minority Report, there is a growing expectation that natural user interfaces (NUIs) will become well established (Wigdor, Wixon, 2011). A key element in NUIs is the use of natural hand-based gestural interaction (Lia & Kapri, 2013; Pavlovic, Sharma, & Huang, 1997).

After the release of the *Oculus Rift*, AR and VR gained traction in the gaming industry. From a research perspective Carter et al. (2014) presented four distinct paradigms of research on the topic of games: Operative, Epistemological, Ontological, and Practice games research. Their observation of Player-Computer Interaction (PCI) research, in particular, points to the experience of embodiment, which sets the context for NUI technologies that could impact the users' experience. Zhou et al. (2008) analysed research published in the ISMAR Proceedings and found that there has been an increase in the number of publications for mobile AR applications and trends regarding visualisation techniques but very little on the interfaces that are currently being developed for HMDs (Zhou et al., 2008).

2.3 MIXED REALITY (MR)

Mixed Reality (MR) is the combination of VR and AR. We can think of this in terms of "virtuality continuum" as seen in Figure 5 (Milgram & Kishino, 1994). Milgram and Kishino distinguish real objects as "any object that has an actual object existence" and virtual objects as objects that "exist in essence or effect, but not formally or actually." Researchers who focus on MR have been interested in exploring ways of creating relationships between the physical world and the virtual world.

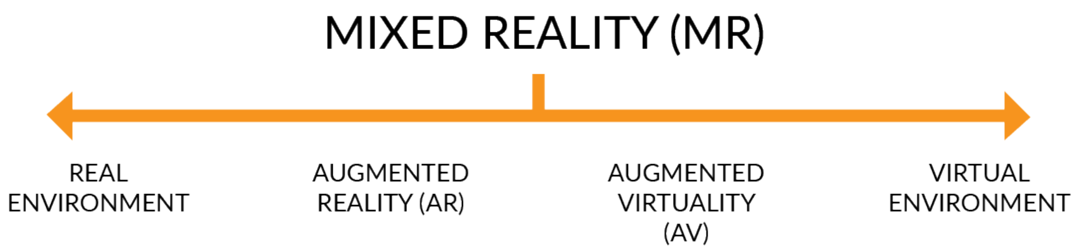

Figure 5. Representation of Milgram & Kishino's "virtuality continuum" (1994)

In relation to both domains (real and virtual), there has been research on the design and evaluation of menu systems, widgets and interaction techniques for immersive virtual environments (Bowman & Wingrave, 2001; Hand, 1997; Jacoby & Ellis, 1992), but there is little academic research on current user interface trends in MR immersive apps. The insufficient amount of research in this area is possibly due to a lack of literature on the design implementations in HMDs (Zhou et al., 2008).

2.4 GESTURAL INTERACTION – THE LEAP MOTION SENSOR

Along with recent developments in HMDs, there have also been progressions in hand/finger tracking devices. Based on Gartner's Hype cycle (Figure 4), shows an increasing demand for of gesture-controlled interfaces that share a high demand for more natural user interfaces (Kyoung, Lee, & Jung, 2007). The necessity of gestural use in interfaces emerges due to the increasing capabilities of information systems such as portable desktops, wearable technology and the current demand for more natural user interfaces (Pavlovic et al., 1997).

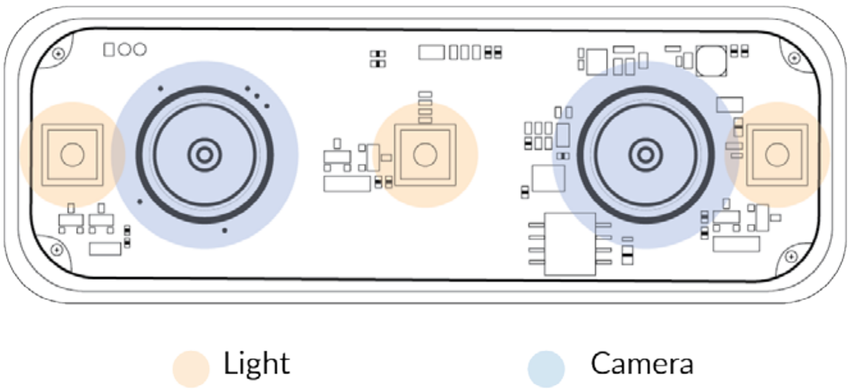

Figure 6. The *Leap Motion* sensor, illustration presenting the cameras (purple) and infrared LED lights (orange)

As this study focuses on the use of the *Leap Motion* sensor and the *Oculus Rift* headset, it is important to explore further how the device works and how it provides the user with the ability to perform in-air hand gestures to control and interact with UIs. Unlike other techniques and technologies for hand tracking that cost between the range of $5,000 - $10,000 (LaViola, 1999). The Leap Motion sensor is only $100 and tracks the user's hands without the need to wear gloves, giving the user a more natural feel when experiencing different applications. The device has two infrared stereo cameras which are the tracking sensors and three infrared LED lights (Leap Motion, 2015).

These sensors can detect joints and tips of a human hand when visible between 25 to 600 millimetres (Figure 6). The data is collected as live images via the infrared lights and camera that then stream into the computer. Once the hands and objects in the environment are captured, it is then analysed by their tracking algorithms which calculate the lights and depth in the imagery to track the finger tips other nodes in the hand (Figure 7).

With the combination of the DK2 and the Leap sensor, developers have the capability to direct these image captures into the HMDs using specific commands in the script code (Leap Motion, 2015). When the device detects a hand either its FOV, it sets that hand with a unique ID that is randomly generated. However, there are a few limitations with the device that could hinder the outcome of the user's experience. For example, if the fingers are pointed outwards, the sensors cannot pick up the fingers IDs, which can cause the tracking to glitch.

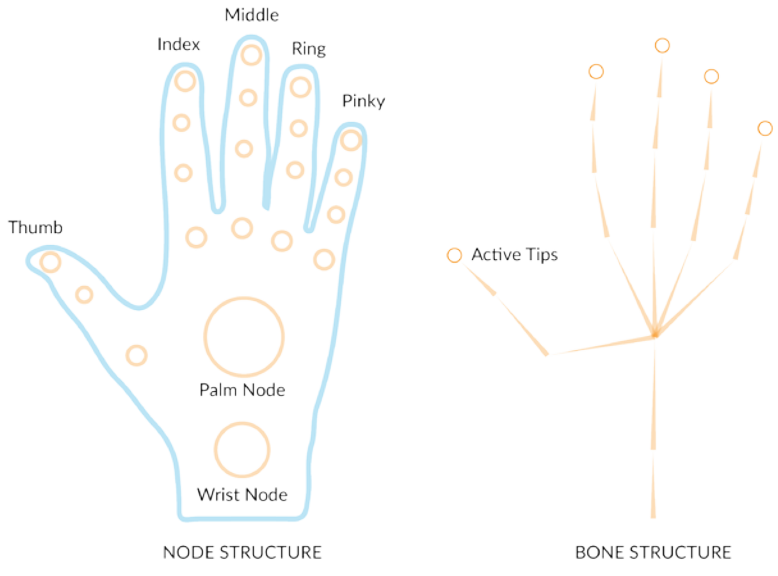

Figure 7**. Hand coordinates and nodes that are tracked by the Leap sensors**

Based on the API document provided by the *Leap Motion* community, there are three main pre-set hand gestural commands that are predominantly used in their apps that focus on VR:

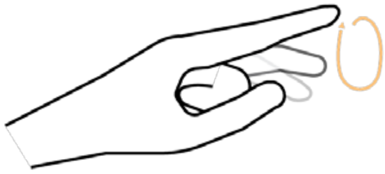

Figure 8. CircleGesture

A circular motion of the finger that is used to direct a user to rotate or highlight certain aspects of an object in the virtual/augmented simulation. Although some theories and experiments suggest that two-handed input is more natural than one-handed interaction when rotating an object (Ware & Rose, 1999).

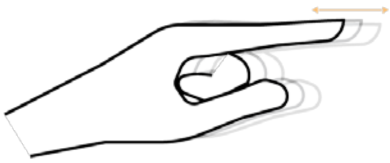

Figure 9. ScreenTapGesture

A forward tapping movement with a finger is mainly used to engage with certain doing actions, in which the system usually provides feedback to the user. This command is typically used as a selecting gesture, pointing towards the screen or open air gestures to command the “want” factor, prompting a doing action.

Figure 10. SwipeGesture

A straight line hand movement with fingers extended out. This command currently is used for swipe navigation and object manipulation. The sensor can pick this movement up by a quick scan of the hand skeleton joints that illustrate the position and tracking of the hand.

2.5 OBJECT MANIPULATION

When users experience immersive virtual environments (VE), they are introduced to a third dimension, X, Y and **Z** (Depth values that determine the distance). This new dimension creates a unique way of interacting with virtual objects. Mine, Brooks & Sequin (1997), present three forms of body related interactions, direct manipulation – using your body to control the manipulation, physical mnemonics – ways to store information relative to the body, and gestural actions – using body related measures to perform commands. In this study, we look into the linking point between direct manipulation and gestural actions which users will perform as commands. One of the reasons why object manipulation in immersive VEs is difficult to perform is due to the lack of touch. The lack of touch causes users to struggle with sense of collision and spatial perception (Mine et al., 1997).

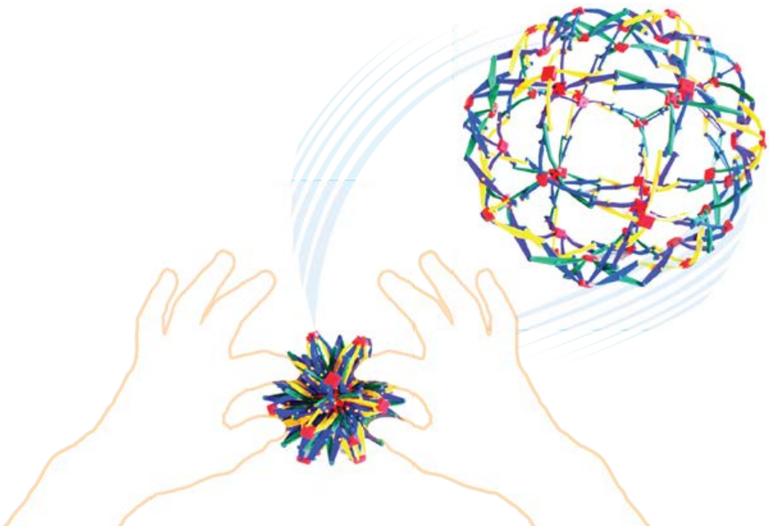

Figure 11. Hoberman sphere, expanding and compressing through gestural interaction

Scaling an object is one of the most frequently used commands on flat screens and desktops, minimising windows and expanding of menu systems. An example of a physical object that can be scaled up and down is the Hoberman Sphere (Hoberman, 2003). The way the Hoberman sphere is designed, it prompts the user to grab the joints and hold it (Figure 11), performing a natural motion of expansion to increase the diameter.

2.6 MULTITASKING

Multitasking is one of the abilities that consumers feel is most productive and useful when given the ability to view more interfaces in a larger workspace. However, to apprehend multitasking, it is important to understand the core element that drives effective multitasking. The core element is the ability to pay attention (Rosen, 2008). Attention is the ability of a person to shift and maintain their focus onto what's most important. For example, psychologist and philosopher William James states that attention "is the taking possession of the mind, in clear and vivid form, of one out of what may seem several simultaneously possible objects or trains of thoughts…it implies withdrawal from some things in order to deal effectively with others."

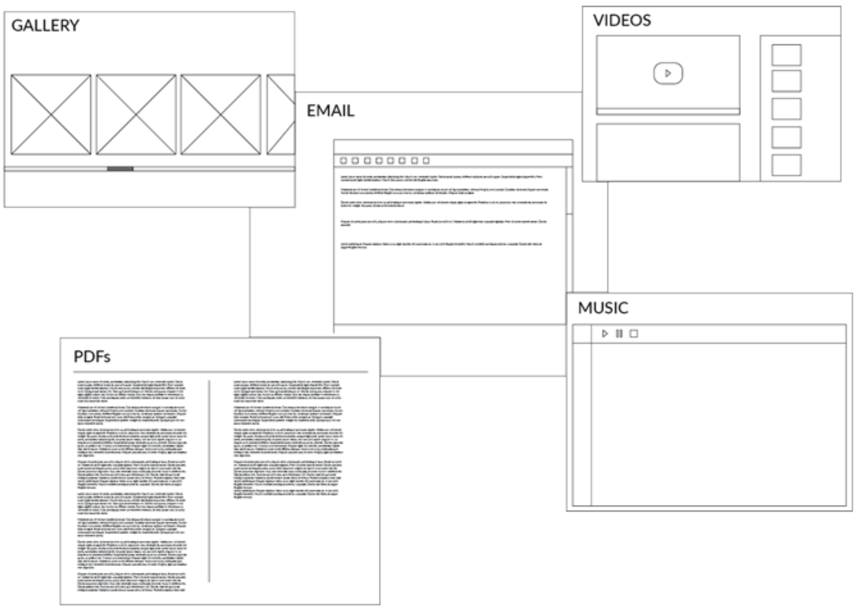

Figure 12. Multiple tab windows with different activities

As mentioned above, attention is the core necessity for multitasking. There have been experiments that are based on cognitive psychology, focusing on dividing attention between simultaneous occurring tasks. These experiments present subcategories that support multitasking which include memory, perception and attention (Hembrooke & Gay, 2003). Multitasking can be defined as the action of when an individual is doing more than one attended task simultaneously. For example, there are situations when a user would be experiencing interface layouts as seen in Figure 12 when writing an email but at the same time attending an online conference chat. There are studies, which report that instant messaging is one of the most common activities that users engage with when doing other computer-based activities (Grinter & Palen, 2002). Some studies that show many negative outcomes from multitasking due to constant switching, which causes lack of attention (Rosen, 2008; Wallis, 2006).

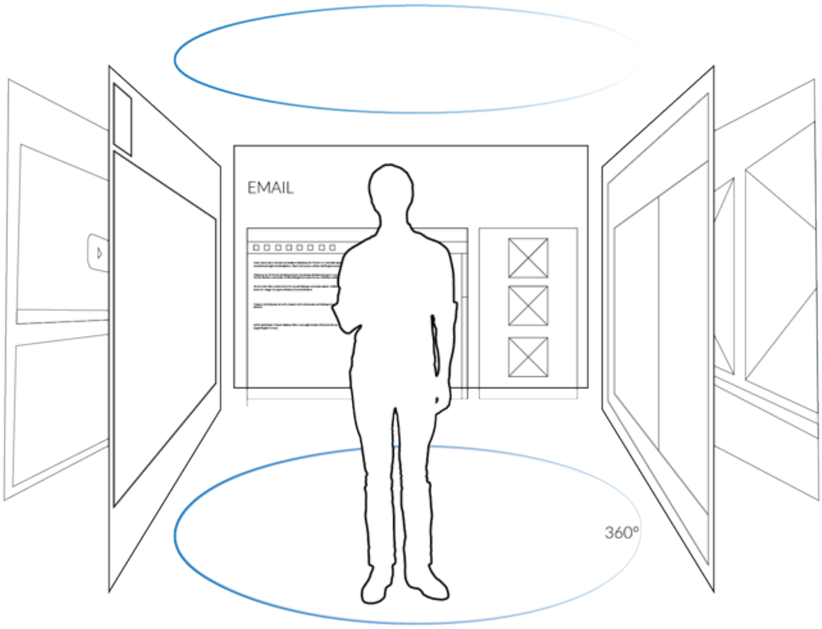

Figure 13. Immersive tab system space overview

However, there are also studies that show positive results for young students who benefit from multitasking and show improved performances (Dzubak, 2007). Dzubak has also stated, "Focus and attention are the keys to efficient and successful task completion". In conjunction with successful task management, one of the most socially active community for MR is on *The Leap Motion* community (Colgan, 2015). According to the developers at the *Leap Motion* community, multitasking can show 40% improvement in productivity as VR and AR provide a large canvas (Colgan, 2015) (Figure 13). Within these immersive environments, there have been experiments with three-dimensional interfaces which propose similar to window management compositions as seen in Figure 12 and 13 (Tomitsch, 2003).

2.7 EVOLUTION OF USER INTERFACES

As technology is advancing with innovative portable devices that are entering the market, it provides new capabilities for users. To further understand the progression of the interaction between computers and humans, it is crucial to understand/analyse the progression of user interfaces (UI). One of the initial interface designs for computers is the command line interface (CLI), which is still currently incorporated in digital computing.

2.7.1 Command-line Interface (CLI)

Early computer interfaces are built around the concept of input prompts, commands and system status. These were primarily presented as text (no images) and known as text-based interfaces (Figure 14) (Shedroff & Noessel, 2012). Users could not just type any set of phrases; there were meant to be set directorial commands which had to be typed in a certain set of words (Figure 14). Only a certain percentage of users who have the technical skills and mainly programme have the characteristics of recall to be able to prompt executable commands.

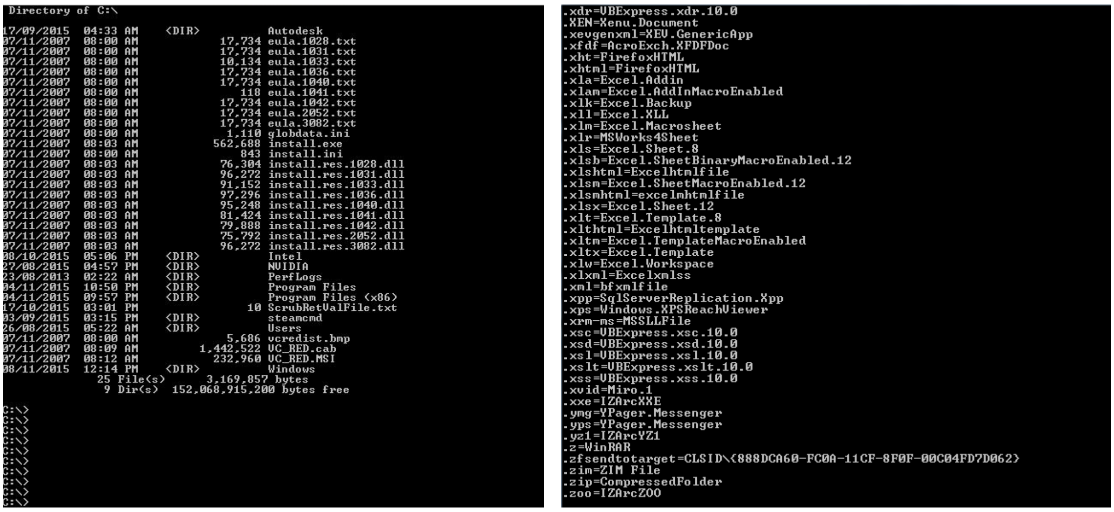

Figure 14. (Left) Command Line Interface (CLI), (right) command line prompts

The CLI is a primary example of an interface which contains presents commands (i.e., instructions telling a computer to do something/perform a task) are typed in by the user. For example, users have to press the ENTER key after typing in a command which then gets interpreted by a programme (Linfo, 2007).

Despite command line interfaces being the first form of visual computational representation between human and computer, it is still being used within graphical user interfaces (GUIs).

2.7.2 Graphical user interface (GUI)

Interfaces that moved beyond CLIs are considered as GUIs. These primarily include WIMP (windows, icons, menus, pointing devices) along with other elements such as buttons, typography and other graphics. For example, a user has the visually avaliable option to click on a menu button which then presents the menu system. They are not required to memorise all the options in the system and they are visually available as buttons or tabs (Figure 15).

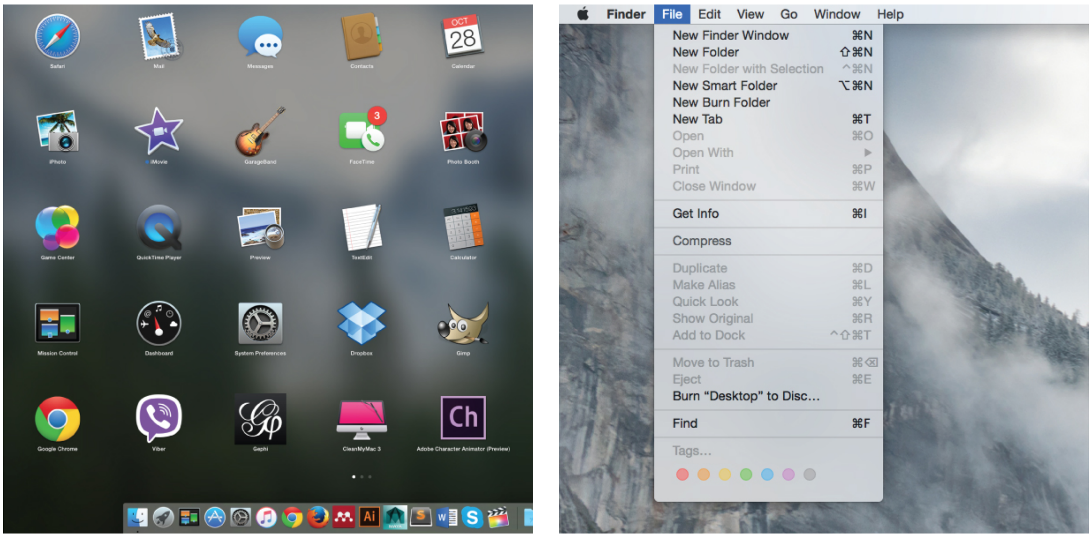

Figure 15. (Left) Mac OS graphical user interface with icons, (right) drop down menu system

Based on the current documentation, It is often suggested that GUIs are more intuitive than CLIs, and can be true in many situations (Linfo, 2007). These situations can vary from different tasks that can be performed by a user. For example, it is easy for a novice user to copy and paste documents in different locations by using direction manipulation with a mouse, rather than having to remember the steps of how to copy a single file. In this case, users would have to enter the copy prompt, followed by the file path and selecting the new destination for the copied file. As described in the previous section about multitasking, GUIs allow users to take full advantage of this by providing users the ability to view multiple programmes and/or multiple instances of single programes that are capable of running simultaneously (Wigdor & Wixon, 2011).

2.7.3 Natural user interface (NUI)

Further expanding from GUIs and WIMP that present graphical icon representations of information, NUIs show information as objects in space. NUIs present a strong influence for human intuition, which is refered as the aspect of "instead of what you see is what you get, NUIs rely on our innate sense of the physical world where what you do is what you get" (Hinman, 2012). Examples of such interactions can be found in touchscreen tablets, when users are minimising, opening or shifting on applications.

According to (Wigdor & Wixon, 2011), a NUI should not be considered to being a natural *user interface* but instead an interface that makes the user act and feel like a natural. Furthermore, NUIs primarily allow users to perform various gestural interactions such as pull, grip, tap and more, rather than direct input via devices such as keyboard and mouse. Based on recent studies, the execution time for each task can vary and be predicted (Erazo & Pino, 2015; Hespanhol, Tomitsch, Grace, Collins, & Kay, 2012).

Figure 16. (Left) Touch screen interface (Hinman, 2012), gestural manipulation, (right) Body movement interaction for navigation (Huckaby, 2013)

Speech recognition has been considered in many applications and systems. Providing users with the ability to navigate and instruct a system with their voice can be a powerful tool. However, many researchers and theories state that it can cause many conflicts within public spaces that may cause contradicting actions (Gilliek & Coz, 1989; Shneiderman, 2000).

Since NUI systems are an emerging paradigm for digital interaction, there are a few essential principles that are currently available for developers and designers to consider. These principles for NUIs have been written and tested by many developers and designers. For example, Dan Shaffer’s book called Designing Gestural interfaces (2008) presents a few fundamental principles of NUI design. Some of these principles look into “Attraction affordance” (Saffer, 2008), which states that users should be introduced to simple gestures to get them using the system. “Avoid unintentional triggers” (Saffer, 2008), which refers to the idea of preventing any accidental triggers that could interfere with users’ natural day to day movement.

In relation to these principles, there have been other principles which cover similar theories. Rachel Hinman's book The Mobile Frontier (2012) which presents principles by Wixons (2008) presentation on the evolution of UIs. These principles for NUIs that also look into the following:

- **Performance Aesthetics –** Presenting users with the joy of performing, presenting positive experiences.

- **Direct Manipulation –** GUIs have indirect manipulation with a keyboard and mouse. NUIs, however, will allow users to manipulate objects directly with gestural interaction.

- **Scaffolding –** Actions and prompts will unfold to the user through their actions in a natural way.

- **Contextual Environments –** The environment can guide and suggest the interaction, rather than having fixed graphical elements for every task.

- **Super Real –** Interactions that present a sense of 'Magic' where the user can stretch to zoom into elements or swipe to change applications, rather than GUIs that are conventional to Windows management systems.

- **Social Interaction –** NUIs are simpler and require less cognitive focus. Unlike GUIs which present extensive amounts of menu options, menus on NUIs are efficient.

- **Spatial Relationships –** Information is presented through objects, rather than visual icons like GUIs.

- **Seamlessness –** Reducing the barrier between users and the information system. Effective uses of gestural UIs to seem more intuitive.

2.7.4 Organic user interface (OUI)

Based on guidelines and theories by Ghalwash & Nabil (2013), OUIs have three main design aspects that contribute to the overall aspect of interaction. (A) Natural, intuitive feel – user must be able to behave with virtual objects as if using everyday real world objects (Ghalwash & Nabil, 2013). Ghalwash & Nabil (2013) mention that "designers should think of an organic interface as part of the whole ubiquitous computing environment, designing the system with the most natural interactions capable for human." (B) Organic, fluid look – the interface does not just include shapes but also uses the incorporation of colour and texture as well. (C) Context-aware, calm design – should be designed using ubiquitous and calm design elements when objects or interfaces are not in use. Organic user interaction is not only dependent on touch and manipulation of physical objects, but also includes in-air gestures and also speech inputs.

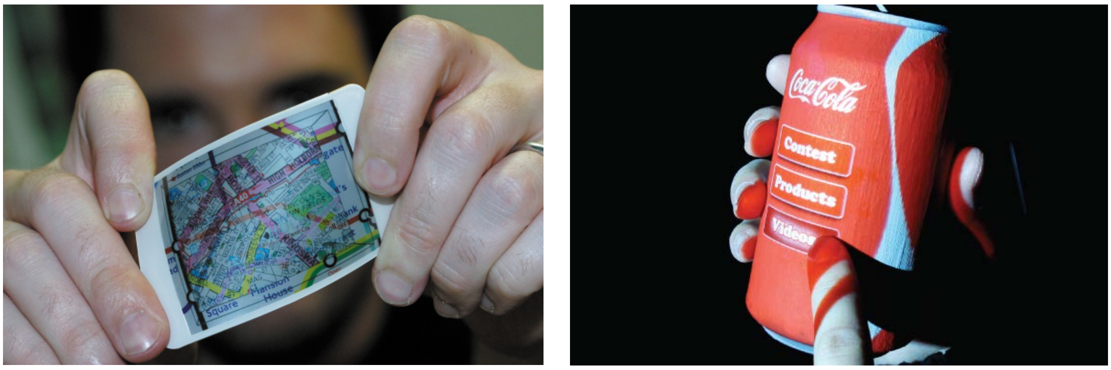

Figure 17. (Left) A credit- card mock-up (Hinman, 2012), (right) projected interface on hard surface (Superdiddly, 2010)

2.8 IMMERSIVE MENU SYSTEMS

VR and AR have been part of the digital computing age for a long time. There has been sufficient amount of research and ideation that has shaped the way menu systems would work within these two realities. One of the first menu systems that were used in virtual environments (VE) was the pull-down menus which floated in 3D space were interacted with ray-casting interaction techniques (Bowman & Wingrave, 2001). Based on the current existing content of UIs there are a few existing types of menu systems such as Floating menu systems, which was commonly used with on wall projection or presented on tablet-based screens (Figure 18). Further research into these floating menu systems presented insight which showed that it was only easy for expert users to use; novice users found it very challenging to understand the 3D depth in which the user interfaces were presented.

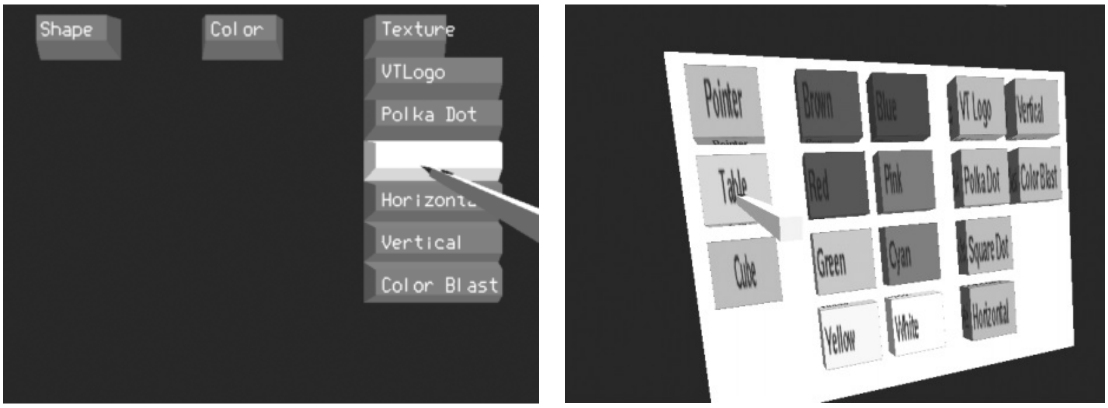

Figure 18. (Left) Floating menu system being used with a tool for interaction, (right) tablet interface projected on a physical surface (Bowman & Wingrave, 2001)

The second type of UI was based on point system navigation that consisted of using additional input devices/tool for navigation and control (Figure 18). By using external input devices, it provided easy haptic feedback which further reinforced the element of touch. The third type of UI is the embodied systems, which relied on the use of the user's physical body to generate the UI. For example, the Three-Up Labels in Palm (TULIP) menu system was based on the utilisation of the hand for navigation and interaction. Users are able to visualise menu tabs that appeared on each finger, which meant that users would have the ability to present the UI on one hand while their other hand could be used for interacting and corresponding with the system.

According to Bowman and Wingrave (2001) the TULIP menu system presented a few constraints on the amount of content that could be visual for selection. For example, five fingers provided only room for five tabs (Figure 19). This brought on the development and incorporation of the Scrolling menu prototype which enabled the user to scroll on a text that appeared in the centre of their hand. The majority of the interaction were performed by pointing and flicking through each tab. There has been additional research that also looks into the hand-menu system, which presents more tactile feedback (Lee, Choi, Oh, & Park, 1999; Sasaki, Kuroda, Antoniac, Manabe, & Chihara, 2006).

In relation to the TULIP menu system, it can be seen as the experience of UI embodiment. Many computer scientists and HCI researchers like Dourish (2001) have observed and studied “embodied interaction”. He explains, “By embodiment, I don’t mean simply physical reality, but rather, the way that physical and social phenomena unfold in real time and real space as a part of the world in which we are situated, right alongside and around us…Interacting in the world, participating in it and acting through it, in the absorbed and unreflective manner of normal experience.”

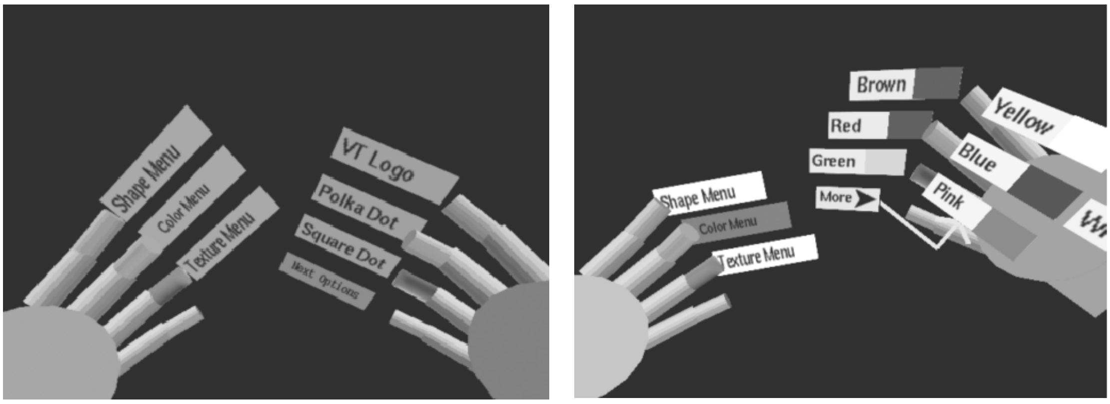

Figure 19. (Left) Three-up menu prototype, (right) the TULIP menus with modifications

2.9 SUMMARY

This background and literature review has investigated current types of UIs and presented with the main existing principles. Researchers have also presented many theories and documentation that look into immersive interactions with gestural. However, despite the evolution of human-computer interaction (HCI) and virtual displays, there is a gap to be further analysed, especially with the current apps that have been developed for MR experiences in immersive virtual environments (VE). This research focuses on the contribution towards this gap which provide the opportunity to examine possible characteristics in current immersive apps that are hindering a more natural user experience. Despite the current principles for NUI systems and principles for the *Leap Motion* device, they provide a clear indication on further analysing other key factors that will be provided from the observational study (5. PHASE 2: USER BEHAVIOURAL STUDY).

3. METHODOLOGY

In order to achieve the primary aim of this study, the following phases were conducted that look into the usability of current apps, the analysis of what felt intuitive/natural and what issues were raised during the experiences. These findings can further help guide app developers to think about better ergonomics, reinforcing system feedback and intuitive object manipulation through gestures. These results could also be implemented to improve the interactions within the selected apps from the *Leap Motion* and *Oculus Rift* community. The following methodology involves three phases. Each phase plays an important part in answering the research questions formed in this study.

3.1 PHASE 1: TREND ANALYSIS

Phase 1 focuses on an independent study by researchers which is based on analysing the top 10 most popular apps available on the *Leap Motion* market. In total, there are around 49 applications. However, in this analysis the selection is narrowed to the top 10 most viewed apps. These apps were selected after being marked against Coomans and Timmermans (1997) definition of virtual reality user interfaces (VRUIs).

After selecting the ten apps, the next step in this phase was to analyse the current trends in the UIs for each app against individual characteristics of the four types of UI by Wixon (2008). By undergoing this analysis, it presented us with characteristics that were missing in current demo apps on the *Leap Motion* community which could potentially lead towards a more positive NUI and OUI experience. This stage was critical for the research study because it provided the initial foundations of the existing flaws which many hinder full immersion. It also provided insights into new alternatives for novel implementations.

3.2 PHASE 2: USER BEHAVIOURAL OBSERVATION

The focus of this phase is to analyse and observe how digital interfaces and 3D objects can be manipulated and interacted with by using natural hand gestural commands. This test included five applications that had looked into menu systems that present (a) navigations performed by hand gestures that focus on 3D objects in the environment, (b) exploring and understanding a dataset, and (c) interaction with widgets/buttons and legibility of text within augmented interfaces.

During this study, the user was provided with a swivel chair to sit on when experiencing the virtual headset. It is important to point out the type of chair in which the user was seated in during this study as they were NOT provided with a fixed chair. This seating arrangement gave users a much easier way to move around and rotate their body without much effort.

Also, to provide the best possible experience for the users, the observations were held in the Mezzanine, which is located in the Faculty of Architecture, Design and Planning at the University of Sydney. This lab space in the Design Lab is used mainly for researchers to conduct user studies and experiments.

The reason for running the user study in the Mezzanine was because it is a dark room that provided the *Leap* sensor to perform to its best capabilities. The *Leap Motion* sensor is sensitive to bright light can could have reduced the performance of the applications.

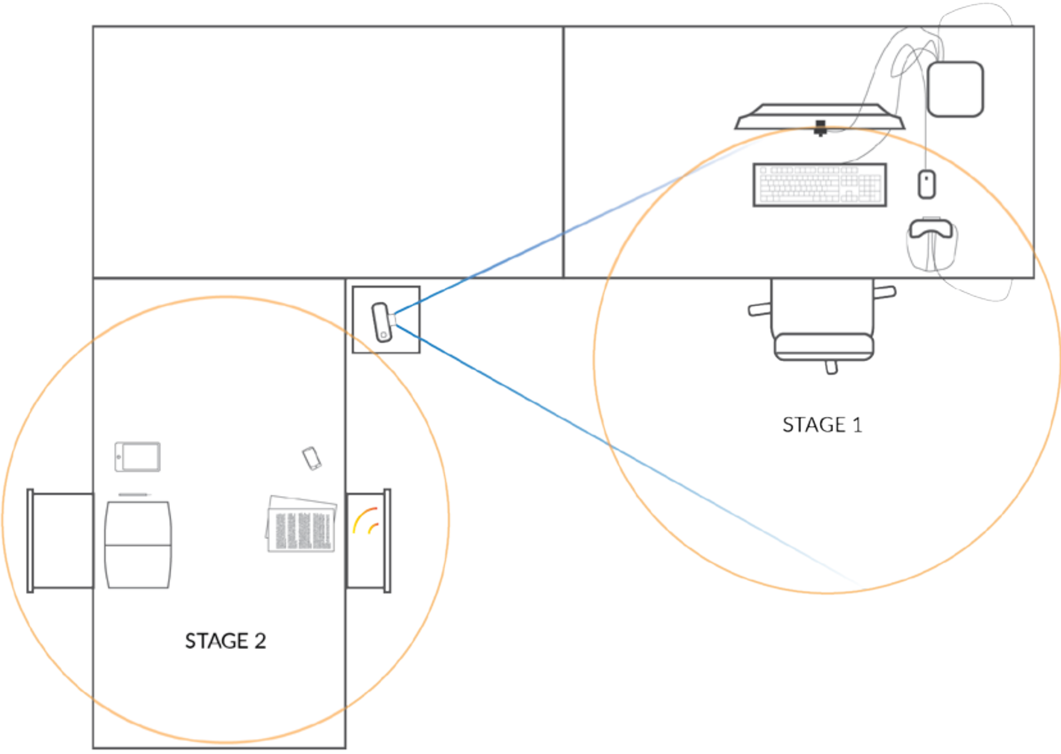

Figure 20. User study setup in the Mezzanine space

The following five apps were included in this study:

1. Widgets
2. Brain connectivity
3. Planetarium
4. Soundscape VR
5. Hovercast VR menu

Phase 2 focuses on testing existing material and content provided by the *Leap Motion* market. However, in comparison to the previous phase, this phase focused on the observing the participants. These participants were recruited at the university via seeing advertisements around the campus (APPENDIX C). During this stage, the participants got to experience existing content that is currently being used by developers and digital users who own HMDs. This phase is critical for the research study because it presented existing flaws and new alternatives for novel implementations and most importantly, present themes that arose from the study.

Participants were first provided with the participation information statement (PIS), which provided them with all details about the study that took place in Phase 1 and details about Phase 2. After reading this statement, they were further given participant consent form (PCF). Once the participant agreed to the terms and conditions of the user research test and signed the form, they were provided with a pre-study questionnaire. The questionnaire asked the user for their age group, sex, ethnicity, which devices they use on a daily basis, and if they had experienced VR and AR before this study (APPENDIX A).

Upon completing the pre-study questionnaire, the participants were given 5 to 10 minutes to adjust to the HMD and get comfortable. Once the participant agreed to continue further, they were introduced to the first app. The first app was based on the use the *Oculus Rift* headset to navigate and interact with the UI presented in the app. As the participant began to interact with the first app, the participant was once again be reminded that the study is on the app and not the participant. They were informed that they are not being judged based on their performance in the study, but only observed for further improvements within the digital experience of the app.

At this stage, the audio and video recordings started as the participant would interact with their first application. Upon completing the first app, they were introduced to the following five apps. During their interaction with these apps, the participants were also asked to think out loud (Van Someren, Barnard, & Sandberg, 1994) when experiencing each app. The method of think out loud is a crucial part of the observational study as they expressed which form of buttons or slider widgets were most useful or easy for interaction. After the completion of the experience, the participants were asked to be interviewed. The interview consisted of three categories, first impressions, usage and evaluation. These categories have sub-questions as seen in APPENDIX B.

This phase took approximately 1 hour and 10 minutes (per participant), which gave participants enough time to not rush or feel pressured into completing quickly. Also at any point in this study, participants were instructed that they could leave at any point if they started to feel any discomfort or illness.

3.3 PHASE 3: GUIDELINES

After conducting the studies in Phase 1 and 2, all the data collected from them are extracted and further categorised to produce final guidelines that complement current principles provided by *Leap Motion* community and researchers on NUI systems.

This phase contains two parts: Part 1 is about the development of the following guidelines that were created from the trend analysis and observational study. These are further explained on how to achieve and follow these guidelines. Part 2 focuses on the evaluation of the guidelines and its implementations in an application to further support the purpose and functionality for each of the guidelines.

3.4 DATA ANALYSIS

The data collected from Phase 1 and Phase 2 include quantitative data (age, sex, ethnicity, device uses) and qualitative observations, (comments, interview transcripts). These were analysed and transcribed to see what types of UIs hand gestures fit particular commands and also give a better understanding of any disturbance or unclear design choices within each application. Throughout Phase 2, participants were recruited from the University of Sydney. Although there was no particular age range required for the study, the participants averaged between the ages of 18 – 27. Also, participants included both male (5) and female (5) (Figure 28).

Figure 21. Infinity diagram with transcripts printed out and grouped.

Participant filled out the printed pre-study questionnaire before interacting with the applications. The collected answers were digitised into an Excel sheet for statistical analysis. Participants were also filmed while engaging with the apps. The video recording were watched solely by the researcher and notes from the viewing are used to collect additional data that is beyond the scope of the questionnaire such as, the time taken to achieve a task or part of and mainly to capturing specific hand gestures and their body language and spatial use.

All of the qualitative data from the 10 participants have been transcribed and grouped in an infinity diagram. This diagram is based on the three sections of the interview questions (First impression, usage, evaluation) (Figure 21). After grouping all responses, the transcripts have been further grouped based on the findings of common and unusual themes.

3.5 PILOT STUDY

Before undertaking any user behavioural study (Phase 2), a pilot study was conducted in order to identify any significant/minor flaws in the methodology. The pilot study followed the same procedures as outlined in the proposed methodology.

During the pilot study, there were a few technical issues:

1. Some of the apps were not compatible with Mac computers and required a Windows platform. Despite the machine having the facility of Boot Camp installed on the computer, it would still require restarting the system for individual apps. This caused many inconveniences and led to distractions during the pilot study. Therefore, it was essential to convert all apps to be compatible with one platform, in the case of this study a Windows operating system is used.

   In order to convert the apps, it was important to have the source code for the app to be executed to the required platform. However, not all apps could be converted to Windows as not all the developers for the apps provided their source code to be publicly used.

2. The applications that ran on Mac also didn't go full screen to match the resolution of the Oculus Rift DK2 headset. This change in resolutions caused some limitations to the choices of apps that could be analysed. This issue was further resolved by recompiling the applications that would provide a custom resolution setting to fit any screen size.

3. Due to the latest update on Windows, the DK2 headset now has a default setting which directly projects into the headset, rather than presenting it on the desktop screen. The reason for this setting change is so that it stops the switching of resolution size between the computer screen and the headset. However, this made it challenging to capture the experience users were going through when recording them from outside of the app experience.

4. The cables for the HMD and the computer were getting tangled up and getting in the way of the participant. Precautions were taken by managing all wires to be out of the way of the user's area of interaction. By sorting out the wires of the HMD, gave the participant ease of movement without having the wire getting stuck or interfering the experience.

These four issues that were discovered during the pilot study was resolved before conducting Phase 2 which focuses on user behavioural observations. In addition to this study, further observations of prototypes took place during events such as open day and graduation shows. During these events, none of the users were recruited or forced into taking part. Each individual attempted to explore the prototypes based on their own interests and desire.

4. PHASE 1: TREND ANALYSIS

Before conducting user tests on current applications, we[1] carried out an independent study that focuses on the top most viewed applications on the *Leap Motion market* for MR and analysed them against the characteristics of the four types of UIs by Dennis Wixon (2008). These characteristics for UIs have also been further described and analysed by Rachel Hinman (2012). This analysis uses the *Oculus Rift* DK2 and the *Leap Motion* sensor. With the combination of both these devices, users are able to experience real-time imaging of their surrounding physical space.

4.1 METHOD

Some of the popular marketplaces for apps, such as *Google Play* and Apple's App Store, provide users with apps that include VR and AR experiences. However, there are very few apps that offer MR user interfaces for HMDs. We, therefore, focused on analysing applications that are currently available on the *Leap Motion* market. During the time of undergoing this independent study, there was a total of 49 apps available on the *Leap Motion* market that offered support for the *Oculus Rift*. These apps span across different categories: games (19 apps), simulation experiences (19), UI (6), virtual networks (1) and visualisations (4).

Many of these apps offered no or little user interaction mechanisms with menu or interface systems. For example, only immediately after launching the app and subsequently progressing to a pure simulation experience in VR. In order to determine which apps should be considered for our analysis, we used Coomans and Timmermans' (1997) definition of virtual reality user interfaces (VRUIs) to narrow down the choice of applications for the analysis. Coomans and Timmermans state four categories that define VRUI:

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[1] "We" is used in this thesis to acknowledge the input from supervisors and mentors, even though the actual work was carried out by the author of this thesis.

1. **Interaction** - The application should present a form of natural user interaction.
2. **Immersion** - The experience in the application must have full body immersion or partial immersion.
3. **Simulation** - Visual, acoustic, and haptic simulation; also scientific simulations and virtual prototyping.
4. **Visualisation** - Making native non-visual information visual.

After evaluating the apps against Coomans and Timmermans' (1997) criteria, we arrived at a list of 16 apps. From this list, we selected the ten most viewed apps for further analysis (Table 1). There was an additional app that was currently on the *Leap Motion* market (VR Cockpit) that presents hybrid interfaces. However, this app could not be analysed as the executable file was not available to the public. The final selection of apps spanned a range of categories, which was important, as HMDs are not limited to gaming experiences. The apps, therefore, give a good representation of the variety of tasks supported through MR interfaces, from medical data visualisations, to interface navigations and virtual walkthroughs. All the apps below have been recorded and tested on the 19th September 2015.

App #	Application Title	Views	Categories
1	Brain Connectivity	1,200	Visualisation
2	ElementL: Ghost Story	1,600	Game
3	Firework Factory VR	847	UI
4	Hovercast VR Menu	5,400	UI
5	Planetarium	12,900	Visualisation
6	Sorcerer VR	1,900	Game
7	Soundscape VR	1,400	Visualisation
8	Widgets	11,700	UI
9	World of Comenius	5,000	Visualisation
10	WrenAR VR/UI	895	UI

Table 1. The ten top viewed applications on the Leap Motion market (in alphabetical order) that involve some form of VRUI and their associated categories as listed in the Leap Motion market.

To further assess these apps, we used the categories and characteristics presented by Wixon (2008) (further described in Hinman 2012). Wixon proposes four progressive user interfaces: command line interfaces (CLIs); graphical user interfaces (GUIs); natural user interfaces (NUIs); and organic user interfaces (OUIs). Properties associated with each of these categories are outlined in Table 2.

In the next section, we compare each app against these characteristics and determine the most common UI types across all apps. All the authors jointly analysed and evaluated the apps, by applying the taxonomy to the specific characteristics of the apps.

	CLI	GUI	NUI	OUI
Characteristics	Static	Responsive	Evocative	Fluid
	Disconnected	Indirect	Unmediated	Extensive
	High – Low	Double Medium	Fast Few	Constant Zero
	Directed	Exploratory	Contextual	Anticipatory
	Recall	Recognition	Intuition	Synthesis

Table 2. Interface types and their characteristics presented by Wixon (2008)

4.2 TAXONOMY - RESULTS

Following the method that was proposed in the previous subchapter which explains the steps taken in order to present our findings. Figure 22 presents the ten apps in terms of Wixon's (2008) properties and categories. In this section, we discuss these properties, categories and their occurrence in the apps.

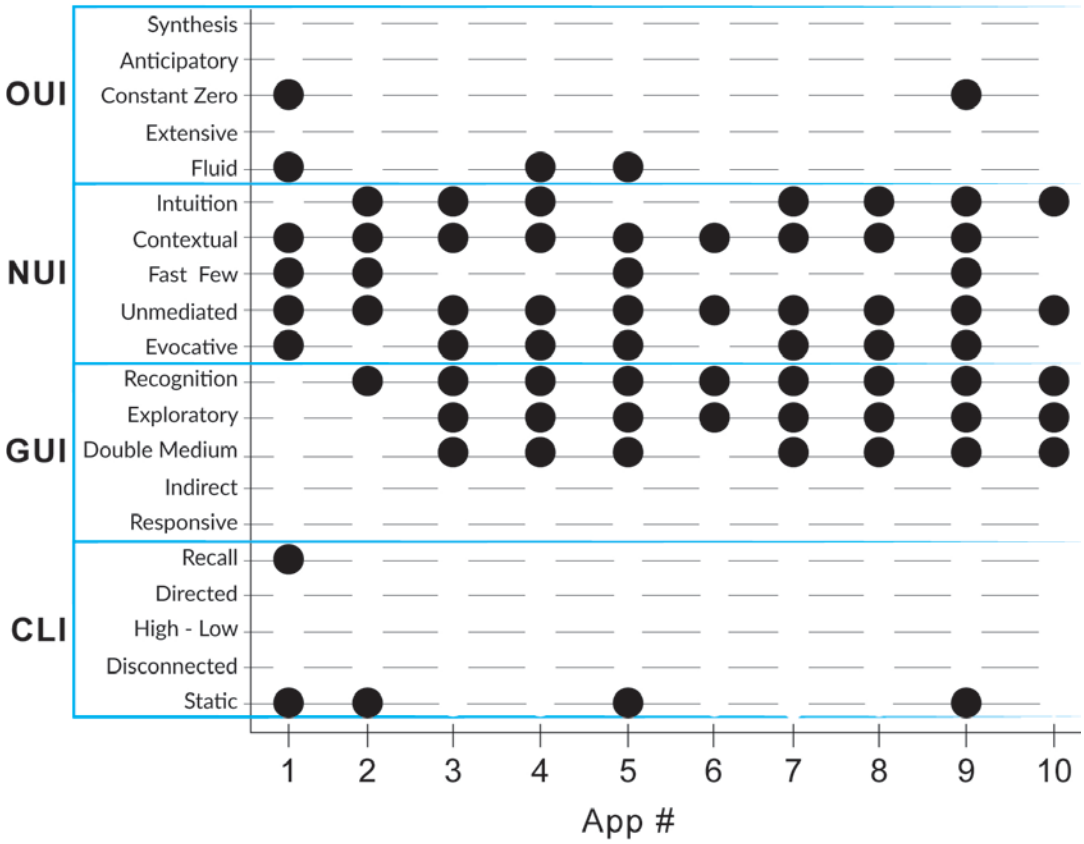


Figure 22. Comparison of apps against the characteristics for each UI types (left column). 1 = Brain Connectivity, 2 = ElementL: Ghost Story, 3 = Firework Factory, 4 = Hovercast Menu, 5 = Planetarium, 6 = Sorcerer, 7 = Soundscape, 8 = Widgets, 9 = World of Comenius

4.2.1 Command Line Interface (CLI) characteristics

As described in the background chapter, CLIs are considered as the first generation of computer interfaces. According to Wixon (2008), CLI has five characteristics: *static*, *disconnected*, *high-low*, *directed* and *recall*.

Our analysis revealed that four of the ten apps presented static characteristics, which refers to the system having to wait for the user's input in order to proceed to give feedback and continue with the application. This was experienced in apps 1, 2, 5 and 9. For example, App 1 has a long list of text that the user has first to read through in order to be prompted to press enter to start the application (Figure 23).

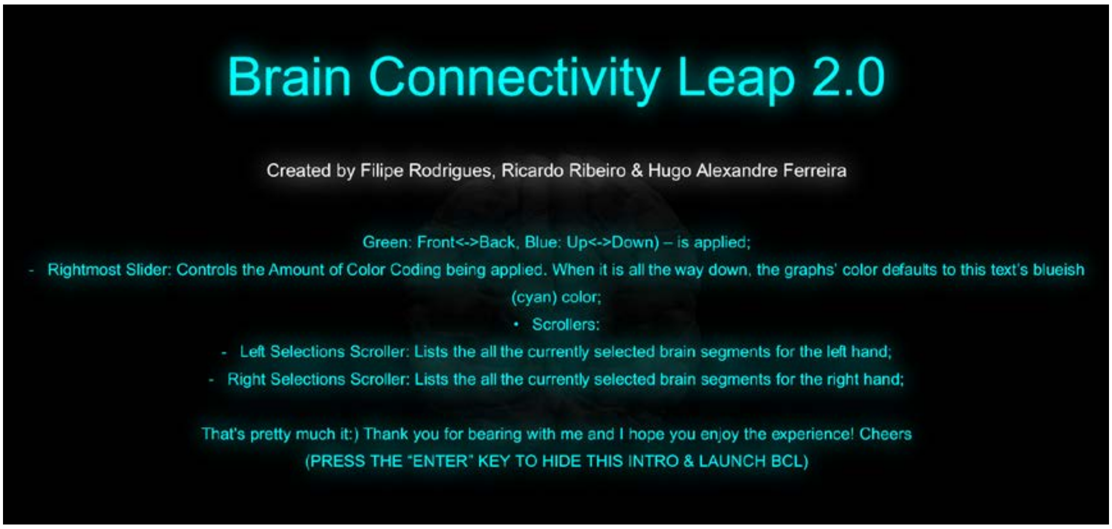


Figure 23. Screenshot of App 1 (Brain Connectivity) with initial text loading.

App 1 was further built around the psychological function of recall, which refers to users having to remember all the commands from memory to use the system. For example, all the hand gestural commands were described in text form at the start of the application but once immersed in the experience, it required users to recall all the hand commands for interaction. If the user fails to remember the gestural commands, there is no possibility to bring up instructions or a help page.

None of the apps showed any of the following characteristics: directed, meaning being text-based and highly dependent on the user. Despite the first app presenting a heavy text load at the start of the application, it still wasn't built around the overall use of text input throughout the experience. High-low, describing a high number of commands but a low number of interactions; and disconnected, suggesting that users have to prompt commands, such as setting directories and showing lists of files.

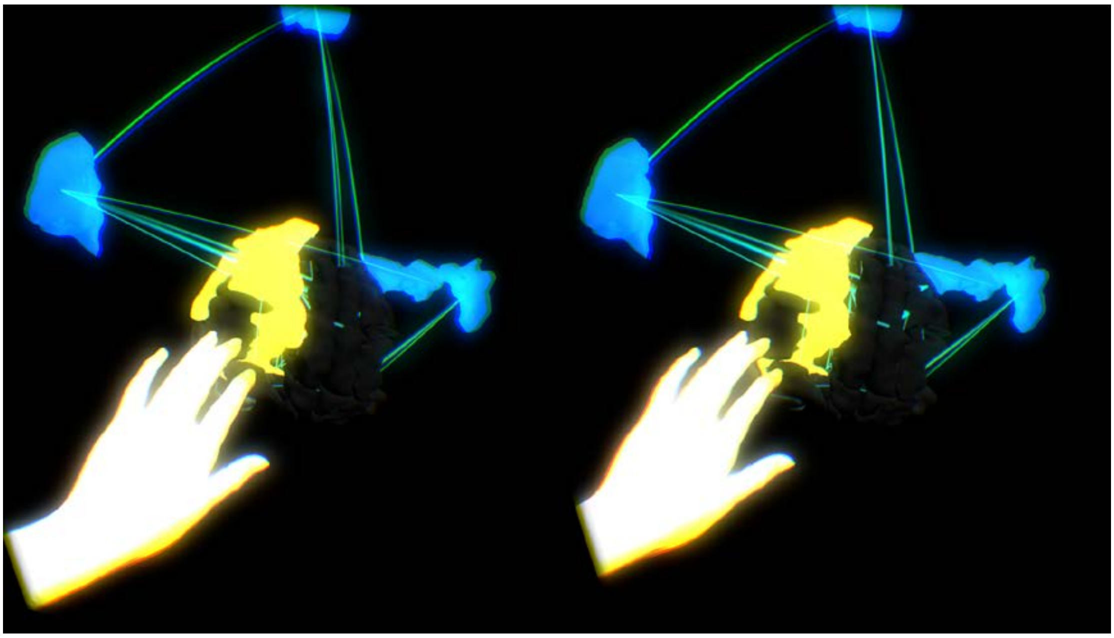


Figure 24. Screenshot of App 1 (Brain Connectivity) object manipulation of the brain.

4.2.2 Graphical User Interface (GUI) characteristics

As devices have become driven by graphics, CLIs have increasingly been replaced by GUIs. The five characteristics of GUIs are responsive, indirect, double medium, exploratory, and recognition. Seven of the 10 apps (3, 4, 5, 7, 8, 9, and 10) offer the characteristic of being double medium. This means that these apps presented more than a few commands and all of them are visually available to the user. For example, in App 3 there are many commands available, which are presented to the user to control and interact with the firework visualisation (Figure 25).

Eight of the 10 apps (3, 4, 5, 6, 7, 8, 9 and 10) are exploratory, as the apps provide the user with an ability to pull down menu systems in order to see the currently available options and tools. Exploratory characteristics also allow users to perform undo and redo commands, giving them the ability to explore without making permanent mistakes (Figure 26). Nine of the 10 apps (2, 3, 4, 5, 6, 7, 8, 9 and 10) share the characteristic of recognition, as users do not have to recall all commands and settings to interact. Only App 1 relies on the user to recall the gestural commands presented at the start of the app.

Since the analysis focuses on the interaction of hand gestural commands, the apps should not rely on the use of a keyboard and mouse. This means they do not share any indirect and responsive characteristics.

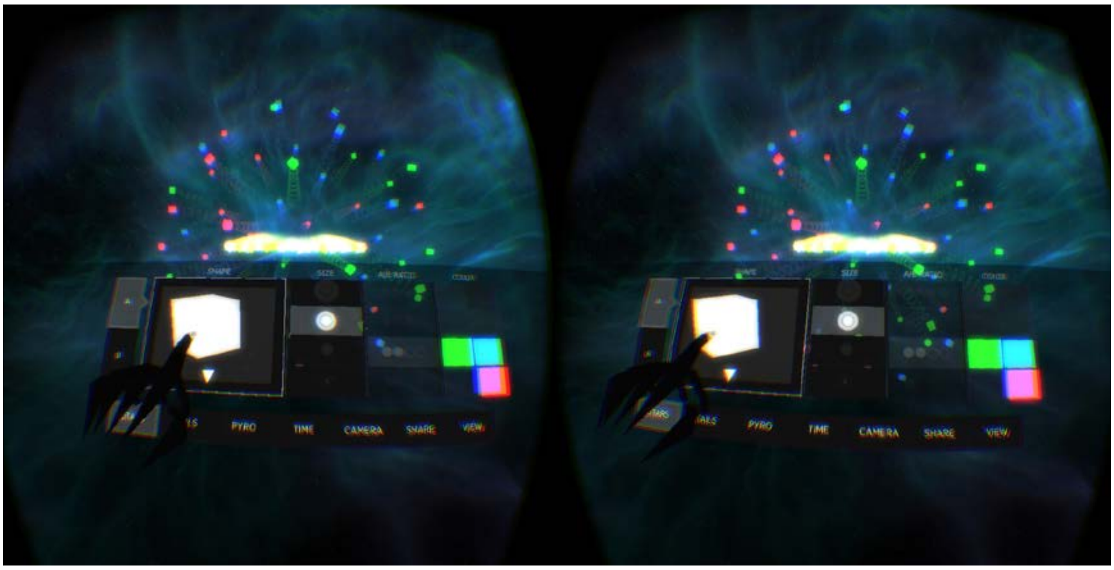


Figure 25. App 3 (Firework Factory VR) presenting the menu interface for object interactions with the firework

4.2.3 Natural User Interface (NUI) characteristics

Wixon and Wigdor (2011) argue that NUIs are not necessarily natural interfaces, but instead make the user behave in a natural way while interacting with the interface. Wixon (2008) further presents five characteristics for NUIs: evocative, unmediated, fast few, contextual and intuition.

There are seven of the 10 (1, 3, 4, 5, 6, 7, 8 and 9) apps are evocative, as these apps enable users to 'behave' in a natural way. For example, App 1 presents a 3D model of the neural network visualisation of a human brain in the centre view. The model animates with flickering lights that prompt and evoke the user's behaviour to manipulate and engage with the visualisation (Figure 24). This is a clear indication for prompting the user to interact and thus evoke the behaviour of object manipulation.

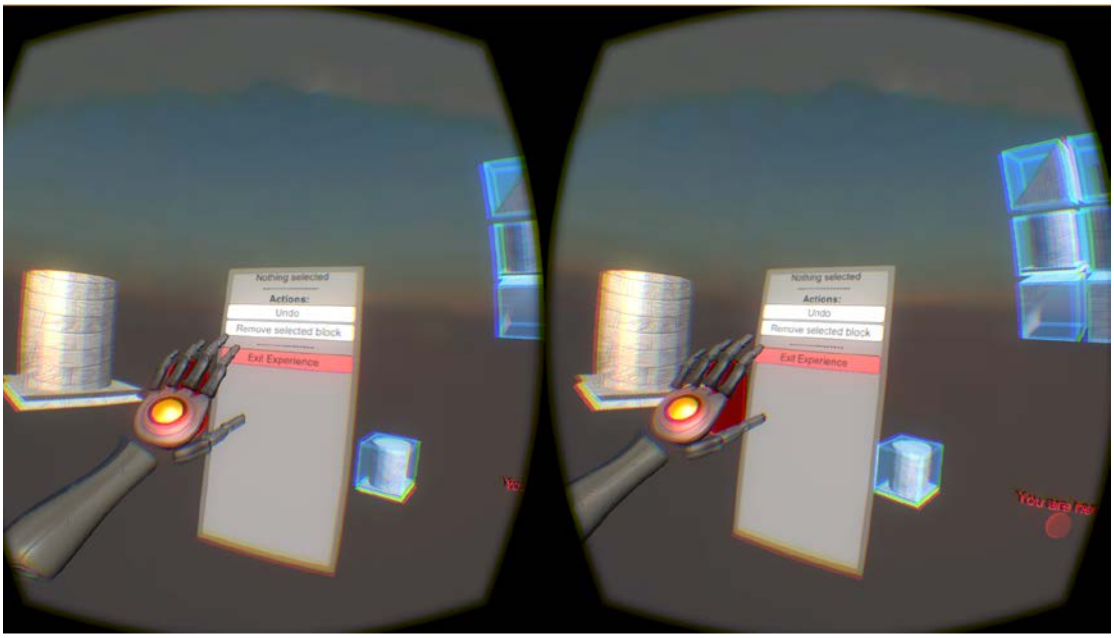


Figure 26. Screenshot of App 9 (World of Comenius) is presenting an undo button.

Only four out of the ten apps (1, 2, 5, and 9) are fast and few, which means that they focus on the natural properties of the objects rather than being based on clicking menu systems. App 5 (Planetarium) shows a good example of where the user can reach for the stars and grab them to see them up close, rather than having to click on a menu system.

Nine out of the 10 apps (1, 2, 3, 4, 5, 6, 7, 8, and 9) are contextual, which refers to the interfaces having the ability to understand the environment they are in and respond to users in a natural way. Seven apps are based on intuition, which is when users expect the interactions to work according to their intentions. For example, in App 4 the menu system worked based on natural hand motion, in order to go back and forth, the user has to shake their hand to flick back to the previous menu (Figure 27). This type of menu system shares similar attributes and functionalities to the TULIP menu system (Bowman & Wingrave, 2001) which was previously mentioned.

All ten apps are unmediated, which means they are not based on secondary device systems. Users must interact with the computer in an unmediated way, for example, by using their hands or body to interact with the device.

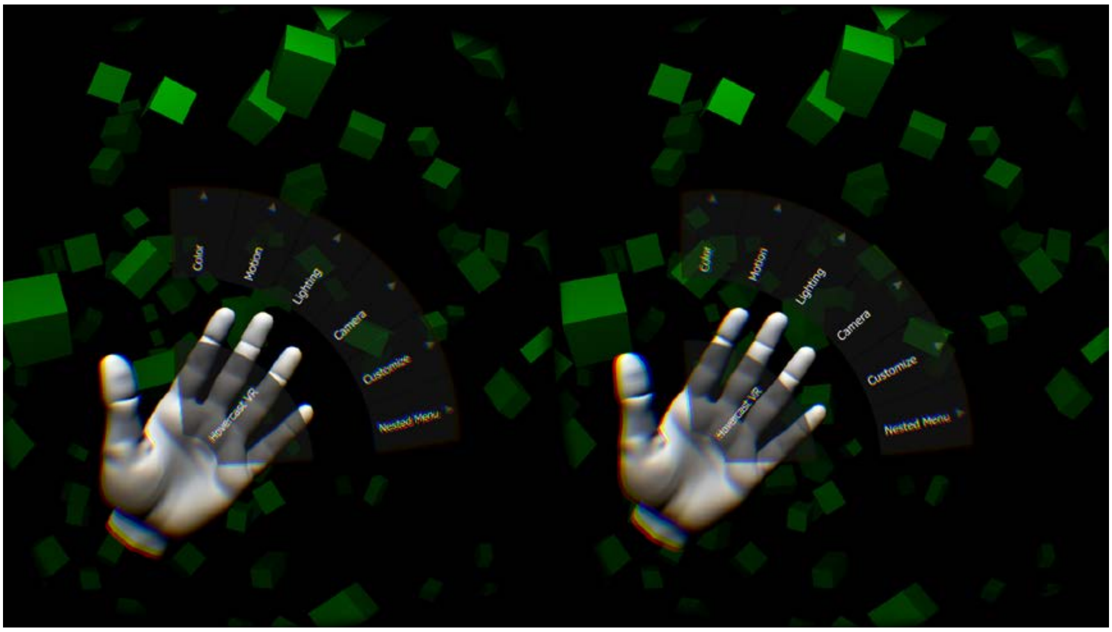


Figure 27. App 4 - Hovercast VR Menu

4.2.4 Organic User Interface (OUI) characteristics

Wixon (2008) predicts that OUIs will eventually supercede NUIs. OUIs are defined as organic, flexible interfaces that change shape via a physical interaction. Wixon presents five characteristics of OUIs: Fluid, extensive, constant zero, anticipatory and synthesis.

The majority of the apps do not display OUI characteristics. Three out of the 10 apps (1, 4 and 5) have a fluid relationship between the actions of the user and the actions of the system. This means that these apps provided seamless feedback when performing actions and not having any delays. Two out of 10 apps (1 and 9) are constant zero, as they have a constant interaction between the user and the system. For example, when performing a command or action in App 9, the system constantly prompts the next step for interaction.

There were three characteristics of OUI that have not been implemented by any of the apps. These characteristics are: extensive, meaning the user is able to push the interface further to what it can do in a natural way; anticipatory, referring to the ability to anticipate the user's next step and respond in a meaningful way; and synthesis, suggesting a closer alignment between the user and the system.

4.3 DISCUSSION

All apps included in our study were unmediated, meaning they required the use of hand gestural interactions. Instead of applying existing principles for NUIs and OUIs, we focused our analysis on the characteristics of each type of UI. This helped us discover specific aspects for each app, which may lack or hold back the apps from being more intuitive and present more natural experiences. The ten immersive apps presented characteristics across GUIs and NUIs, but there are some characteristics that are overlooked, which correlate to CLIs as seen in Figure 22. For example, apps 1, 2, 5 and 9 were static and only allowed the experience to be fluid after entering a command. We also noticed that many apps have overlapping characteristics. For example, some showed signs of *double medium* but also there are *fast few* characteristics within some parts of the app.

Based on the results of the analysis we can see the possible limits caused by the *Oculus Rift* and the *Leap Motion* are potentially hindering the adoption of OUIs. A few of these limitations could be due to conflicts with glitches with hand gestural recognition and the lack of tactile feedback. This can be seen as one of the few reasons why NUIs are currently the main trend for immersive apps. However, our findings show that there are still few characteristics that need to be considered, such as focusing on the natural properties of the object rather than constantly interacting with menu systems. From this analysis, we can advise developers and designers to consider the characteristics of the four types of UIs presented by Wixon (2008) when creating immersive experiences.

4.4 CONCLUSION

With the arrival of VR and AR consumer products, such as the *Oculus Rift* and *Leap Motion*, along with their APIs, NUIs have become easier to build and distribute to users. To identify trends and guide the design and development of future applications in this emerging market, we analysed 10 immersive apps from the *Leap Motion* market. We compared each app against the four types of interfaces and their characteristics (CLI, GUI, NUI, and OUI). We discovered some characteristics that reduce the experience of current apps that are trending towards NUIs. For example, our findings indicate that there are still *static* and *recall* characteristics used in current apps, which date back to the period of CLIs.

As the underlying technology matures, and given the ephemeral and transient app market, it is important for developers and designers of immersive apps to ensure that their designs have low learning effort, quick learning curves, and mechanisms that enable natural and efficient recall and static experiences. Our findings further highlight that more focus needs to be placed on the implementation of characteristics of OUIs in order to bring interfaces to the next level. Our analysis also points out opportunities for future research into how OUIs can be achieved within HMD-based MR apps, such as phantom haptic with sound and animation.

From this analysis, we gained some insight which was not clear to us from performing other methods of testing such as heuristics or comparing to principles for NUIs. In order to further establish these preliminary findings and support this analysis, we conduct a user observational study in the next chapter, to gain a much deeper understanding to find similar or contrasting results.

5. PHASE 2: USER BEHAVIOURAL STUDY

5.1 QUANTITATIVE RESULTS

	Age	Sex	Ethnicity	Devices Used
P1	24-35	M	White/Caucasian	Desktop Computer, Laptop, Mobile Phone
P2	24-36	M	White/Caucasian	Mobile Phone, Laptop, Desktop Computer
P3	16-24	M	White/Caucasian	Mobile Phone, Laptop, Desktop Computer
P4	16-25	M	Asian	Mobile Phone, Tablet, Laptop, Desktop Computer, Smartwatch, Camera
P5	16-26	F	Asian	Mobile Phone
P6	16-27	F	East Indian	Mobile Phone, Laptop, T.V
P7	24-36	F	Latino / Hispanic	Mobile Phone, Laptop
P8	16-25	F	East Indian	Mobile Phone, Laptop, T.V
P9	24-36	F	Asian	Mobile Phone, Desktop Computer
P10	16-25	M	Asian	Mobile Phone, Laptop, Camera

Table 3. Participant numbers associated with their pre-study answers

Prior to the commencement of the observational study, all participants were asked to fill out a pre-study questionnaire (APPENDIX A). The following statistics signify the results from ten participants:

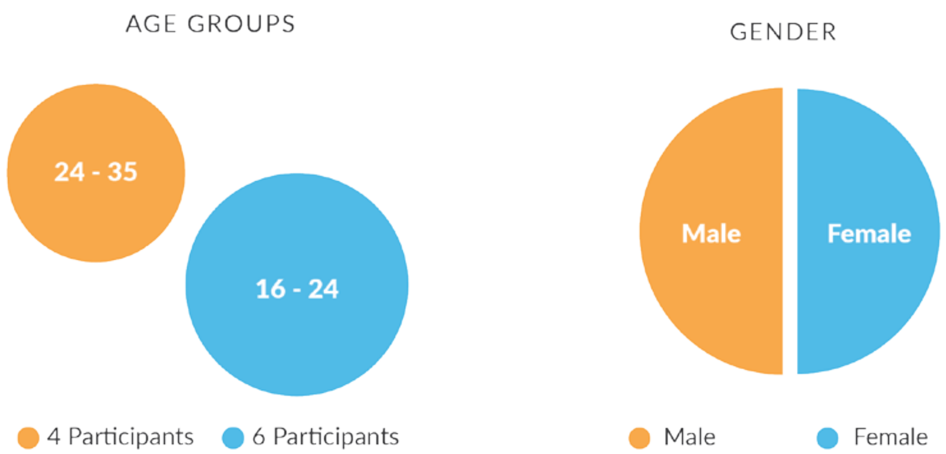


Figure 28. Statistics of 10 participants (Left) Age group statistics, (right) gender balance

The purpose of undergoing a quantitative data analysis prior to organising the qualitative data is so that we are presented with some initial insights on current types of interaction experiences with particular devices being used by each participant. These results further helped determine the likeliness of possible trends in behaviours through each application.

As seen above in Figure 28, there was an equal distribution of male and female participants and the age group was primarily between 16 and 35. All participants are students who are currently enrolled at the University of Sydney. Their degrees go across various disciplines and share many different experiences with technology uses.

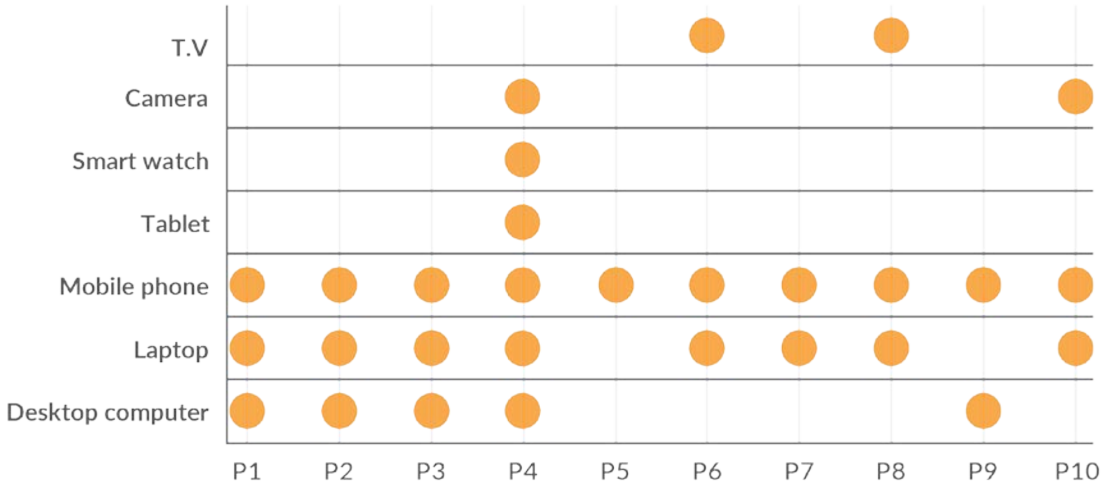


Figure 29. Overview of device usage in %

The following data seen in Figure 29 presents the number of devices that were mentioned during the pre-study. The graph also represents the number of devices that are most popular amongst the participants. Based on the results, we can see that the participants range from users who use NUI like interface interactions and very physical object based interactions which devices such as cameras, TV and tablets. There is also a majority of users who use much indirect input with Laptops and desktop computers.

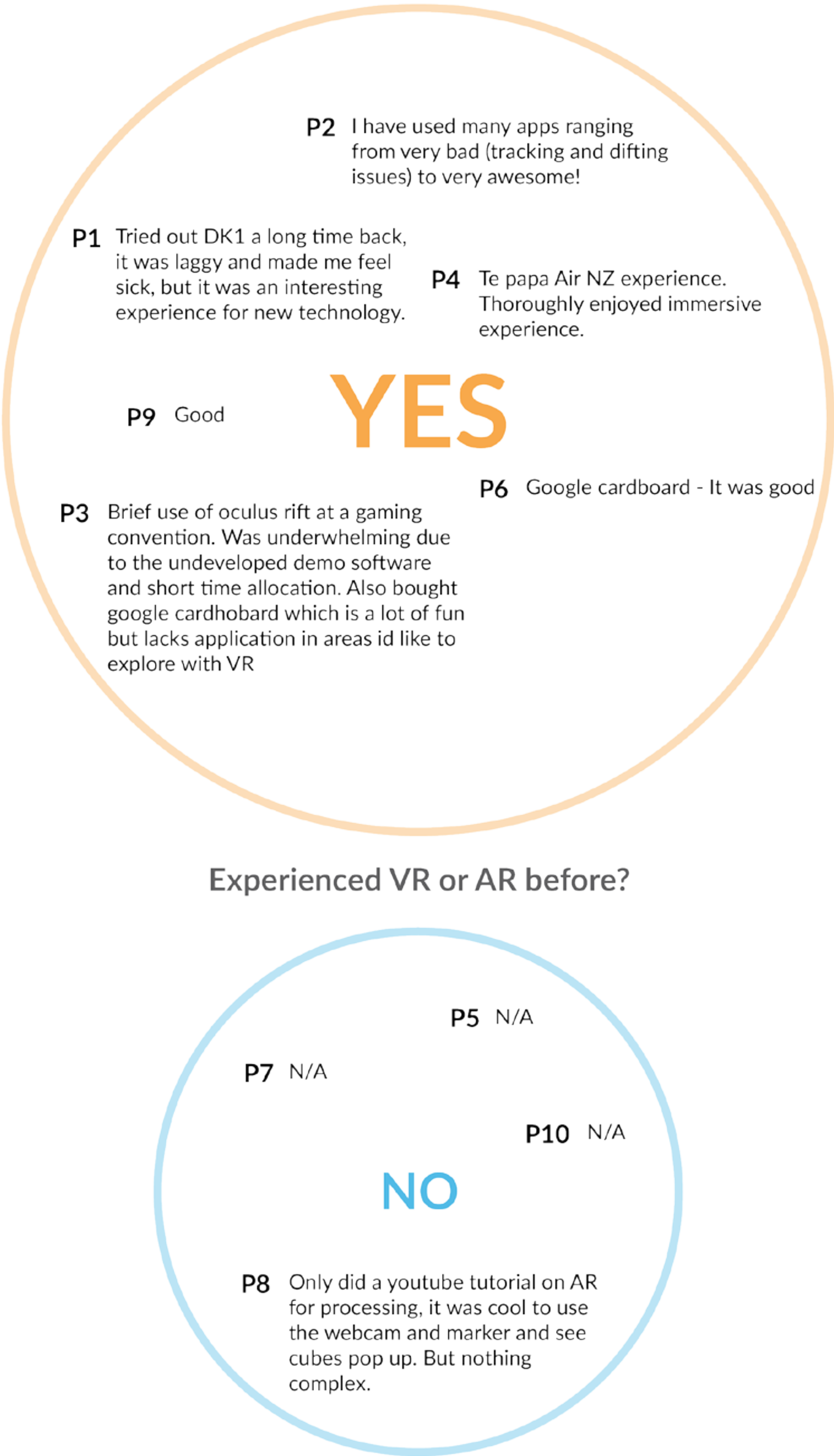


Figure 30. Participants who have experienced virtual reality (VR) and augmented reality (AR) and their responses

Based on the data collected from the pre-study questionnaire, we further discovered that 6 out of 10 participants have experienced some form of VR or AR experiences (Figure 30). Out of these six participants, four of them experienced immersive applications with HMD, while two only experienced mobile based simulations.

5.2 QUALITATIVE RESULTS

It is important to state that all studies in this analysis were conducted in the same environment with the same space and structure (Figure 20). The room had no bright lights and had minimal intrusions around the confines of the participants' area.

After analysing the pre-study data and conducting a user behavioural study, the data was then further analysed as an inductive content analysis (Elo & Kyngäs, 2007). Key phrases were extracted from the interview transcripts (APPENDIX E). These transcripts were printed out and coded into an affinity diagram as see in Figure 31. When reading each data transcript, it was easy to see groups forming which describe similar themes. These themes are colour coded to identify some of the main themes and their subcategories.

There were a few challenges that slowed down the process of sorting out the data as some of the points raised by participants were sometimes abstract and contradicting points. To address this issue, we had to analyse each participant's transcript carefully and group similar points into categories. Additional notes were also transcribed from the video recordings during the user's experience. By grouping them further into categories and subcategories, we are presented with the following themes.

Figure 31. Infinity diagram stage one - Interview transcripts

Hype ride within immersive environments:

When grouping up all transcripts from the interview, participants' first impression of the experiences presented a clear hype pattern that occurred during each app. Participants would start off excited as none of them have ever experienced MR with gestural interactions in an immersive environment prior to the study.

> *Participant 6: "Yes, it was an exciting way because it is something I have never experienced before. So that was good."*

> *Participant 8: "It definitely is a new and exciting way of interaction, especially with menu systems and other user interfaces."*

Some participants found the experience with all apps exciting but at the same time found it very challenging which led to frustration from the long learning curve with the UI designs and navigations.

> *Participant 9: "Yes, it was exciting and also challenging at the same time."*

> *Participant 10: "Yes, it is an exciting way, but also quite a challenging one to interact with because there are a lot of difficulties with the navigation of the interfaces."*

> *Participant 4: "Yes, it was very exciting and I loved the interaction with my hands, even though it was very bad at responding to my commands."*

A few participants faced much eyestrain and discomfort when putting on the HMD, due to its physical size and weight.

> *Participant 4: "Eyestrain, probably just because he has something fitted onto your head. You know it is a lot heavier than glasses. I do not actually now. Doing it the second time I do not think that it was actually my eyes that were straining, like you know we watch too much T.V. But it was rather just the weight of the thing on my head."*

> *Participant 3: "And then toward the end of the session the plastic part of the Oculus was on the end of my nose pressing. Slight discomfort from wearing it."*

Convergence of digital and physical realities:

Part of the excitement and hype that was caused by these experiences was because each participant was not expecting to see their physical hands or any form of the physical environment that would be mixed in with virtual elements.

This caused a positive reaction and made them feel more connected with interface interactions.

> *Participant 5: "I liked the mixed reality feel because I could sense where exactly I am and how I was interacting with the objects around me, I thought that was really cool."*

> *Participant 1: "I did not expect it to be this immersive when wearing a headset like this. It felt unreal and almost as if everything was happening to me in a real state."*

> *Participant 8: "I liked the mixed reality, how you could see your hands and it felt like you were there in the experience and were in control and you were using your own hands to navigate through the menu systems."*

> *Participant 2: "I think this would be a better experience because it gives positive abilities of both realities and provides a nice convergence."*

> *Participant 10: "I feel that virtual elements in the scene are really cool and important but virtual embodiment was not so great because it kept confusing my gestures. I feel the mixed reality of having physical reality around me is a good option."*

Only a small number of participants favoured full virtual experiences for all the applications.

> *Participant 9: "I like virtual reality better because it can give me the experience that the physical space distracts me. I think VR is really good for that and should be used more often."*

> *Participant 1: "I feel that virtual reality would be better because it is good to experience things that you do not see or face in reality all the time. Augmented reality only gives illusions that potentially make things seem more subsided when interacting with."*

One participant mentioned from their experience of augmented reality, labelling the experience as a "Gimmick". Further, the participant suggesting the power and usefulness of using HMDs rather than mobile devices or virtual augmentation through built-in cameras on laptops.

> *Participant 4: "When you blend the real world into you know on screen computing. What they call augmented reality on these phones? It is Terrible. It is a gimmick feature that I've never ever actually used in real life like who wants to go like this you look around saying like an idiot but also like you can really easily just you know use a compass. To point in the right direction. People would rather see the real world which then seeing a portion of it on the screen."*

Ergonomic - spatial awareness and composition of digital content:
Despite the fact that HMDs are not portable for users to be able to roam around freely, there are still considerations that need to be looked into towards spatial awareness within a confined workspace. Throughout the experiences, participants would find it challenging and very rarely interact with graphical elements or virtual objects that would be placed behind them. From observing the participants during their experiences and revisiting the video recordings, it was clear to see that most of them performed their interactions and gestures in an 180-degree range from where they were seated.

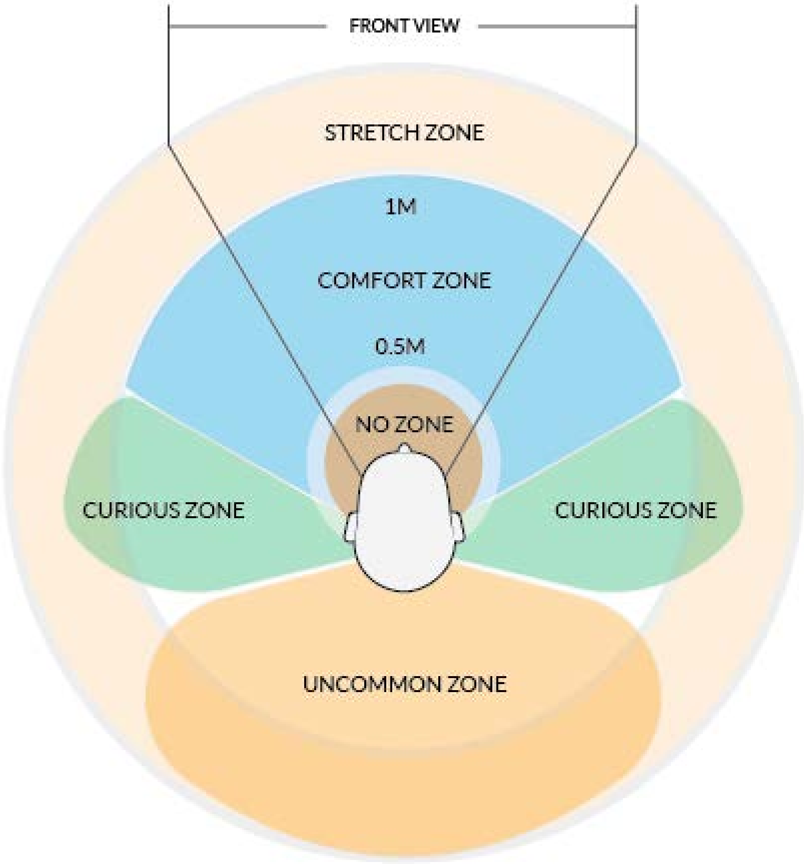


Figure 32. The five zones for spatial interaction

Furthermore, we observed that there are five different areas in which users respond (Figure 32). Stretch zone, the extent of which UIs are placed causing the user to go out of their position for successful interaction. Comfort zone, a safe distance for positive feedback and lack of collision with other objects accidently being triggered. This zone is best explored 0.5 metres away from the headset up till 1 metre. Curiosity zone, where users notice graphical elements in their peripheral vision that cause them to turn their heads. Uncommon zone, the position in which is rarely noticed and interacted with that causes redundancy in the system unless there are graphical prompts that extend into the curiosity zone which guide the user's eye and attention into the uncommon zone. The last of these is the no zone, which is the distance that should be avoided to cause irritation and blindness to the users view through HMDs.

A few participants mentioned their awareness of a 360 environment around them, however during their experience they rarely looked back to interact with widgets and menu systems.

> *Participant 8: "I expected it to be immersive, even though when I wore it, I did not think to myself that I should turn around and notice a 360 view, even though I knew that beforehand that I could do that."*

> *Participant 1: "Also the ability to move and swipe interfaces so that there is more customising of the menu system since it is all around in 360 degrees."*

> *Participant 7: "That was a bit tricky like there were a couple of interfaces that were having wheels behind me in the widgets app, but I did not know if I was touching it."*

> *Participant 9: "I liked the fact that in the widgets one I had interfaces around me that I could see and read, but was annoying to interact with."*

> *Participant 1: "One of the most memorable difficulties I faced when experiencing these realities was figuring out what is around me. Because I had to turn a lot first, did make me a bit nauseated and lost at times, making me lose track of where my starting point was for the interaction."*

However, in addition to the focus range that users found comfortable, 3 out of 10 participants felt the need to stand and interact with the UIs.

> *Participant 3: "The second and third app one is a little bit less just because I could not see the rest of the room so I was really sure where I was standing and if I was going to hit things."*

Participant 2: "I guess being able to walk up close to things is really cool. Something I did not realise that you could do, that I found out from this test is the use of Leap Motion, it adds another dimension."

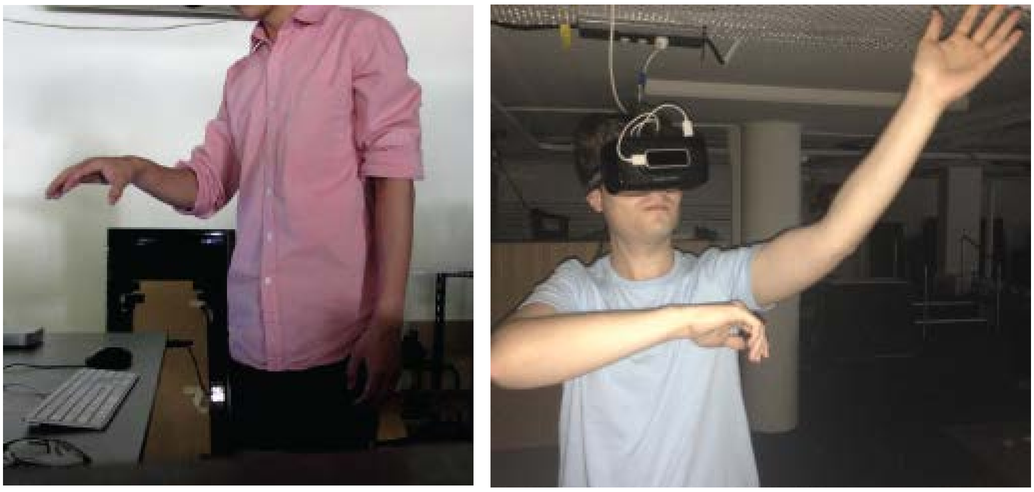


Figure 33. Participants who decided to stand in order to interact with ease

Spatial discomfort:

In relation to ergonomics within immersive experiences, there was frequent mention of discomforts during the spatial experience with each application.

Participant 1: "One of the most memorable difficulties I faced when experiencing these realities was figuring out what is around me. Because I had to turn a lot first, did make me a bit nauseated and lost at times, making me lose track of where my starting point was for the interaction."

There is a possible connection between the discomforts of wearing an HMD that may reinforce spatial discomfort to some participants

Participant 1: "I felt a lot of suspense as if feeling like something scary or shocking is going to hit my face. I have never felt anything this close to my face before. I felt anxious about what I was going to experience."

Two participants complained about body strain when interacting with the composition of the UIs. This strain is caused due to the distance of the widgets that force the participant to push their body away from their comfort zone.

> *Participant 1: “Some parts were intuitive but not all. There are many parts that required me to use all my focus to get it to work, but it still was glitchy and didn’t feel all that natural.”*

Interactive element scale:

About the discomfort caused by certain interactions, a few participants found the size of the buttons and widgets a bit too small and hard to interact with in-air gestures.

> *Participant 4: “I think what people understand with virtual reality is that if you are not holding a control if you are just simply using your hands, you have to make the buttons as big as possible.”*

> *Participant 2: “I did not like the palm interaction but I liked the big buttons.”*

Some participants pointed out a few aspects in apps such as Soundscape VR to have decent button sizes. These buttons were wider giving more room for the virtual hands to press more accurately, regardless of any glitching.

> *Participant 2: “Going back to the D.J. (Soundscape VR) on I think the buttons were quite big and were a lot easier to press on.”*

Virtual 3D model hands:

During the observational study for each app, 3 out of 5 apps provided the participants with the experience of viewing 3D virtual hand models that would replace their physical hands and mimic their actions. 7 out of 10 participants found this experience very distressing and caused much discomfort and confusions (Figure 34).

Participant 6: "Because I did not like seeing those freaky hands on me!!! They were really glitching and also felt weird being someone else."

Participant 7: "Two or three of the apps the thing did not recognise the way my hands were facing so that made me want to just had shake it off. Yeah, the virtual hands were not responsive all the time. One of the apps was especially frustrating when the fingers were not recognising my fingers and identifying which was my thumb and which was my index finger."

Participant 10: "I felt the quality was good in some cases but most cases the interaction was a bit challenging because the hands kept glitching and see those fake hands on me really made me feel weird and uncomfortable."

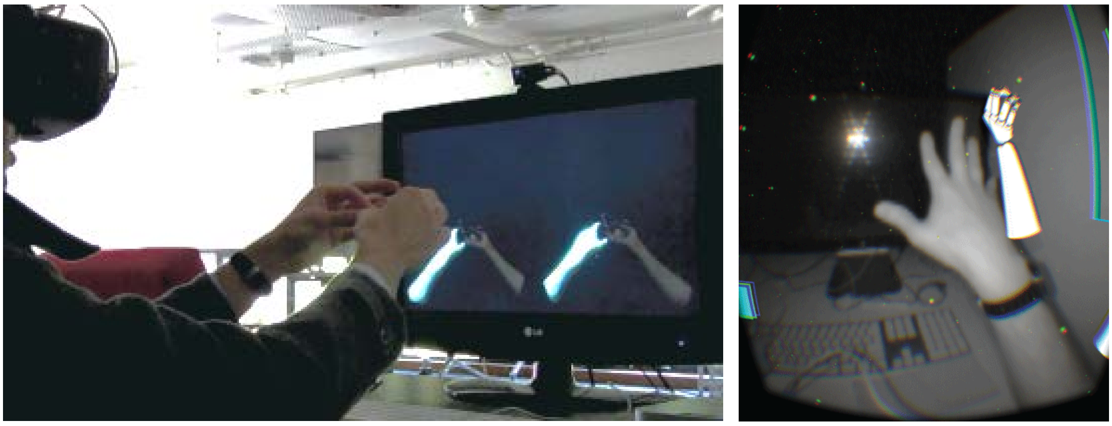


Figure 34. (Left) Participants encountering glitches with Brain connectivity app (right) participant experiencing floating virtual hand meshes that glitches from false hand detection.

Participant 4: "If we focus on, for example, an aspect of your hand. Yes, totally. I mean I'd rather see my hand than a computer tries to guess how my actions are being augmented, especially as how inaccurate it was."

Some participants found the virtual hands were not matching their gender which caused much confusion and negative experiences. The apps provided the ability to switch between male and female hands (Figure 35). However, this still caused discomforts and distractions from further progressing with the app.

> *Participant 7: "It felt odd because well my hands did not look like my hands even with the female hands on, that was slight discomfort. Yes, I would prefer to see my own hands, was weird to see other hands doing what I do."*

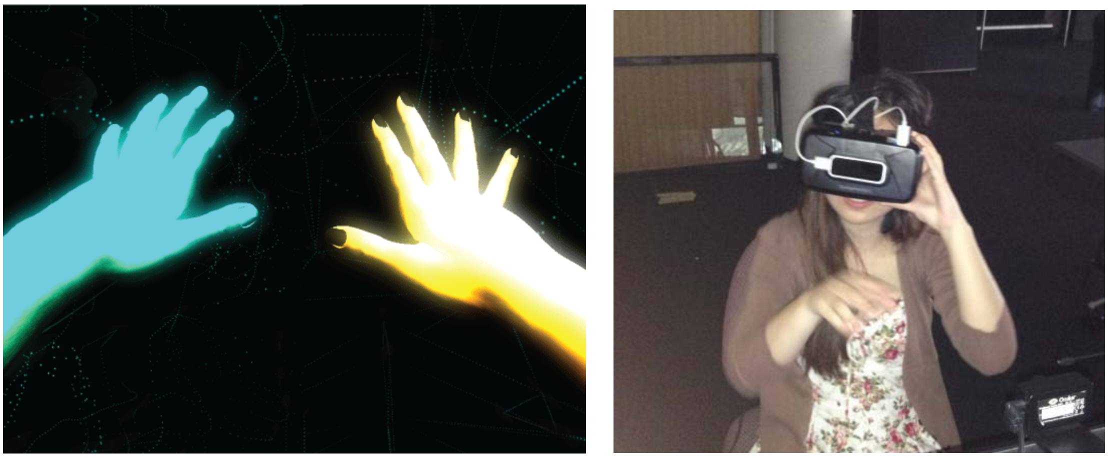


Figure 35. (Left) Gender type for virtual hands (right) participants reaction.

Embodied user interfaces:

The majority of participants were extremely surprised by the visual capabilities of displaying interfaces on their physical bodies (primarily their arm and hands) and found it an exciting way of interacting with UIs compared to floating menu system.

> *Participant 8: "I did like the Hovercast one because it was easiest to navigate through, because I caught on with it. Also the planetarium, the time comes on your arm. So once I knew that it was really cool and intuitive."*

Some participants mentioned the aspect of embodied UIs tending not to glitch as much as other types of UIs. This is due to the fact that the Leap sensor works best when the users' fingers are spread out flat and perpendicular to the FOV.

> *Participant 10: "I found that the hand menu system was very beneficial and didn't glitch on me because it was facing me and worked really well."*

> *Participant 1: "I feel the experience was really nice and enjoyable, and it presents a lot of growth in the design and experience for interaction with the capabilities of using your hands."*

However, there were a few participants who had picked up on a few negative issues with embodied UIs, which reduced their positivity within the experience.

> *Participant 5: "I thought that the UI was not good because like for example in the planetarium app, the arm UI was all loose like my arm was very skinny but then it's like kind of chubby like it was kind of wide"*

Text overload:

Eight out of 10 participants found the amount of text in the apps a bit too overpowering which distracted from the experience of being in an intuitive system. This was due to the fact that the interaction was driven by textual directions, rather than symbols or graphical use to direct the user's behaviour.

> *Participant 4: "Firstly, because the screen is not high resolution. I do not know what it is called where the lines appear when you move which are a pain when you move too much. Hard to read. That whole the brain connectivity one with the text was tiny and so hard to read."*

> *Participant 2: "I guess the issue with the brain one was I could not really read the text of the starting instructions very well. Either way,*

I do not really like reading Instructions for things I like just diving in and first and experimenting.”

Participant 8: “The brain connectivity, I did not really get, I do not know if there were instructions beforehand even though I saw the text and didn’t read all the text.”

One participant commented on text overall being blurry due to the limitation and resolution of the device, but still pointed out the overload of text that is being used in different parts of the apps.

Participant 9: “I could not see any of the text. Even the warning sign was hard to read because it was blurry and dependent on your eyesight.”

One-time menu appearance:

The majority of the menu systems within the experience would vanish after the participant has entered a command or interacted with it. Participants would try and reopen the menu system to recall the commands or have the option to change settings but failed to do so. This caused much frustration and limited the future interactions in the apps.

Participant 4: “In terms of something that's critical is an exit button and also once menu systems disappeared like an onboarding would be good.”

Participant 7: “There was an icon that was telling you what to do, but it disappeared so that was frustrating so maybe the timing is off over there.”

Participant 9: “There needs to be a back menu button to return to the tutorial or menu system because it is so annoying not to see the UI once it is gone or disappeared.”

Participant 4: ‘Gestures with the maps in the Planetarium app were a little hard to figure out if you do not know if you do not read that to tutorial beforehand.”

Participant 6: “Maybe if there were basic instructions that came up that said swipe this way or pinch this way, or select it this way. These kinds of options would be good.”

Guidance for gestural command prompts:

Some of the apps provided images that would pop up to hint at the participants when they were close to performing a command. However, participants were not able to understand these images as they were too static or kept disappearing while they would try to carry out the gestures recommended.

Participant 5: “I can see a hand gestured image on my hand but when I perform its instructions it doesn’t give me results.”

Participant 8: “It took me a while to learn the gesture command, even though I had a visual tutorial in front of me. And when I did figure out the command, the visual of the image prompt was nothing like the command I was performing.”

Participant 4: “Maybe a video like a tutorial basically that people won't just text in a virtual reality is hard.”

Illusion of touch linked towards phantom haptics:

Many participants described the experiences that they got the sensation of touch from some of the graphical elements. These graphical elements were usually buttons or objects that were animated.

Participant 2: “As I said before I guess haptic feedback would be really good. I guess you could get away with like actually knowing *the button is visually being pressed, I guess as the end goal would be for haptics."*

Participant 10: "I almost felt like I touched a button or widget and made me feel like I could feel the button actually on my fingertips but at the same time I could not."

Participant 5: "Also I was not sure like how far I have to press down on a button until it changes. But when it did I thought I felt something that was pressed."

Digital feedback:

The majority of the participants found the visual feedback was not strong when interacting with the UI across all five apps. There was a lack of visual prompt when the participants attempted to trigger buttons and other UI elements. Part of this suggests that prompt feedback was very static, where the main feedback was given when the system provided a change in the environment.

Participant 9: "First of all it was very hard to press the button, would be good to see colour changing of the button, so that you know there is more feedback when clicking on the button. So when you click its more obvious if you see a colour change."

Participant 1: "There needs to be more menus that present more feedback when interacting, like when hitting a button."

Participant 5: "Yes, I feel that there needs to be more colour and or sound feedback when the buttons are pressed or being pressed, that would give me a better idea if I am pressing down on things or not."

Participant 6: "Getting feedback from the buttons in the applications was very challenging."

Participant 7: "The feedback was lacking and the interaction did not happen when I expected it to happen."

Two participants found the visual feedback effective in the Widgets App. Due to the visual response of the buttons being able to show depth and represent the push of a real button, presenting clear affordances of the button being triggered.

Participant 8: "The widgets with the button in the start was a good one too and it gave me a nice feedback with the buttons that showed depth."

Participant 2: "…the widgets app actually pressing on the slider button and it was actually like making an indentation like the button was actually being pressed visually see that actually made it more compelling for me."

Participant 1: "The widget buttons had good feedback and easy to use because they had depth in them."

However, in some cases the visual feedback was not enough or noticeable and required more supporting effects to prompt a stronger illusions of phantom haptics.

Participant 4: "Although you know you are seeing it and you are touching. That is not enough feedback maybe would be cool if you have a vibration or sound when you've hit something."

Participant 7: "That was a bit tricky like there were a couple of interfaces that were having wheels behind me in the widgets app, but I didn't know if I was touching it. The feedback was lacking and the interaction didn't happen when I expected it to happen."

Object intuition and prompt for gestural interaction:

During the observations, there were stages in each participant's interaction that made it clear to see what prompts certain hand gestures when interacting with certain widgets. For example, Participant 2, 7, 9 and ten would primarily use one hand for most widget interactions but when it came to objects that were larger than the side of their palm, they would intuitively try to engage with the virtual object with both hands (Figure 36). This confusion caused frustrations and errors when interacting with certain with some of the apps, like the virtual compass in Planetarium and the button sizes in Soundscape VR.

> *Participant 2: "A compass just didn't seem right, and because it was sphere I tried to rotate it with both my hands."*

> *Participant 9: "it was still annoying and difficult to grasp the compass to navigate in space. It was just so hard to grab a ball that's bigger than your hand to hold and move around. Didn't feel intuitive at all."*

> *Participant 7: "For example, for the compass in the planetarium app, what was most annoying was once I tried to interact with it, it would disappear. I would have liked to interact with it with both hands since it was a sphere, to be able to hold it would make me feel more confident that it would not disappear."*

> *Participant 10: "I found the compass hand gesture in the planetarium app very confusing and it was almost difficult to know that I had to drag it around. I thought I had to hold it with my two hands since it was a sphere to navigate."*

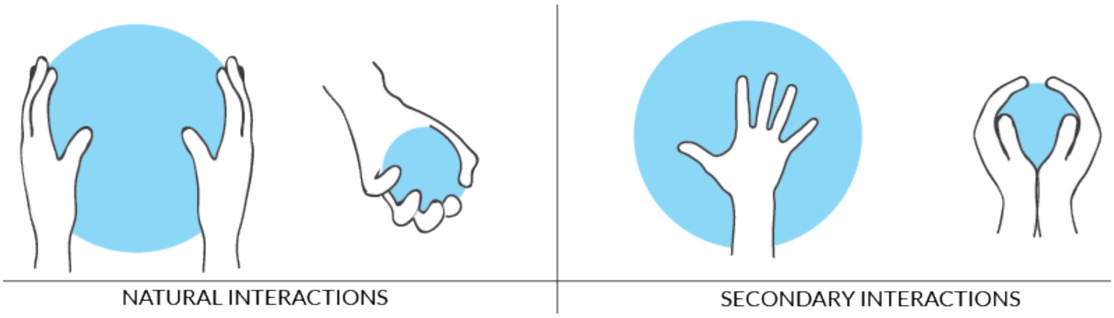


Figure 36. Object intuition - use of hands based on the size of the object

Participant 7: "I would have liked to interact with it with both hands since it was a sphere, to be able to hold it would make me feel more confident that it would not disappear."

Swipe gestural motion for interface shifting:

Despite gestural swipe being one of the main common gestures available on the leap motion API (Figure 10), it was the least used gestural navigation. The majority of participants first tried to swipe on text interfaces and other types of floating UI systems. It took participants a few seconds until they realised that the interaction was missing. From the quantitative and qualitative data, we noticed that were many participants who were still very used to GUI and NUI interactions which lead them to prompt actions and behaviours with current systems.

> *Participant 1: "I would really like to add a scale gesture to the apps because that is something that really needs to be present. Also the ability to move and swipe interfaces so that there is more customising of the menu system since it is all around in 360 degrees."*

> *Participant 3: "Probably would mainly be I guess touch interface that I am more used to so there were times I was trying to like sort of bring the menu on like to swipe down on the iPhone and Android if you just sort of slide down thing to bring that down. I was thinking of it like you know when I had that sort of a list of texts that I saw them*

to get to the brain one I was from left to right what that was right all times I am in to get past it. And at time things used to touchscreen devices."

Participant 5: "I can't think of anything on the top of my head but I think that having a swipe or move control would be really nice, in the widgets app I was trying to scale the scrolling text but couldn't. I guess that would be useful."

Participant 8: "I like the whole idea of swiping, I did not know how to stop reading and continue certain apps."

There was only 1 participant who complained about eye strain but that was only due to the fact of the heavy text load in the applications. As the *Oculus Rift* is known for creating motion sicknesses and nauseousness, a strong majority of the participants enjoyed the experience for an hour straight without having any discomforts after the experiences.

6. PHASE 3: GUIDELINES

“Design is not just what it looks like and feels like. Design is how it works”. – Steve Jobs

In this phase, we focus on the convergence of our findings from Phase 1 – trend analysis and Phase 2 – observational study. From these results, a set of guidelines was derived that complement the principles that currently are available for developers and designers by the *Leap Motion* and NUI research communities. These guidelines focus on the implementation of MR and UI systems, to reinforce positive experiences and reducing flaws with tracking systems and natural behaviours.

6.1 DEVELOPING GUIDELINES

The following guidelines were derived from the trend analysis and the observational study which can be applied to strengthen and create more positive natural user experience:

Actual object scale to prompt users’ natural gestural interaction:
It is important to think about the size of the virtual object in order to prompt a natural behaviour for object selection and manipulation. If an object is twice the size of a human hand, the probability of the user interacting with both their hands is high in comparison to just using one hand (Figure 36). Unlike objects presented in augmentation through mobile devices, it is important to consider the scale and size of the object to prompt more accurate gestural interactions. This aspect could be considered in current and future apps which consist of navigational tools which rely on object interactions with gestures.

Virtual and actual physical elements for hand recognition intuition:
Instead of displaying a whole virtual hand model over the users’ physical hand as seen in Figure 34, it is important to consider implementing minimal virtual elements. For a more intuitive and for better object recognition, it is essential to

present these virtual elements on the tip of the fingers in order for the sensors to pick up on easier object selection.

Minimal spatial distribution for ease of interactivity through zones:
Try to implement and set UI and interactive objects within the comfort zone to provide users with easier access for discovering and engaging with UIs. It is important to keep a limit of the distribution of virtual objects to reduce redundant graphics. It is important to consider the five zones (Figure 32) when implementing and deciding the composition of your UI elements. It is important to try and avoid placing content in the no zone area, which can cause nauseousness and blindness to the users.

Embodiment with user interfaces driven by object and graphics:
One of the conventional methods for interaction within immersive VR experiences is by showing floating menu systems that hover in space. However with the possibilities with digital game engines and tracking sensors, there are possibilities to use physical properties in real space to trigger and drive menu systems and user interfaces. As suggested by the Leap Motion guidelines, it also reinforces the idea of UI embodiment that provides much easier hand recognition as users would face their fingers front on to the camera, rather than having their fingers pointing away from the sensors.

Reinforcement for positive human-computer feedback towards phantom haptics:
In order to reinforce feedback from widgets and UIs, there should be a convergence of four elements, sound, visual modification, animation, and mesh collision. The use of sound should be triggered upon the interaction point between the user and the system. In connection with sound triggers, visual modifications such as hue change, contrast and saturation can further enhance feedback responses. In addition to both these attributes, the use of slight animations and mesh collision between two objects can present more visual dimension towards stronger feedback. It is important to present all four

elements to provide as much feedback as possible to reinforce phantom haptic feedback.

Flexible and dynamic navigations through menu systems with dynamic visuals:

Rather than depending or graphical buttons (GUIs) for UI interactions such as undo, switch and closing off browsers, you could consider incorporating natural hand gestures to trigger these commands rather than using graphical buttons. This will help reduce the number of buttons to confuse the user and deduct repeated use of going back and forth between menu systems. Also, it is important to consider using dynamic visuals to prompt more fluid interactions. Try to avoid using static imagery or sequences of images that demonstrate a gestural command, instead use videos or animated visuals which illustrate a more clear instructions.

6.2 EVALUATION OF THE GUIDELINES

In order to evaluate these findings, a prototype app was built which demonstrates the use of the guidelines. To further assess and support these implementations, we presented the following app during the two opening nights of the Anthelion grad show at the University. This app consists of the use of an open-source project called the Hovercast VR, created by Zach Kinstner. This type of menu system shares similar styles and functionalities as Bowman's TULIP menu system (2001) that presents options on the users fingertips.

Visitors from various backgrounds and age groups took part in experiencing the Realm weather app. There were roughly around 181 visitors who attempted in trying out the app. From observing all these visitors, none found them found the app to cause any discomfort or dizziness during and after the experience. The prototype is based on the implementation and interaction with live weather data from 6 different countries such as Moscow, Sydney, Paris, London, Dubai and Antarctica (Figure 38). The reason for selecting certain locations is so that there is a high probability for dynamic weather visualisations.

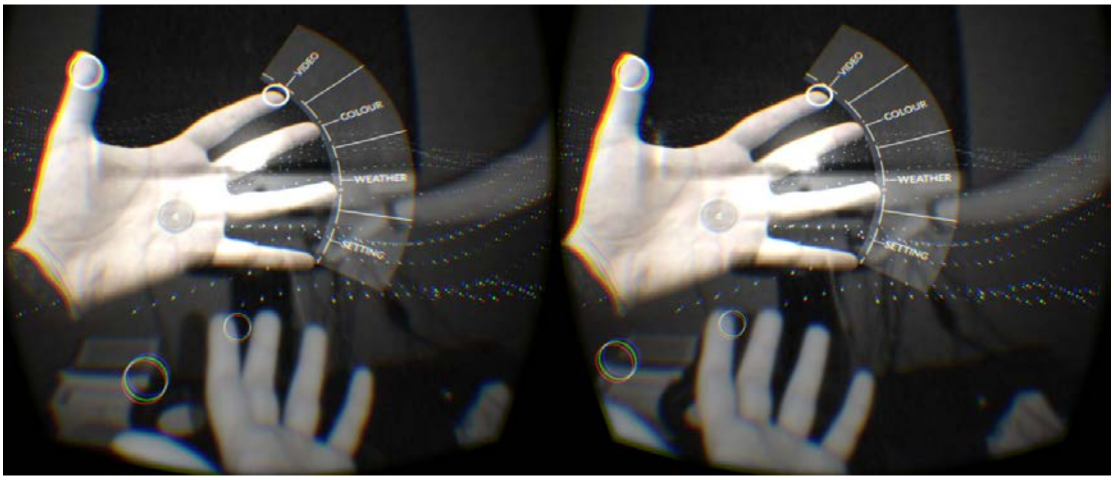


Figure 37. Video demonstration of the Realm app inside the immersed experience

The app is driven by the use of an embodied menu systems and UI interactions. The reason for implementing and developing with an embodied UI is so that it causes fewer conflicts with the Leap sensor. The interface also provides the user the ability to customise their experience to an extent, such as changing the text size of the UI, colour, and transparency. Also, users have the ability to customise the ambience around them, giving them the opportunity to control how much exposure they want for a VR experience or have more visual rendering their physical space.

During their experience, we further evaluated the guidelines that were implemented in the app. We noticed that visitors found it easy to start the experience without any static experiences. This is because as the video played at the beginning of the app, it evoked their behaviour to lift their hand up to the sensor that triggered the menu system to appear, giving them the motive to interact with the UI elements (Figure 37). While users were interacting with the virtual menu system, they received accurate responses back from the system without having to extend further out from their comfort zone. However at times the head tracking device for the Oculus would reset the composition of the layout which caused a few confusions.

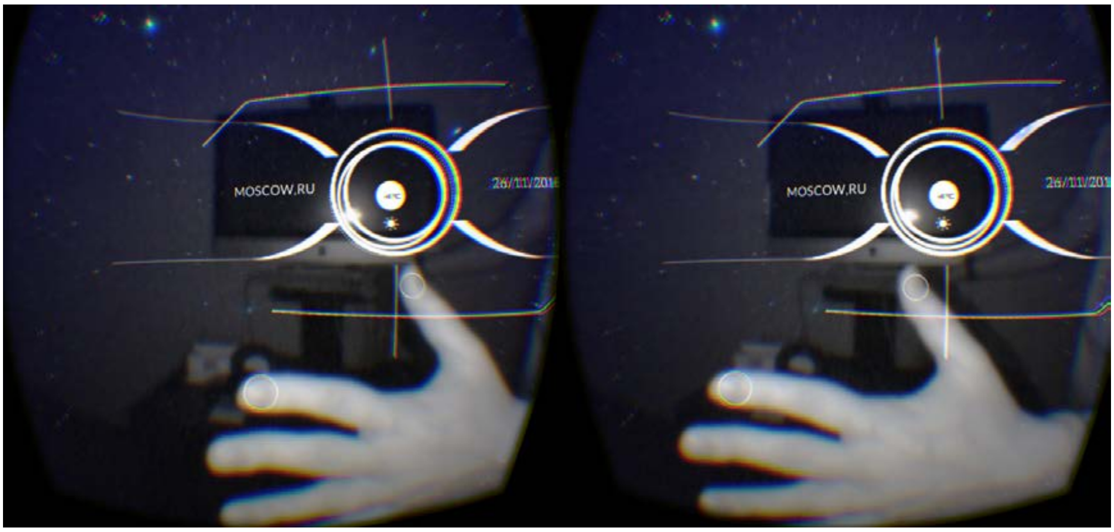


Figure 38. Weather system with UI interface design

From this observation, it has clearly reinforced the importance of the size of the object that plays a significant role in the intuition of the gestural interaction. The object in the virtual space must be scaled to the appropriate size in relation to the size of a person's hand. This will prompt the intuition for the user to interact with the object based on the size of the object. For example, in this study we observed many of the participants struggled to grab the compass "joyball" in the Planetarium app. When visitors would try and scale the sphere in weather app for the first time, they would always try to scale it two fingers, resembling the gesture performed on touch screens.

Figure 39. Finger recognition dots for virtual object interaction

6.2.1 Prototype refinements and further findings

Despite the guidelines being useful and successful in creating a positive experience for users, there were a few a few minor flaws that were discovered from observing users when attending the grad show. These minor issues were mainly due to the choice of navigation and GUI placements. For example, the button to go back to the previous menu interface was still visible when the main section was visible, which caused confusion for the users and thought the button was not working or that there were more options in the system. In future, this GUI button will be removed and present a prompt for using their physical hand gesture to perform a back and forth switch between menu tabs.

Another issue with the prototype was that when users would scale the font size past 30, the mesh does not expand enough to fit the whole text, which causes the labels on the UI to disappear or only present half of the word. For instance, the weather tab would be seen as ‘weat’, rather than showing ‘weather’. This error in the UI caused confusions and further needs to be fixed.

In addition to these two issues, another minor issue that needs to be implemented for future refinements is to add a limit to how much value a user can navigate between effects. For example, when users enabled the sea particle effect, they had access to high values which created uncomfortable experiences to some, due to the velocity and extreme frequency of the animation. There should be limited options for how much a user can toggle between values, which help towards creating a more pleasant visualisation.

These minor issues support the findings from Phase 1 and 2, providing a much more precise direction towards the six guidelines that have been derived from the observational studies and complementing current NUI and Leap Motion guidelines.

7. DISCUSSION

In this chapter, we will discuss the process of this study which conducted three phases, reflecting on the methodology and the proposed guidelines that were derived from current apps. These topics will be further examined in relation to the research questions and the research aim, which is to study and observe the interaction and experiences within immersive MR experiences and how gestural interactions affect UI and widgets in off screen spatial interactions.

7.1 METHODOLOGY REFLECTION

The process in this study was conducted in order to find out the trend in menu UIs that are currently available in existing MR apps. This provided an initial insight into what developers and designers have produced. In addition, the analysis for each app was compared against the characteristics of UIs by Wixon (2008). After which, a user observational study was conducted on five apps that are focused on menu UIs, which presented characteristics found in Phase 1 but also provided deeper insight into user behaviour with immersive gestural interactions.

7.1.1 Interviews and data collection

The interviews were successful and beneficial in this study as it provided very insightful qualitative data. A challenge encountered with the qualitative data was that many comments from the participants were too abstract and required to be further interpreted and supported by their video recordings during their experience. Also, the quantitative data that was collected before the interviews were helpful and provided an initial analysis of what sorts of behaviours would be seen by the participants.

In addition to the behavioural observation phase, the trend analysis data portrayed the current and future direction for apps and the results reflect many limitations of the devices and what alternatives could be presented for developers and designers to consider.

7.2 LIMITATIONS

There are a few technical limitations with the use of the devices that were used in this study. These limitations consisted of the tracking range that restricted the types of gestures that could be performed. For example, users do not have the ability to exaggerate their arm movements, causing them to have very limited focused hand gestures within the capture range of the infrared sensors. The pre-set hand gesture commands were difficult to converge with other open source libraries provided by developers. The conflict caused additional supporting scripts to implement new features to the application.

There were various issues with system compatibilities due to constant updates from the *Oculus Rift* and *Leap Motion*. However, this restriction of the capture range of the *Leap* sensor presents both negative and positive results. For example, the *Leap* provides users with the capability of being aware of their physical space as well as virtual displays, which helps prevent motion sickness or any other spatial discomforts.

Due to the processing power of the systems used to run the weather app, it was important to add the functionality to enable and disable particles and the UI so that the computer does not lag and lower the frame rate that could lead to camera distortion and cause server discomforts. However, by adding this feature in the app stops the user from experiencing a fluid experience, which is one of the characteristics of an organic experience.

There were also some limitations with the process of this research as well. For example, the results and findings of this study may be biased towards experiences which only may apply to the *Oculus Rift* and *Leap Motion* sensor. This further presents future studies to be conducted with other HMDs and analysing if there are similar findings and guideline uses. Also, the study was not done in real life scenarios such as a work environment or for educational purposes. Also, the final app prototype was not formally evaluated because of time constraints.

7.3 OUTCOMES

In this subchapter, we reiterate the three research questions of this study along with our findings to further address the outcomes from this study.

The first question focused on how effective natural hand gestural commands could be when using menu systems in virtual or mixed reality? Natural hand gestural commands are effective when using menus in immersive realities, especially when the composition of the widgets and interfaces are placed within the comfort zones and provide sufficient amount of feedback (Figure 32). In addition to this, from our observations it was also critical to consider the option for UI embodiment that present the ability to use graphical overlays on live imagery that projects into the headset (Figure 39). Furthermore, participants in this study also pointed out that by using gestures when navigating through multiple windows can be more intuitive and less of a hassle, rather than having to locate and press a physical button to shift between tabs.

The following question presented the opportunity to further explore on how the use of three-dimensional widgets and interfaces could create a more informative understanding of spatial interaction? Throughout the observational phase in our study, we noticed that the use of three-dimensional widgets did create a more informative understanding of spatial interactions. This is because the infrared cameras in the *Leap Motion* capture and present virtual objects that appear to be the same scale as physical objects that are presented to the user when wearing a HMD. This explains how the scale of an object/widget can evoke the users' behaviour for gestural use (Figure 36).

Since the following two questions above address the interactions and object manipulation within the *Oculus Rift*. The third question presented this study, looks into the investigation of how issues with HMDs could potentially stop users from experiencing natural and organic user interfaces? In the case of this study, the HMD is the *Oculus Rift*. As mentioned previously on the limitations of this study, despite the HMDs not having high resolution and having a limited FOV, there have been fewer issues with HMDs compared to the hand tracking capabilities on the *Leap Motion*. Since the Leap sensor is originally designed for being placed on a flat surface to interact with desktops and laptops, developers from the community have posted blogs on current guidelines for freelancers to read and apply methods to their apps. However, these guidelines focus on in-air gestures with physical desktop screens, rather than in-air gestures in immersive spaces for HMDs. As this study focuses on immersive experiences with HMDs, the presented guidelines in the previous chapter complement existing guidelines for immersive MR experiences.

Furthermore, the complementing guidelines below presented valuable insight towards the research questions which were derived from this study:

- Gestural interaction driven by actual scale for virtual objects
- Virtual and physical elements for hand recognition intuition
- Minimal spatial distribution for ease of interactivity through zones
- Embodiment with user interfaces driven by object and graphics
- Reinforcement for positive human-computer feedback towards phantom haptics
- Flexible and dynamic navigations through menu systems with dynamic visuals

These guidelines were further evaluated and used in creating a demo app that focuses on the use of embodied UI and gestural interactions to experience an immersive simulation of live weather data. This demo app will be submitted to the VR and AR communities as an open-source project for researchers and developers to further test and analyse for future works.

8. CONCLUSION

The growth in immersive virtual technology is continuously evolving for current and future generations. The action of 'doing' has been a part of users' interactions for many years, both in the digital and physical world. Users have access to direct input devices such as a keyboard, mouse and joystick, which share many properties of physical feedback such as vibrations, tactile sense and force touch. These devices share one common purpose in translating human input into digital commands. With the upcoming convergence of computing and the genesis of a new era in wearable HMDs, it presents a novel realm that presents the opportunity for further exploration into the world of the physical embodiment of user interface designs and widget interactions.

One of the main areas that require attention is the physical interaction with virtual perceptions in which users can be placed in, and further pushing the experience towards positive interactivity. The studies that were conducted in this thesis investigate how natural gestural interactions can be performed with UIs and menu systems within an immersive space and what differences and similarities are present between real life interactions and virtual object manipulation.

With current research in augmented and virtual realities, there continues to be an interest in both experiences which leads towards MR. This shift in realities is caused due to the high demands in physical augmentation and embodied UI. To further build on the existing guidelines for NUI and sensors like the *Leap Motion*, this thesis presents six complementing guidelines to enhance a positive experience for users when wearing HMDs.

Other improvements could be taken into consideration for the methodology in this study, which include the reduction of technical issues and analysing more apps that focus more on gestural UI interactions. Furthermore, it would be interesting to examine apps from other stores that provide MR experiences with other devices like the *Google* cardboard.

The contributions of this research present an in-depth analysis that gathers themes and guidelines from observing characteristics in user interface trends and observing user behaviours within existing applications. These applications are built for the use of the *Oculus Rift* and *Leap Motion* sensor which provide users with VR and MR experiences. To assist the results from this research, a prototype of a weather visualisation app was designed, implemented and followed the derived guidelines. This was accomplished after phase 3 to show future implementations which can produce more positive experiences for users who are experiencing MR and holographic UIs for the first time.

The results of this study offer new and current themes that may benefit future immersive experiences by reflecting on the proposed guideline principles. By further building on existing principles provided by the *Leap Motion* community which focus on desktop interaction, it allows this research to get a much deeper insight into user behaviour when interacting with user interfaces with in-air gestures within an immersive state. To further evaluate the findings, the app from this research will be submitted to the Leap Motion community as an open-source project for others to develop with for future works. Furthermore, this study presents alternatives and preferred commands for more immediate results, providing a clear idea of what kind of gestural navigational commands would be most appropriate when interacting in the new digital era.

In conclusion by conducting this research, developers and designers can utilise the data and findings to think about what is next in the realm of immersive mixed and virtual realities.

9. REFERENCE

Boas, Y. (2013). Overview of Virtual Reality Technologies. *Mms.Ecs.Soton.Ac.Uk*. Retrieved from http://mms.ecs.soton.ac.uk/2013/papers/yavb1g12_25879847_finalpaper.pdf

Bowman, D. a., & Wingrave, C. a. (2001). Design and evaluation of menu systems for immersive virtual environments. *Proceedings IEEE Virtual Reality 2001*, (0106).

Carter, M., Downs, J., Nansen, B., Harrop, M., & Gibbs, M. (2014). Paradigms of games research in HCI: a review of 10 years of research at CHI. *Proceedings of CHIPlay '14*, 27–36.

Colgan, A. (2015). Designing VR Tools: The Good, the Bad, and the Ugly. Retrieved from http://blog.leapmotion.com/designing-vr-tools-good-bad-ugly/

Dede, C. (2009). Immersive interfaces for engagement and learning. *Science (New York, N.Y.)*, *323*(5910), 66–69. http://doi.org/10.1126/science.1167311

Dourish, P. (2001). Where the Action Is : The Foundations of Embodied Interaction (Vol. 36, pp. 412–413). MIT Press.

Dzubak, C. (2007). Multitasking: The good, the bad, and the unknown. *Synergy The Online Journal of the Association of the Tutoring Profession*, *1*(2).

Elo, S., & Kyngäs, H. (2007). The qualitative content analysis process. *Journal of Advanced Nursing*, *62*(1), 107–15. http://doi.org/10.1111/j.1365-2648.2007.04569.x

Erazo, O., & Pino, J. A. (2015). Predicting Task Execution Time on Natural User Interfaces based on Touchless Hand Gestures, 97–109.

Gartner. (2015). Hype Cycle for Emerging Technologies. Retrieved from http://www.gartner.com/newsroom/id/3114217

Ghalwash, A. Z., & Nabil, S. K. (2013). Organic User Interfaces: Framework, Interaction Model and Design Guidelines. *International Journal of Ad …*, *4*(4), 39–58. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=09762205&AN=90253279&h=rhhqz7aGEs8ebMaRtc0w8C1vrHYwL9SzFF/zx2Em04W2SFgWlQL7K+5vKWEQr0A0H

s1BP+3iXzTwFkmmtKjc2Q==&crl=c

Gilliek, L., & Coz, S. J. (1989). Speech Recognition Algorithms. *Test*, (61), 532–535.

Grinter, R. E., & Palen, L. (2002). Instant messaging in teen life. *Proceedings of the 2002 ACM Conference on Computer Supported Cooperative Work CSCW 02*, *2118*(New Orleans, Louisiana, USA), 21. http://doi.org/10.1145/587079.587082

Hand, C. (1997). A Survey of 3D Interaction Techniques, *16*(5), 269–281.

Hembrooke, H., & Gay, G. (2003). The Laptop and the Lecture : *Journal of Computing in Higher Education*, *15*(1), 46–64. http://doi.org/10.1007/BF02940852

Hespanhol, L., Tomitsch, M., Grace, K., Collins, A., & Kay, J. (2012). Investigating intuitiveness and effectiveness of gestures for free spatial interaction with large displays. *Proceedings of the 2012 International Symposium on Pervasive Displays - PerDis '12*, (June), 1–6. http://doi.org/10.1145/2307798.2307804

Hinman, R. (2012). *The mobile frontier: A guide for designing mobile experiences*. Brooklyn: Rosenfeld Media.

Hoberman, C. (2003). Hoberman Transformable design. Retrieved from http://www.hoberman.com/

Huckaby, T. (2013). The Engaging User Experience & The Natural User Interface. Retrieved from http://eecatalog.com/digital-signage/2013/12/09/the-engaging-user-experience-the-natural-user-interface/

Jacoby, R. H., & Ellis, S. R. (1992). Using virtual menus in a virtual environment, *1668*.

Kyoung, D., Lee, Y., & Jung, K. (2007). Immersive Viewer System for 3D User Interface. In *Human-Computer Interaction* (Vol. 4551, pp. 624–633).

LaViola, J. (1999). A survey of hand posture and gesture recognition techniques and technology. *Brown University, Providence, RI*. Retrieved from http://www.pervasive.jku.at/Teaching/_2012SS/SeminarausPervasiveComputing/Begleitmaterial/Related Work/1999_A Survey of Hand Posture and Gesture Recognition Techniques and Technology_LaViola.pdf

Leap Motion. (2015). Camera Images. Retrieved August 26, 2015, from https://developer.leapmotion.com/documentation/csharp/devguide/Leap_I mages.html

Lee, C., Choi, J., Oh, K., & Park, C. (1999). Hand Interface for Immersive Virtual Environment Authoring System. *… on Virtual Systems and …*. Retrieved from http://www.research.rutgers.edu/~chansu/paper/1999/VSMM99_CS.pdf

Lia, A., & Kapri, F. Von. (2013). InReach: Navigating and Manipulating 3D Models using Natural Body Gestures in a Remote Collaboration Setup.

Linfo. (2007). What is a command line interface definition by The Linux Information Project (LINFO). Retrieved from http://www.linfo.org/command_line_interface.html

Manresa, C., Varona, J., Mas, R., & Perales, F. J. (2005). Hand Tracking and Gesture Recognition for Human-Computer Interaction. *Electronic Letters on Computer Vision and Image Analysis*, *5*(3), 96 – 104. http://doi.org/10.5565/rev/elcvia.109

Milgram, P., & Kishino, F. (1994). Taxonomy of mixed reality visual displays. *IEICE Transactions on Information and Systems*, *E77-D*(12), 1321–1329.

Mine, M. R., Brooks, F. P., & Sequin, C. H. (1997). Moving objects in space. *Proceedings of the 24th Annual Conference on Computer Graphics and Interactive Techniques - SIGGRAPH '97*, 19–26. http://doi.org/10.1145/258734.258747

Pavlovic, V. I., Sharma, R., & Huang, T. S. (1997). Visual interpretation of hand gestures for human-computer\ninteraction: a review. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *19*(7), 677–695.

Rosen, C. (2008). The Myth of Multitasking. *The New Atlantis*, *Spring*(20), 105–110. http://doi.org/http://dx.doi.org/10.1038/scientificamericanmind1204-62

Rubin, P. (2014). The Inside Story of Oculus Rift and How Virtual Reality Became Reality. Retrieved from http://www.wired.com/2014/05/oculus-rift-4/

Saffer, D. (2008). *Designing Gestural Interfaces*. *Annals of Physics* (Vol. 1). Retrieved from http://www.designinggesturalinterfaces.com/samples/interactivegestures_ch1.pdf

Sasaki, H., Kuroda, T., Antoniac, P., Manabe, Y., & Chihara, K. (2006). Hand-Menu System : a Deviceless Virtual Input Interface for Wearable Computers. *Romania*, *8*(2), 44–53.

Shedroff, N., & Noessel, C. (2012). *Make it So: Interaction Design Lessons from Science Fiction*. Retrieved from http://rosenfeldmedia.com/books/make-it-so/

Shneiderman, B. (2000). The limits of speech recognition. *Communications of the ACM*, *43*(9), 63–65. http://doi.org/10.1145/348941.348990

Superdiddly. (2010). Dynacan: An interactive multitouch pop can and example of a rigid Organic User Interface. Retrieved from https://commons.wikimedia.org/wiki/File:Dynacan_interactive_multitouch_pop_can.jpg

Takatalo, J., Nyman, G., & Laaksonen, L. (2008). Components of human experience in virtual environments. *Computers in Human Behavior*, *24*(1), 1–15. http://doi.org/10.1016/j.chb.2006.11.003

Tomitsch, M. (2003). Trends and Evolution of Window Interfaces, (December).

Van Someren, M. W., Barnard, Y. F., & Sandberg, J. A. (1994). *The think aloud method: A practical guide to modelling cognitive processes*. *Department of Social Science Informatics, University of Amsterdam*. http://doi.org/10.1016/0306-4573(95)90031-4

Wallis, C. (2006). The multitasking generation. *Time*, *167*(13), 48–55.

Ware, C., & Rose, J. (1999). Rotating virtual objects with real handles. *ACM Transactions on Computer-Human Interaction*, *6*(2), 162–180. http://doi.org/10.1145/319091.319102

Wigdor, D., & Wixon, D. (2011). Brave NUI world. *ACM SIGSOFT Software Engineering Notes*. http://doi.org/10.1145/2047414.2047439

Wixon, D. (2008). UX Week 2008 | The Challenge of Emotional Innovation. Retrieved August 25, 2015, from https://vimeo.com/2893051

Zhou, F., Dun, H. B. L., & Billinghurst, M. (2008). Trends in augmented reality tracking, interaction and display: A review of ten years of ISMAR. *Proceedings - 7th IEEE International Symposium on Mixed and Augmented Reality 2008, ISMAR 2008*, 193–202.

APPENDIX A

Pre-study questionnaire

The study of natural hand gestural commands to navigate and interact with immersive 3D Interfaces and widgets

1) What age group are you in?

☐ 16 - 24

☐ 24 - 35

☐ 35 - 46

☐ 46 - 60

☐ Over 60

2) Which gender are you?

☐ Male

☐ Female

3) Please specify your ethnicity:

☐ Aboriginal / Torres Strait Islander

☐ Asian

☐ Black / African descent

☐ East Indian

☐ Latino / Hispanic

- ☐ Middle Eastern
- ☐ Pacific Islander
- ☐ White / Caucasian

If other, please specify below:

____

____

____

4) Which devices do you use on a daily basis?

(Example : Mobile phone, desktop computer, laptop...etc.)

____

____

____

____

____

5) Have you ever experienced virtual or augmented reality before?

If yes, please specify how your experience was like, either good or bad.

____

____

____

____

____

APPENDIX B

Interview questions

The study of natural hand gestural commands to navigate and interact with immersive 3D Interfaces and widgets

First Impression

1) What were your expectations of the Oculus Rift as a device?

− Could you elaborate on how it felt like when putting on the device?

2) Did your experience live up to what you thought augmented reality is about?

− Would you say this is an exciting way of interaction?

Usage

3) Was the interaction easy and would you say it was intuitive?

− Is there any particular task or app that you found most useful?

− Would you prefer doing this task on a virtual headset or any other device?

4) How did you feel about the quality of the interaction?

− Do you think virtual reality would be better than augmented reality?

− Why would this be a better experience?

5) Do you think the pre - set hand gestures were easy to use? / How do you think it could improve?

− Can you name a few of the existing commands you find most beneficial for navigation on a natural interface?

- If you had to add any new gestural commands, what would they be?
- How do you see these gestural commands useful?

Evaluation

6) Were there any difficulties you faced when navigating through the virtual/augmented space?

- Do you think these difficulties are important to fix?

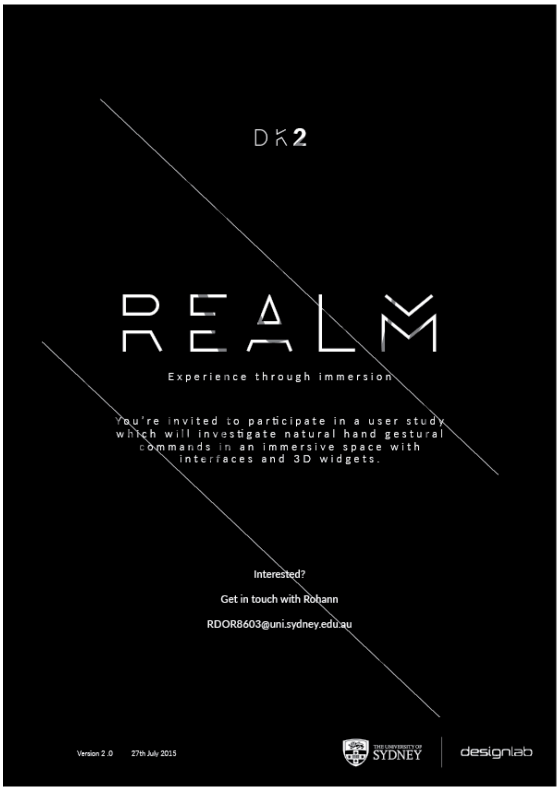
7) Are there any possible changes that you feel are critical for the interaction?

8) Do you have any other comments about your experience with the three tasks?

APPENDIX C

Recruitment advertisements

Posters:



Information Flyers:

APPENDIX E

Interview Transcripts

Participant 1

First Impression

1) What were your expectations of the Oculus Rift as a device?

It is really amazing, a bit blurry at first but once you use it for more than 5 minutes it is really easy to see things and experience without feeling weird.

− Could you elaborate on how it felt like when putting on the device?

I felt a lot of suspense as if feeling like something scary or shocking is going to hit my face. I have never felt anything this close to my face before. I felt anxious about what I was going to experience.

2) Did your experience live up to what you thought augmented reality is about?

I did not expect it to be this immersive when wearing a headset like this. It felt really unreal and almost as if everything was happening to me in a real state. But when there were a few glitches here and there, it started to wake me up, and I could tell that this was all a gimmick.

− Would you say this is an exciting way of interaction?

Definitely, this the most exciting way of interaction with systems that I have experienced. I enjoyed using my hands to navigate and move around with different commands.

Usage

3) Was the interaction easy and would you say it was intuitive?

Some parts were intuitive but not all. There are many parts that required me to use all my focus to get it to work, but it still was glitchy and didn’t feel all that natural.

- Is there any particular task or app that you found most useful?

One of the apps that stood out for me was the planetarium that was really useful to use and see spatial networks. The menu system was glitching when switching between the arm displays and constantly kept showing me different hands around the area. The animations in the app also slightly made me feel dizzy when it zoomed into open space.

- Would you prefer doing this task on a virtual headset or any other device?

I would prefer to do it on a headset because it gives me a much more immersive experience that would be hard to do on a mobile device for example. I think it would be still really cool to see it in a projected display to be surrounded by it.

4) How did you feel about the quality of the interaction?

I feel like it was good but has a lot of room for improvement and reconsideration towards the interaction of the user interfaces in the scene. There need to be more menus that present more feedback when interacting, like when hitting a button.

- Do you think virtual reality would be better than augmented reality?

I feel that virtual reality would be better because it is good to experience things that you do not see or face in reality all the time. Augmented reality only gives illusions that potentially make things seem more subsided when interacting with.

- Why would this be a better experience?

It would be a better experience because it can present new innovative digital content to users and provide a new element of surprise to the content for the interface interactions.

5) Do you think the pre-set hand gestures were easy to use? / How do you think it could improve?

Some of the pre-set hand gestures were easy to use, like the ones in Hovercast were easy to use but also tricky because they did not give much of a feedback response when hitting the buttons. The widget buttons had good feedback and easy to use because they had depth in them.

− Can you name a few of the existing commands you find most beneficial for navigation on a natural interface?

Despite having difficulties with the brain app, I found that the whole way of moving the parts of the brains with my open hand gesture was good and very useful, made it feel natural, but didn't have much purpose to it.

− If you had to add any new gestural commands, what would they be?

I would really like to add a scale gesture to the apps because that is something that really needs to be present. Also the ability to move and swipe interfaces so that there is more customising of the menu system since it is all around in 360 degrees.

− How do you see these gestural commands useful?

I feel these would be useful especially since these interfaces and systems are now capable of being used in a third dimension, and it is no longer on a flat surface. Would be great to see that functionality.

Evaluation

6) Were there any difficulties you faced when navigating through the virtual/augmented space?

One of the most memorable difficulties I faced when experiencing these realities was figuring out what is around me. Because I had to turn a lot first, did make me a bit nauseated and lost at times, making me lose track of where my starting point was for the interaction.

- Do you think these difficulties are important to fix?

Yes, because it gave a very insecure feeling when diving into a new space where you are not aware of your surroundings, and having to turn around every so often can get very tiring and hard on the eyes.

7) Are there any possible changes that you feel are critical for the interaction?

There should be a menu tab or an information tab that would remind me how to go back and forth; there were only two apps out of the five that provided the option to go back and forth without getting lost. At times, I would forget what commands I was meant to do and just ended up breaking or fooling around.

8) Do you have any other comments about your experience with the three tasks?

I feel the experience was really nice and enjoyable, and it presents a lot of growth in the design and experience for interaction with the capabilities of using your hands.

Participant 2

Interview Questions:

First Impression

1) What were your expectations of the Oculus Rift as a device?

Well, I expected a lot, I know a lot about the Oculus, I read a lot about it. I do not have one myself, but I use the Google cardboard and what I was expecting was it to provide fully immersive experiences, and it did that. I think it does not have the issues that other devices like Google cardboard has like the drifting issue, so everything stays in one place which is really cool. I guess being able to walk up close to things is really cool. Something I did not realise that you could do that I found out from this test is the use of Leap Motion; it adds another dimension. Adding something to Oculus that is missing, making it an intuitive control method.

- Could you elaborate on how it felt like when putting on the device?

Already mentioned this above – It felt pretty awesome, like the movies like Iron man reference which is pretty fitting for this kind of experience.

2) Did your experience live up to what you thought augmented reality is about?

Yea, it did live up to the experience of mixed reality. I did see you in one of the examples, in the Planetarium one, I could look right up and see the pipes in the room. That kind of brought me back to reality a bit. Gave me a glimpse of virtual and physical space.

- Would you say this is an exciting way of interaction?

It was a very memorable experience for me. It’s weird like it's different to just playing a video game. Like video games, you forget what your do pretty easily. This just feels like a real experience for me. So you know it is really cool.

Usage

3) Was the interaction easy and would you say it was intuitive?

Yes, it was for everyone except for the brain connectivity one and I guess the issue with the brain one was I couldn't really read the text of the starting instructions very well. Either way, I don't really like reading Instructions for things I like just diving in and first and experimenting. So yeah I figured out a lot of stuff on my own like making a red thing come out of my hand and then using the sliding things to make the brain bigger or something that I didn't really fully understand it is I don't think, I did everything that I suppose to in that one. The other one that was a bit strange was the last one the D.J. one which was kind of expecting to be able to use my finger like the previous ones but this one just had a little cross hair thing underneath my hands. So I didn't really feel that natural, I got used to it eventually and it was working quite well but at the start it just didn't feel quite natural to me compared to actually the finger.

− Is there any particular task or app that you found most useful?

Going back to the D.J. on I think the buttons were quite big and were a lot easier to press on. But I guess the other cool thing was the first one I used called the widgets app actually pressing on the slider button, and it was actually like making an indentation like the button was actually being pressed visually see that actually made it more compelling for me.

My brain was like. But it shouldn't be working. You should actually feel something. I knew when to stop my finger, when it made that indentation I knew that was when it was getting triggered having my finger was going through the button, kind of sort of felt weird. I guess like in the future once on a haptic glove or something a little bit better than. Maybe that will be solved to make it better.

− Would you prefer doing this task on a virtual headset or any other device?

No that was cool I think the demos are very suitable for virtual headsets.

4) How did you feel about the quality of the interaction?

As a said with a button, that feedback was good for letting me know that I've actually pressed something. I think that's quite important. Especially if you don't actually have the haptics. Which is natural. Like if I touch on the table like I can feel it, and I know where to stop my finger. You know that stuff its good.

− Do you think virtual reality would be better than augmented reality?

Depends on the usage scenario like for those apps, they suited well for VR because there are good demonstrations of the technology. But like if it was in the real world. It depends on what I'm doing like if I'm trying to visualise like if I'm walking around if I'm an architect or something and I'm walking around the building, and I want to see the pipes inside the wall. Then obviously AR would be the way to go, but then even VR may work to be physically there. It could be done to personal preference and their usage.

Perhaps if you are really using multiple uses a new wanted to see the representation of other people that are also in that same world that could actually be a good usage scenario instead of actually having an avatar representation. You can actually just see the real person. That's good. And actually many of the same my hands as well. That was another thing like in the in our world. I have used other be our experiences with other interaction methods like using a controller and using the magnet switch on the cardboard but this is so much better to me and way more natural.

Yeah very intuitive. I think that's kind of what your brain expects to be able to see your hands if you lift your hand up, and you flip your hands then you can actually see that.

− Why would this be a better experience?

I think this would be a better experience because it gives positive abilities of both realities and provides a nice convergence.

5) Do you think the pre-set hand gestures were easy to use? / How do you think it could improve?

The planetarium one had pre-set hand gestures for example for rotating the earth which I think was beneath me. That wasn't really obvious I could do that at the start, and then I found that by accident I just put my hand down. And then suddenly that appeared like the outline of the compass, and I'm like oh what that is. So then I reached down and then the compass appears again. And this time it's brighter. And then a little box comes up and shows me that I can actually like I have to close my hand, but it doesn't actually tell me like what actually do from there. So then it took me awhile to figure out that it's actually just to turn the compass.

First to improve it, the animation was very fast. It was way too fast for me. I think if it was a bit slower and maybe. Actually I wouldn't use a compass for that. A compass just didn't seem right, and because it was sphere I tried to rotate it with both my hands.

− Can you name a few of the existing commands you find most beneficial for navigation on a natural interface?

Well, I did some research a while back earlier this year with a digital information. This is not VR or anything but actually navigating we found that users felt the grab and pull gesture to like navigate horizontally. Is actually quite intuitive more intuitive than say like just touching to navigate to the next slide or whatever it is. And actually having it actually reacting with like what I mean is like actually when you do the grab as you're pulling. Whatever you're pulling is actually moving with you as well. And then once you let go it will snap back to where it was before. Part of transition. That was like that's quite intuitive I think.

− If you had to add any new gestural commands, what would they be?

There might be some cases where you want to do a pinch gesture as well. Depends again on the usage scenario I guess like maybe for the like the little dials you had like when I had to push and then move my finger. Maybe it might be more natural to do the pinch. And then move. Because I guess, that’s what we do in real life. If we had that sort of thing

− How do you see these gestural commands useful?

I guess one of the gestures you had in that all the demos is the push gesture. That's very natural and obvious. And which was that. I think every one of them had a button.

Evaluation

6) Were there any difficulties you faced when navigating through the virtual/augmented space?

Something that comes to mind is the D.J one or whatever that was called. I kept accidentally hitting the menu, but that was possibly the only time.

But in and maybe the text wasn't clear enough on this well, so I didn't really like straight away recognise what the things were that I was pushing on or like if I wanted to go back to a previous menu was the really obvious where that button was and only found it by mistake.

- Do you think these difficulties are important to fix?

Yes, I feel they need to be addressed or looked into especially the stillness and load of text for the brain connectivity application.

7) Are there any possible changes that you feel are critical for the interaction?

As I said before, I guess haptic feedback would be really good. I guess you could get away with like actually knowing the button is visually being pressed

I guess as the end goal would be for haptics. Like that, that's something I personally would really like in a system is being out of touch and not being able to put my hand through the thing. It's another thing like there were many cases where my hand would go through menu items.

And that kind of wasn't really. I don't know if it was immersion breaking. The visuals kind of felt like it was a hologram anyway.

8) Do you have any other comments about your experience with the three tasks?

I can probably use these apps all day. Even though they look quite boring, they are quite fun just to play around with.

I think the widgets was really awesome that felt really good and natural, and I like the Soundscape VR. I didn’t like the palm interaction, but I liked the big buttons. The worst one was the brain connectivity app; it was horrible.

Participant 3

Interview Questions:

First Impression

1) What were your expectations of the Oculus Rift as a device?

To put me in another world. To take me away from where I was sitting which it definitely did.

− Could you elaborate on how it felt like when putting on the device?

Yes, I mean the straps are a little confusing I didn’t see the velcro thing aside from that it was all sweet. And then toward the end of the session the plastic part of the Oculus was on the end of my nose pressing. Slight discomfort from wearing it.

2) Did your experience live up to what you thought augmented reality is about?

Ah, yes I believe so. The second and third app one's a little bit less just because I couldn’t see the rest of the room so I was really sure where I was standing and if I was going to hit things I wanted to put the first one the source that was like you know I could see the computer could see you interact with things directly in front of me which is cool.

− Would you say this is an exciting way of interaction?

Yeah, definitely that was it was fun to hit buttons in front of me and like sort of scrolling stuff in front of me straight out of a Sci-fi, Sci-tech movie.

Usage

3) Was the interaction easy and would you say it was intuitive?

On the most part. I think like there were times when the device wasn't picking up my hand movements or like my hands would sort of like flip around stuff which made things a bit hard especially the last one that sort of soundscape. It didn't seem to be picking up my presses and was like hitting things I was attending I had to skip like spasming out in the air.
The fake hand wasn't more than picking up. What I was trying to do. There was a point something that I think was part of the programme where I had a button and then everything just went red and I think I might have been late I was changing a setting, I thought I was like it's something wrong.

− Is there any particular task or app that you found most useful?

I think the first scrolling on was pretty was pretty intuitive. Having the second one where I was playing with the brain. That was pretty cool just to be able to look up and see things come down but over time I'm not sure if they're supposed to move or whatever, but they're like moving next to me and I'm like moving down the ramp. I kept looking in the same spot for the controls, but they weren't in the same place every time.

− Would you prefer doing this task on a virtual headset or any other device?

Probably the headset so you can sort of still like to move around certain things like especially the brain one. I was cool to be able to let me my head around underneath it and stuff.

4) How did you feel about the quality of the interaction?

The most part of it was good, especially in the first two apps. But then the second two it was not picking up on my hands as much.

− Do you think virtual reality would be better than augmented reality?

I suppose it depends on what you're trying to get out of it. Yeah of you want to if you like controlling stuff and actually doing. I guess some sort of work with all those systems and mixed reality would be good. But VR in terms of the immersion. I guess you'd probably want one of or at least like the mix of both.

Maybe like it's a virtual world within a sort of representing some of the limitations of your room like you said make fake walls or something run into.

− Why would this be a better experience?

It would be better because it can make the eye believe what is impossible in reality to be possible through illusions through virtual reality.

5) Do you think the pre-set hand gestures were easy to use? / How do you think it could improve?

I think like intuitively, when I picked up and pressing the buttons are required that sort of extended motion and stuff. And for the most part, it was pretty it made sense. I didn’t really understand how to use the scrolling things with the animals on it. I was trying to I was finally spin it but maybe I wasn't doing any I was in not doing the right action. Aside from that that everything, like the pre-set hand gestures, seemed to make sense apart from the soundscape one I think I was doing something wrong in terms of just poking things.

− Can you name a few of the existing commands you find most beneficial for navigation on a natural interface?

Probably would mainly be I guess touch interface that I am more used to so there were times I was trying to like sort of bring the menu on like to swipe down on the iPhone and Android if you just sort of slide down thing to bring that down. I was thinking of it like you know when I had that sort of a list of texts that I saw them to get to the brain one I was from left to right what that was right all times I'm in to get past it. And at time things used to touchscreen devices.

− If you had to add any new gestural commands, what would they be?

Bring down the menu in some way or wipe the screen or even like a calibrate function that like sort of examines the way I was pointing when I was in that sound app. I think I was supposed to be doing some like specific pointing gesture something which didn’t make me feel right.

− How do you see these gestural commands useful?

It would make things a lot easier to understand what I could do on the app. I think if the objects don’t speak out loud on what they are meant to do, or what you can do with them. It can get frustrating if no useful tip is presented.

Evaluation

6) Were there any difficulties you faced when navigating through the virtual/augmented space?

Not necessarily only in terms of the not understanding my goal for someone like the first I thought also solve some problem, but it was just like pressing buttons. And also the second one I was playing with the brain and sort of doing like sliding the sliders but I was unsure if I was supposed to activate something to get past to go further in the app.

- Do you think these difficulties are important to fix?

Yes, I think these need to be addressed so that people can understand what they are going to experience and add more purpose to the apps.

7) Are there any possible changes that you feel are critical for the interaction?

An info tab or help section if you get lost and maybe some labels to some of the sliders like in the in the brain like wasn't really sure the sliders did and just thought I was just playing around and nothing was happening.

8) Do you have any other comments about your experience with the three tasks?

Not really it was pretty fun, Thanks.

Participant 4

Interview Questions:

First Impression

1) What were your expectations of the Oculus Rift as a device?

First expectations were it’s like a big giant computer monitor that's like an inch away from the head, I that's how it feels. Now I'm going to guess the expectation is even before I tried one which was about two months ago. It's hard to describe. I read reviews about the Oculus Rift the original one the second one the other one for the camera. And it's interesting people literally are reviewing it and saying there are no words to sort of describe it and that you have to experience it for yourself and I never understand why. Because there are times you actually feel so immersed by it especially say that I want to you've landed. And I did I was looking up and looking all cool.

- Could you elaborate on how it felt like when putting on the device?

Eyestrain, probably just because he has something fitted onto your head. You know it’s a lot heavier than glasses. I don't actually now. Doing it the second time I don't think that it was actually my eyes that were straining, like you know we watch too much T.V. But it was rather just the weight of the thing on my head.

2) Did your experience live up to what you thought augmented reality is about?

Yes, totally, I guess I’m not so smart but I'm well and knowledgeable enough about how the technology works. In this current evolution of it to know that it's not perfect and that like. You know what you see can definitely improve but I think it's a great proof of concept and there're so many different uses for already. Things like you know graphics or like the. Sometimes when you move the tracking gets a little off. But it's really really cool. I mean definitely that's up to expectations because it was fabulous.

- Would you say this is an exciting way of interaction?

Yes, it is a fresh and exciting way of interacting with user interface systems, I think it has a lot of potentials and can be a new form of human and computer collaboration.

Usage

3) Was the interaction easy and would you say it was intuitive?

I think out of all of them, the first app widgets and the last one Hovercast VR is the easiest. I think having all the controls spaced out makes a huge difference. One of the issues I have with the VR soundscape sequencer was that when you go to tap on the boxes and accidently hit every other box except the one you're wanting to hit. Also the way that it tracked your hand maybe the software and in which you know if I was pointing or not wasn't very good but it felt like at times like this and it didn’t work. And also just for those buttons you know there was no feedback you know when you press a button it squishes down. And most interfaces. I didn't see that and was really tricky. Although you know you're seeing it and you're touching. That's not enough feedback maybe would be cool if you have a vibration or sound when you've hit something. You know like on your hand. Something like but it's current form I didn't think the drum sequence was very easy to use. Gestures with the maps in the Planetarium app were a little hard to figure out if you don't know if you don't read that to tutorial beforehand. Basically, I could understand what he's saying about the fist but it can never get it to work until I stumbled upon it and it did take me a long time to get finally shown how to bring the settings up. That was not intuitive at all and I did not know that there was a difference between the left hand in the in the right hand and how Horton they also maybe ones use for obviously grabbing ones your wrist watch. That's something I think maybe it's just like you know you use it and then after to you understand that people develop as well be like that and they you know right importance on the left and right hand. I also am left handed I might say, I rather like pointing with my left hand.

− Is there any particular task or app that you found most useful?
The first one and the last one were very useful and intuitive

− Would you prefer doing this task on a virtual headset or any other device?
I think nothing beats the how massive and Oculus wearing and also a headset can be. You know you see. I've not used obviously but like other devices like the Microsoft HoloLens. Also very cool. I think the difference being that you're wearing telegraphic glasses rather than a headset. I think what you would also trying to achieve its very similar in terms that because you have the leap motion. But then the field of vision for that apparently is very limited so I think this is a great. I wouldn't say compromise but another way of trying to get that interaction into the hands of people Widget interface. When you blend the real world into you, know on screen computing. What they call augmented reality on these phones? It's Terrible. It's a gimmick feature that I've never ever actually used in real life like who wants to go like this you look around saying like an idiot but also like you can really easily just you know use a compass. To point in the right direction. People would rather see the real world which then seeing a portion of it on the screen. That being said if you're wearing an Oculus then that would be cool. I guess maybe like if you have to walk around. That would make it for a very interesting scenario. And also maybe how far away those widgets appeared in front of you. When you said that you use the interfaces to exploring that in your honours, project the first thing came to mind was Minority Report. A lot of people might have probably said that. And like I was expecting to use gestures with your hands do things like that and I think at the very from the how I felt. But it's like almost we've taken a step forward in a step backwards in the step forward in the sense that we're using Oculus Rift and virtualizing it instead of having out on the screen like a glass screen and a step back in that the control isn't as intuitive as expected. Yeah, maybe you need an expert on some of that's right that's coming what was studying. What it takes to become an

expert what sort of instructions you need to be shown I think if you saw in the Deep end of it in that they'd be terrified.

4) How did you feel about the quality of the interaction?

I felt the quality of the interaction was decent once I figured out the methods of interaction, but it was very frustrating and challenging and took a long time to figure out what to do.

− Do you think virtual reality would be better than augmented reality?

If we focus on, for example, an aspect of your hand. Yes, totally. I mean I'd rather see my hand than a computer tries to guess how my actions are being augmented, especially as how inaccurate it was. But I think there's a place for both. I mean if you could play Second Life you know I think and World of Warcraft and that's just virtual reality. That would be cool but at the same time. There are so many different uses for mix reality. You're a pilot flying a plane you get to see where you're going all like you driving a car. You can also have control. Maybe not have like the new Twitter feed you know it's going down this side but like important information and I think the right way of doing mixed reality is context and so having the right amount information shown at the same time to not overloading the person.

− Why would this be a better experience?

Because it would give me a better sense and understanding of what I'm going to be doing. So that is why it would be better.

5) Do you think the pre-set hand gestures were easy to use? / How do you think it could improve?

The Hovercast VR and widgets were easy to use, but the other apps were not easy without a tutorial.

− Can you name a few of the existing commands you find most beneficial for navigation on a natural interface?

Physically pressing the button. Like when you go to flick a light switch the gesture you have where you know you have your index finger pointing out and everything else is folded and clicking. That makes. I think it makes it easier for it to understand but also as a person that's the first thing you will try to do when you see a button, to try to click it.

− If you had to add any new gestural commands, what would they be?

Grabbing handle. TouchPoints. That's less than a larger touch when you don't have to be that. I think what people when you see those movies like Minority Report I'll go back to that example because it’s easier to explain. Seemed very like doing a simple like things like that that's hard because it's like you have to be so accurate and I think what people understand with virtual reality is that if you're not holding a control if you're just simply using your hands, you have to make the buttons as big as possible.

− How do you see these gestural commands useful?

For simple manipulation and interact with the menu systems would be useful and best to work with. I think this will reinforce the whole interaction with the experience.

Evaluation

6) Were there any difficulties you faced when navigating through the virtual/augmented space?

Once I got the hang of the planetarium one it was fine but they were hard to use. They too sensitive to the compass. And I got dizzy from just like. I mean maybe it's a real slight gesture. I had this is really tricky because I understand. You know how to track your hand is hard but like if I went like that too much to be too dizzy. Did not have any idea about the whole fist with one hand. Turning it over to face yourself. I actually had to be told by that from you twice because you told me how to grab a star and twist my hand over. Now that you've mentioned to me it makes sense much like an idiot. But at the same time I'm never suggested. Also, I didn't mention much about the brain connectivity one because I didn't understand it very well.

- Do you think these difficulties are important to fix?

Yes, they have to be addressed because they tend to get me distracted and wanting to stop the experience and put down the headset.

7) Are there any possible changes that you feel are critical for the interaction?

Maybe a video like a tutorial basically that people won't just text in a virtual reality is hard. Firstly, because the screen isn't high resolution. I don't know what it's called where the lines appear when you move which are a pain when you move too much. Hard to read. That whole the brain connectivity one with the text was tiny and so hard to read. Though I could see your widget application fine, but on the other hand. Like I had to strain of it to read some of the edges of writing but I so I don't know. In terms of something that's critical is an exit button and also once menu systems disappeared like an onboarding would be good.

8) Do you have any other comments about your experience with the three tasks?

Second one very hard to use. I don't know if it was just the first simple but like simply grabbing something. Confuse the hell out of me. I think the coolest thing about that was I could face my head. And I'd like go right into the brain but I can see much. If I had to rank these apps, I would say the widgets and Hovercast is number one, and brain connectivity would be last. Soundscape would be three and planetarium would be two.

Participant 5

Interview Questions:

First Impression

1) What were your expectations of the Oculus Rift as a device?

Yeah, I really enjoyed it. I thought it was going to be like the flight simulator. Kind of thing where there's like a space and then this like control panel. But I didn't think that people around me would look like zombies because all was black and white and that was really cool because it's scary.

- Could you elaborate on how it felt like when putting on the device?

I felt the device was a bit too loose for me even though it was adjusted to the smallest size and that sort of gave me like the experience of a slight headache but otherwise it felt all right, a bit heavy, though.

2) Did your experience live up to what you thought augmented reality is about?

I wasn’t sure what those realities were until I experienced these applications

- Would you say this is an exciting way of interaction?

Yes, it was very exciting and I loved the interaction with my hands, even though it was very bad at responding to my commands.

Usage

3) Was the interaction easy and would you say it was intuitive?

No to be honest. The interface wasn't easy to use. I thought that the UI was not good because like for example in the planetarium app, the arm UI was all loose like my arm was very skinny but then it's like kind of chubby like it was kind of wide and then I try to like look for which button to press and when I hit the button it didn’t work, because then I realized that it wasn’t a button, so it was a poor affordance. Until I found the edit button which was when I realised that there were more functions to it. So I was really unclear like the buttons that were presented. And also it disappeared from time to time and didn’t know how to make it stable. But yes it took a while to figure it all out.

− Is there any particular task or app that you found most useful?

The second one the brain connectivity because it's most flexible as well the third one which was the planetarium one that was boring until I found the editing process. But the second one was fun. Like because you can sort of like move your hands around you feel like you're in control. You have power. And I like the red and blue stuff.

− Would you prefer doing this task on a virtual headset or any other device?

Yes, I think the apps worked really nicely on the virtual headset and would have lost its properties if it was presented to me on for example a mobile, or even a projector.

4) How did you feel about the quality of the interaction?

I felt the quality was not great, the only one I found easiest to use was the widgets app because it was clear in the direction of the interaction.

− Do you think virtual reality would be better than augmented reality?

I liked the mixed reality feel because I could sense where exactly I am and how I was interacting with the objects around me, I thought that was really cool.

− Why would this be a better experience?

Because it felt more natural than being completely in the dark and having this heavy device on the face, I think there needs to be a good balance between the wearable experience and the digital experience it’s presenting me with.

5) Do you think the pre-set hand gestures were easy to use? / How do you think it could improve?

No, I don't think any pre-set hand gesture was easy to use. Maybe because it was my first time. Also, I wasn't sure like how far I have to press down on a button until it changes. But when it did I thought I felt something that was pressed. Maybe it would be better if there was some sound to this that would make it feel more like I pressed something and support that feeling.

− Can you name a few of the existing commands you find most beneficial for navigation on a natural interface?

I think the two finger and palm commands were most beneficial when it came to navigation, but I also thought that pointing would play a good useful part in the menu interaction.

− If you had to add any new gestural commands, what would they be?

I can't think of anything on the top of my head but I think that having a swipe or move control would be really nice, in the widgets app I was trying to scale the scrolling text but couldn't. I guess that would be useful.

− How do you see these gestural commands useful?

These would be useful to see text more clearly and also play with the depth that you are in; I think that would be much better to do which you cannot do on a computer screen as such.

Evaluation

6) Were there any difficulties you faced when navigating through the virtual/augmented space?

No, not really. I think that if everything was really easier to work with then it would have been really fun. It's just a bit hard at times to see what exactly you're doing, especially since you have to move and turn your head and body a lot.

- Do you think these difficulties are important to fix?

I think this should be looked into because swiping objects rather than body movement may increase the enjoyment within the experience.

7) Are there any possible changes that you feel are critical for the interaction?

Yes, I feel that there needs to be more colour and or sound feedback when the buttons are pressed or being pressed, that would give me a better idea if I am pressing down on things or not.

8) Do you have any other comments about your experience with the three tasks?

No, thank you for sharing the experience!

Participant 6

Interview Questions:

First Impression

1) What were your expectations of the Oculus Rift as a device?

Well, I had seen a lot of images and like opinions from people beforehand. And it was pretty so much what I thought it was going to be like being able to touch things move things. I did not expect for there to be like custom or hand interfaces that came up with the watch interface; I don't know what it's called but yeah there was like bottoms and I could change some of those like my own control with being the virtual world. But yeah I didn't expect that bit.

- Could you elaborate on how it felt like when putting on the device?

It felt weird at first in the black screen but then felt good and ok when the apps came on.

2) Did your experience live up to what you thought augmented reality is about?

Yes, yes it did.

- Would you say this is an exciting way of interaction?

Yes, it was an exciting way because it's something I have never experienced before. So that was good.

Usage

3) Was the interaction easy and would you say it was intuitive?

I don't think it was easy. It took a while to like get used to the space and the bottoms and how you had to select different types of bottoms because some of them had to be pinched. And some of them had to be tapped. And then some of them only worked from a certain distance. And then you have to play around that for a while and then you have to figure out what each one does and what the consequences of pressing a certain button were then you could go back and sort of go through the app again probably.

- Is there any particular task or app that you found most useful?

I think the planetarium one was the easiest to navigate to have everything sort of similar to the Hovercast one as well. You knew where you were in the information architecture when it was on the hand.

- Would you prefer doing this task on a virtual headset or any other device?

No, it would not be the same on a 2D or flat screen because you can move your head and stuff and see different perspectives and all.

4) How did you feel about the quality of the interaction?

Feels like it still a long way to go because it was all blurry and everything took a while to read and see but it was good. Like I said, I kept having to adjust the Oculus on my head to see more clearly.

- Do you think virtual reality would be better than augmented reality?

Oh yeah, I did enjoy seeing my hands, especially when they were in x-ray mode and all black and white. I did enjoy the mixed reality feel of seeing the virtual ones and being able to move within my own real hands.

- Why would this be a better experience?

Because I didn't like seeing those freaky hands on me!!! They were really glitching and also felt weird being someone else.

5) Do you think the pre-set hand gestures were easy to use? / How do you think it could improve?

Once I knew them then yes. But before that it was a little bit confusing. Maybe if there were basic instructions that came up that said swipe this way or pinch this way, or select it this way. These kinds of options would be good.

− Can you name a few of the existing commands you find most beneficial for navigation on a natural interface?

Pinching, because I felt that I could use that well, pointing was hard because I didn't know if it was affecting, pinching was very satisfying because that worked much better.

− If you had to add any new gestural commands, what would they be?

Pushing and pulling and swiping, like I wanted to push things away, like the text interface, for example, I just wanted to move it away.

− How do you see these gestural commands useful?

I see them useful because they make a nice tie into the existing devices I use. At the moment, I use an iPad and a touch screen so that really makes me want to do more swiping and pinching.

Evaluation

6) Were there any difficulties you faced when navigating through the virtual/augmented space?

Just knowing what the buttons would do is difficult, difficult to navigate through the app and to know what I'm doing. Getting feedback from the buttons in the applications was very challenging. The planetarium one was very difficult to figure out and find how to do things in that scene.

- Do you think these difficulties are important to fix?

Yes, I do because I couldn't experience all the apps to their full potential because of the confusion in the gestural commands.

7) Are there any possible changes that you feel are critical for the interaction?

Better instructions, like audio instructions where someone tells you to do something when you are not doing it correctly.

8) Do you have any other comments about your experience with the three tasks?

It was very fun and cool. And I can't wait to see what you do with it in the future.

Participant 7

Interview Questions:

First Impression

1) What were your expectations of the Oculus Rift as a device?

Umm to be able to interact in a complete way with a computer. I was curious about that before. So yes, Curiosity.

− Could you elaborate on how it felt like when putting on the device?

I was curious when I put on the device because I never felt something like this before, it was very interesting and I didn't know I could put my hands out and see them. I thought it was just looking through these glasses.

2) Did your experience live up to what you thought augmented reality is about?

Yeah. I like that it was an immersive thing. I felt inside the apps.

− Would you say this is an exciting way of interaction?

It felt odd because well my hands didn't look like my hands even with the female hands on, that was slight discomfort. Yes, I would prefer to see my own hands, was weird to see other hands doing what I do.

Usage

3) Was the interaction easy and would you say it was intuitive?

Some were easier than the others. I liked the Hovercast one; the menus were very intuitive the UI and the sliders worked in a way that was natural for the way fingers would move. The second one where you had to press enter to experience the app was a bit hard; the brain connectivity was confusing because I didn’t expect to press the keyword on the keyboard because I couldn’t see it.

− Is there any particular task or app that you found most useful?

The UI I liked the most was of the last one the Hovercast, but that was more amusing than useful so it was fun but the planetarium one was more useful and informative. If it showed something of my interest, then it was useful. The Hovercast was easiest for me to relate to, but what I saw was very random.

− Would you prefer doing this task on a virtual headset or any other device?

This one seemed to be working better in the way of using the headset but yeah I've seen planetariums on mobile phones and they are nice but not immersive, this feels more real.

4) How did you feel about the quality of the interaction?

A couple of aspects were hard to approach which lacked in quality like I wasn’t able to tell how much I have to approach objects in order to have any impact on them. That was a bit tricky like there were a couple of interfaces that were having wheels behind me in the widgets app, but I didn’t know if I was touching it. The feedback was lacking and the interaction didn’t happen when I expected it to happen.

− Do you think virtual reality would be better than augmented reality?

I like the later ones. It’s like I had the framework of where I was, and it was impressive to see the environment I was in with the virtual elements.

− Why would this be a better experience?

Because it felt more like a dream. You know and you have real objects combine with things that are not real but somehow that makes the experience more real. But what I like the special about the planetarium, for example, was that I could tell where I was and at the same time be in a virtual space. Yeah, that makes it more immersive somehow. Because I could feel myself there.

5) Do you think the pre-set hand gestures were easy to use? / How do you think it could improve?

They were easy to use once you understood how they worked but it was kind of tricky to understand at first hand. There was an icon that was telling you what to do, but it disappeared so that was frustrating so maybe the timing is off over there.

− Can you name a few of the existing commands you find most beneficial for navigation on a natural interface?

I like to be able to point that's very intuitive to do which is just like in real life. And also the sliders were very easy to understand. Also grabbing things from afar was easy to understand.

− If you had to add any new gestural commands, what would they be?

I would like to be able to approach things. Like going closer to them smaller by scaling.

− How do you see these gestural commands useful?

It would be useful command because I can then have more control over the objects natural properties and not having to be fixed. Like on desktop computers u can move windows, would be good if you can grab and scale objects too.

Evaluation

6) Were there any difficulties you faced when navigating through the virtual/augmented space?

Two or three of the apps the thing didn't recognise the way my hands were facing so that made me want just to shake it off. Yeah, the virtual hands were not responsive all the time. One of the apps was especially frustrating when the fingers were not recognising my fingers and identifying which was my thumb and which was my index finger.

- Do you think these difficulties are important to fix?

Yes, they are important because they stop the other parts of the apps from being better.

7) Are there any possible changes that you feel are critical for the interaction?

For example, for the compass in the planetarium app, what was most annoying was once I tried to interact with it, it would disappear. I would have liked to interact with it with both hands since it was a sphere, to be able to hold it would make me feel more confident that it wouldn't disappear.

8) Do you have any other comments about your experience with the three tasks?

What I like the most about the last one that. It was very easy to understand. I not sure why the other menu systems are not more like that. The other apps felt like a computer interface.

Participant 8

Interview Questions:

First Impression

1) What were your expectations of the Oculus Rift as a device?

I expected it to be immersive, even though when I wore it, I didn't think to myself that I should turn around and notice a 360 view, even though I knew that beforehand that I could do that.

− Could you elaborate on how it felt like when putting on the device?

I think it's still a bit slow but I think like the whole mechanic like how you can use your hands to navigate and move around more.

2) Did your experience live up to what you thought augmented reality is about?

− Would you say this is an exciting way of interaction?

It definitely is a new and exciting way of interaction, especially with menu systems and other user interfaces.

Usage

3) Was the interaction easy and would you say it was intuitive?

I think towards the end the soundscape and the Hovercast app was easy to use and understand, how they worked before hand. The brain connectivity, I didn't really get, I don't know if there were instructions beforehand even though I saw the text and didn't read all the text. The planetarium one was intuitive only once I knew it after experimenting but I didn't get it the first time.

− Is there any particular task or app that you found most useful?

The Hovercast app was good for its use and having to use your hand and you can hold down the button to choose what u want, giving it a time frame before having to by mistake clicking other buttons. The widgets with the button in the start was a good one too and it gave me a nice feedback with the buttons that showed depth.

- Would you prefer doing this task on a virtual headset or any other device?

I think it's good especially for the planetarium one, I think you couldn't experience with the stars on the phone and scroll. And the Oculus rift gives that a good use of the 360 view. But the sound one didn't really make sense but the interaction that was still good and things that you couldn't do on a phone.

4) How did you feel about the quality of the interaction?

I felt the quality needs improvement, especially the text. Maybe not have too much text and use symbols that animate instead? That could be easier to understand what is going on.

- Do you think virtual reality would be better than augmented reality?

I liked the mixed reality, how you could see your hands and it felt like you were there in the experience and were in control and you were using your own hands to navigate through the menu systems.

- Why would this be a better experience?

I feel it would be best to have an experience in mixed reality because it gives a good reference to Sci-Fi movies and I like those kinds of movies.

5) Do you think the pre-set hand gestures were easy to use? / How do you think it could improve?

Um, I think they are easy to use once you sort of know what you're doing, I did find it hard to grab a constellation in the planetarium one, I don't know if it was me but the menu card just didn't disappear and I didn't know what to do so I was constantly grabbing things and not sure what I was doing. I did like the

Hovercast one because it was easiest to navigate through because I caught on with it. Also the planetarium, the time comes on your arm. So once I knew that it was really cool and intuitive.

− Can you name a few of the existing commands you find most beneficial for navigation on a natural interface?

Using your hand to navigate, like pointing as a cursor to select. The buttons I knew from other things that if you press it and slide it and made sense.

− If you had to add any new gestural commands, what would they be?

I like the whole idea of swiping; I didn't know how to stop reading and continue certain apps.

− How do you see these gestural commands useful?

I see them useful by getting rid of content that is not relevant to me, and not having to force myself to view things that I don't want to see.

Evaluation

6) Were there any difficulties you faced when navigating through the virtual/augmented space?

The beginning of the app for the brain connectivity, and I couldn't find the enter key because I kept looking around even though I didn't think I had to use the physical keyboard.

- Do you think these difficulties are important to fix?

Yes, they need to address issues like that because it stops me from actually knowing more about what the rest of the application can do, making me want to quit the app.

7) Are there any possible changes that you feel are critical for the interaction?

I don’t like how I have to reach my arms out too much; I like to keep them in a comfortable reach. It’s almost like I only can lift my hand up to my face but to stretch my arm can get tiring. So I would try to make the movements more subtle and not too much exercise.

8) Do you have any other comments about your experience with the three tasks?

Nope, it was fun!

Participant 9

Interview Questions:

First Impression

1) What were your expectations of the Oculus Rift as a device?

Quite high, I used oculus rift a few years ago the first version, and HMD was my research and compared to google cardboard this is so much better. Right before I came I used it and it was so crap.

− Could you elaborate on how it felt like when putting on the device?

Felt weird as always, but I got used to it because I had tried it on before and other HMDs and it was different.

2) Did your experience live up to what you thought augmented reality is about?

It was interesting because in my mind mixed reality is VR and AR and it was interesting to experience the augmentation of virtual elements around me.

− Would you say this is an exciting way of interaction?

Yes, it was exciting and also challenging at the same time.

Usage

3) Was the interaction easy and would you say it was intuitive?

For the app and you know Hovercast app, I couldn't see any of the text. Even the warning sign was hard to read because it was blurry and dependent on your eyesight. For the interaction of the menu things, it would be great if there was a lady's voice that guided you. It was too much text in the apps.

− Is there any particular task or app that you found most useful?

The planetarium app was very useful and it was interesting of how to interact with the surroundings.

− Would you prefer doing this task on a virtual headset or any other device?

I think mobile devices can actually do better on the apps that may reduce the bad quality of the HMD.

4) How did you feel about the quality of the interaction?

First of all, it was very hard to press the button, would be good to see colour changing of the button, so that you know there is more feedback when clicking on the button. So when you click its more obvious if you see a colour change.

− Do you think virtual reality would be better than augmented reality?

I like virtual reality better because it can give me the experience that the physical space distracts me. I think VR is really good for that and should be used more often.

− Why would this be a better experience?

Yes, even for like showing UI and menu systems, it would still be nice to see more VR than just mixed or augmented reality. Because it provided a nice vision of how it feels to be in another world, make it very visionary and creative.

5) Do you think the pre-set hand gestures were easy to use? / How do you think it could improve?

It was easy, as the grab and pulling that was easy. And I think it was easy because people now days are used to smartphones and the gestures are sort of similar.

− Can you name a few of the existing commands you find most beneficial for navigation on a natural interface?

I liked how the UI in planetarium was stuck to my hand that was really useful and good. Also, I liked the fact that in the widgets app where I had interfaces around me that I could see and read, but was annoying to interact with.

− If you had to add any new gestural commands, what would they be?

I would like to grab and throw interfaces, like imagine picking up rubbish and throwing it in the bin, but doing it like physical space in the virtual interfaces. It could also be just a simple add of brightness or contrast on the vision of what you see in the app because everyone has different eyesight so would be nice to have that option.

− How do you see these gestural commands useful?

I see them useful for ease of interaction and providing a comfortable experience that could possibly make users want to stay longer in the apps.

Evaluation

6) Were there any difficulties you faced when navigating through the virtual/augmented space?

Yes, even though I liked the usefulness of the planetarium app, it was still annoying and difficult to grasp the compass to navigate in space. It was just so hard to grab a ball that's bigger than your hand to hold and move around. Didn't feel intuitive at all.

- Do you think these difficulties are important to fix?

Yes, I think it would be worthwhile to investigate alternatives for such scenarios in future applications.

7) Are there any possible changes that you feel are critical for the interaction?

There needs to be a back menu button to return to the tutorial or menu system because it is so annoying not to see the UI once it is gone or disappeared.

8) Do you have any other comments about your experience with the three tasks?

It was good fun and nice to see what the latest technology is doing.

Participant 10

Interview Questions:

First Impression

1) What were your expectations of the Oculus Rift as a device?

I didn't know what to expect as I never heard of the Oculus before. But when I saw it I was like wow this is something new.

− Could you elaborate on how it felt like when putting on the device?

When I wore it, it was a very nerve reckoning at first, but when my eyes focused on the experience, I was stunned.

2) Did your experience live up to what you thought augmented reality is about?

I was not sure exactly what augmented, and mixed reality was before the experience, but from what I know now, it sure is a unique experience and not like anything I have experienced before.

− Would you say this is an exciting way of interaction?

Yes, it is an exciting way, but also quite a challenging one to interact with because there are a lot of difficulties with the navigation of the interfaces.

Usage

3) Was the interaction easy and would you say it was intuitive?

I really thought that the Hovercast app was intuitive and good fun and was quick to learn. I think the most challenging one to understand was the brain app because I could not get rid of the text that I was first presented and didn't know where to look.

− Is there any particular task or app that you found most useful?

I think the planetarium app was very useful and fit nicely in the immersive experience, it felt very natural, and I could see the stars really well. I also found the hover cast menu most useful to navigate.

− Would you prefer doing this task on a virtual headset or any other device?

No, I think it is best done on the virtual headset.

4) How did you feel about the quality of the interaction?

I felt the quality was good in some cases but most cases the interaction was a bit challenging because the hands kept glitching and see those fake hands on me really made me feel weird and uncomfortable. I could not understand where the fingers were pressing and what buttons I was going to hit.

− Do you think virtual reality would be better than augmented reality?

It depends on the purpose of the application; I feel that virtual elements in the scene are really cool and important but virtual embodiment was not so great because it kept confusing my gestures. I feel the mixed reality of having physical reality around me is a good option.

− Why would this be a better experience?

I think this would be a better experience because it gives positive abilities of both realities and provides a nice convergence.

5) Do you think the pre-set hand gestures were easy to use? / How do you think it could improve?

I found the compass hand gesture in the planetarium app very confusing and it was almost difficult to know that I had to drag it around. I thought I had to hold it with my two hands since it was a sphere to navigate. I also found pointing very challenging because the finger wouldn’t stay straight; it kept bending. I think in order to improve it, it would be better to use arrows to click or hold where to navigate in the virtual space, rather than a sphere.

− Can you name a few of the existing commands you find most beneficial for navigation on a natural interface?

I found that the hand menu system was very beneficial and didn't glitch on me because it was facing me and worked really well. I also found that pushing with all five fingers was more responsive than one finger.

− If you had to add any new gestural commands, what would they be?

To scale would be a good feature I think because then I can choose what part to focus on and what part I didn't want to see. I think that would be very helpful.

− How do you see these gestural commands useful?

It is useful because it can give a feature of personalization to the objects in the environment that can help other users know what they want to see and what they want to hide.

Evaluation

6) Were there any difficulties you faced when navigating through the virtual/augmented space?

It took a lot of time to understand the commands all at the first time. The brain app was really frustrating because at first the text was a pain and then when I surpassed the text, I was only breaking the brain around I didn't really understand what more I could do. I felt frustrated and found it difficult to stay in the experience of the app.

- Do you think these difficulties are important to fix?

Yes, I think this needs to be fixed because I would like to see things happening from the start and not having to wait.

7) Are there any possible changes that you feel are critical for the interaction?

I almost felt like I touched a button or widget and made me feel like I could feel the button actually on my fingertips but at the same time I couldn’t. I think that maybe if there was sound and a stronger animation with colour when interacting with the buttons, it would prompt a stronger feel of when pressing on an augmented button.

8) Do you have any other comments about your experience with the apps?
Not really, it was a fantastic experience, despite the range of errors. I still found it very refreshing as it wasn’t like the typical keyboard and mouse interaction that I take for granted every day. So this was a good practice to how the future of computing could lead to.