RABBIT

Exploring Shared Awareness in Virtual Reality

A Master of Design Thesis by
Yiyi Shao

RABBOT

EXPLORING SHARED AWARENESS IN VIRTUAL REALITY

By

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A thesis exhibition presented to OCAD University in partial fulfillment of the requirements

for the degree of

Master of Design

in

Digital Futures

Toronto Media Arts Centre, 12th -14th April, 2019

Toronto, Ontario, Canada, April, 2019

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RABBOT - Exploring Shared Awareness in Virtual Reality

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Master of Design in Digital Futures, 2019

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Abstract

This thesis explores the possibilities of generating shared awareness in virtual reality (VR) experience between a head-mounted display (HMD) wearer and other observers in the same physical space by merging wearable technology, augmented reality, asymmetric game design and wireless communications in the internet of things (IoT). By employing the methodology of Research Through Design (RTD), this thesis project develops a series of prototypes to inform the outcome RABBOT -- featuring a modified VR head-mounted display and asymmetric mobile game experiences with an embedded communication system to create opportunities for shared awareness amongst players. Overall this thesis argues that an engaging VR experience need not focus exclusively on the HMD wearer but also include other audiences in the same physical space.

Keywords: Virtual Reality, Augmented Reality, Wearable Technology, Digital Fabrication, Internet of Things, Wireless Communications, Asymmetric Gameplay, Research Through Design.

Acknowledgements

I would like to express my sincere to supervisors, Kate Hartman and Alexis Morris for their continuous support to guide me through the journey of this thesis. Thank you for your patience, motivation, enthusiasm and immense knowledge.

To my Digital Futures cohort for being supportive and inspirational, for every stimulating discussion to help me think outside the box. And thank you to faculty members, particularly Emma Westcott for her expertise and suggestions.

To Social Body Lab, Maker Lab for facilitating physical making and user testing. To Jessica Wyman at Writing and Learning Centre, Nadine Lessio at ACE lab, Reza Safei at Maker Lab, Chris Luginbuhl and Peiheng (Norbert) Zhao. Thank you for all your help.

To my friend April Xie for proofreading this document and giving me insightful suggestions.

To all user testing volunteers, thank you for your participation and providing helpful feedback.

To my dear parents for providing me with unfailing support and continuous encouragement throughout my years of study. This accomplishment would not have been possible without them.

Special thanks to my boyfriend Daniel Marchena Parreira for his mental and technical help when I stagnate.

Table of Contents

1. Introduction **1**

2. Literature Review **3**

2.1 Virtual and Augmented Reality 3

2.1.1 What is Virtual Reality (VR) and Augmented Reality (AR)? 3

2.1.2 From Past to Now 4

2.1.3 Communications in VR and Perspective Gap in Shared Mixed Reality Experiences 9

2.1.4 Current Trend 11

2.2 Wearable Technology 11

2.2.1 Design Considerations 12

2.3 Digital Fabrication 14

2.4 Wireless Communications in the Internet of Things (IoT) 14

2.5 Game Design 16

2.5.1 Asymmetric Gameplay 17

2.6 Summary 19

3. Related Works **20**

3.2 Flock 21

3.3 Shooting Game 22

3.4 Keep Talking and Nobody Explodes 23

3.5 The Playroom VR 24

3.6 Ruckus Ridge VR Party 25

3.7 Augmented Headsets 26

3.8 Summary 27

4. Methodology 28

5. Iterative Prototyping Stages 32

5.1 Prototype 1: Invisible Destination 33

5.1.1 Description and Process 33

5.1.2 Results and Reflections 34

5.2 Prototype 2: Rabbit HMD 36

5.2.1 Description and Process 36

5.2.2 Results and Reflections 41

5.3 Prototype 3: RABBOT - Waking Up 42

5.3.1 Description and Process 42

5.3.2 Results and Reflections 44

5.4 Prototype 4: RABBOT - Controlling 45

5.4.1 Description and Process 45

5.4.2 Results and Reflections 49

5.5 Summary 50

6. Final Project: RABBOT 51

6.1 System Overview 51

6.2 The Game 53

6.3 Making Process 55

6.4 User Testing 59

6.5 Results and Reflections 60

7. Conclusion and Future Orientation 64

7.1 Contributions and Limitations 64

7.2 Future Work 66

8. Works Cited 68

Appendices 75

Appendix A. REB Approval Statement 75

Appendix B. Questionnaires and responses 76

Appendix C. Game Design Documents 80

Appendix D. Cybernetics and cyberpunk 82

D.1 Cyberpunk, Hacker Culture and Maker Culture 83

D.2 The Relationship and Collaboration Between Human and Animals 84

Appendix E. Thesis Blog 85

List of Figures

Fig. 1. Reality-Virtuality (RV) Continuum from Milgram and Kishino, 1994. (3)..................4

Fig. 2. The AIP Cube from Zeltzer, 1992. (127) 5

Fig. 3. An example of a head-mounted display (Samsung Gear VR).......................................6

Fig. 4. Gartner Hype Cycle for Emerging Technologies from Gartner, 2017. 7

Fig. 5. Hype Cycle for Emerging Technologies from Gartner, 2018. 8

Fig. 6. Integration pattern Cloud from Building the Web of Things Dominique Guinard. 2016..16

Fig. 7. Inhabitat from Haru Ji and Graham Wakefield. 2017. 20

Fig. 8. Ruckus Ridge VR Party from Foreignvr. 2016. 25

Fig. 9. Augmented headset from Hiroto Ikeuchi. 2018. 26

Fig. 10. Possible users in a VR experience 29

Fig. 11. Conceptual framework 30

Fig. 12. Prototypes Map..32

Fig. 13. Design sketch of the Invisible Destination 33

Fig. 14. Rabbit HMD 36

Fig. 15. Initial sketch for Rabbit HMD...37

Fig. 16. Circuit diagram..37

Fig. 17. 3D design in Rhino and 3D printing servo attachments 38

Fig. 18. Testing with DIY sensor..38

Fig. 19. Marker Design and laser cutting..39

Fig. 20. Assembling wires 40

Fig. 21. Multiple image targets test in AR...41

Fig. 22. Rabbit HMD from three angles 41

Fig. 23. Creating textures in Photoshop..43

Fig. 24. VR scene in Unity3D 44

Fig. 25. VR scene in Unity3D 46

Fig. 26. 3D modeling RABBOT in Blender3d and the final visual after rendering out 47

Fig. 27. AR App Design 48

Fig. 28. VR App Design 48

Fig. 29. System overview diagram 52

Fig. 30. The final game interfaces for participating observers 53

Fig. 31. Costume and items design for roleplaying 54

Fig. 32. A collection of the 3D design process 56

Fig. 33. A collection of 3D prints and assembling process 57

Fig. 34. Final product 58

Fig. 35. Participants play-testing RABBOT 59

Fig. 36. User testing data analysis 60

Fig. 37. Response from non-VR player regarding their experience on RABBOT 61

Fig. 38. Response from VR player regarding their experience on the HMD 62

Fig. 39. Install for thesis show 66

1. Introduction

The isolating design of virtual reality (VR) head-mounted displays (HMD) is typical in the single-player experience - immersing one into a virtual environment. This often creates a situation in which only one headset is available but no opportunities for engagement are made accessible for other people nearby. This isolation in VR cuts off social connections and awareness between the virtual world and physical world, between the HMD wearers and other observers. Additionally, the current offerings in the consumer electronics market of the head-mounted display have a dull appearance, which also shows the lack of attention in terms of design for other audiences.

This thesis is designed to address this problem and to explore the possibilities of generating shared awareness in a VR experience between the HMD wearer and other observers in the same physical space by merging wearable technology, augmented reality, asymmetric game design and wireless communications in the Internet of Things (IoT). The principal objective of my thesis project is to argue that an engaging VR experience need not solely focus on the HMD wearer but also other third-party audiences, whether these are participating observers or ambient observers. In particular, this thesis seeks to address the following questions:

- How might we generate shared awareness in a VR experience between the HMD wearer and other observers in the same physical space?
- What technologies, design and fabrication approaches could be useful to produce a customized head-mounted display that enables shared awareness in mixed reality experiences?
- How might virtual and augmented reality technologies be merged into a single shared awareness experience?
- What aspects of game design could help to encourage shared awareness between the HMD wearer and other observers?

As the outcome of this thesis, RABBOT features a modified VR head-mounted display and three-player asymmetric mobile game experiences with an embedded communication system to create opportunities for shared awareness amongst players. In the game, the two participating observers can play cooperatively as *Scientists* to against the HMD wearer who is playing the *Rabbot*[1].

This thesis is composed of seven themed chapters, including this introductory chapter. Chapter 2 presents a literature review by laying out the theoretical dimensions of VR and the importance of creating communications in VR as well as other technical fields (wearable technology, digital fabrication, wireless communications in IoT and game design) to explore the possible intersections and approaches. Chapter 3 discusses a range of VR projects to position my own research. Chapter 4 provides an overview of the use of Research Through Design (RTD) as a methodology for this project. Chapter 5 details a series of iterative prototypes (*Invisible Destination*, *Rabbit HMD*, RABBOT-*Waking Up,* RABBOT-*Controlling)* and how each of them contributes to the final project. Chapter 6 presents the finding of my thesis, focusing on the final project RABBOT with further explanations of technical aspects from hardware, software and game design together with the results analyzed from user testing. Finally, Chapter 7 concludes the thesis with a discussion of the work and avenues for future research.

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[1] *Rabbot* -- The character's name in the game.

2. Literature Review

This chapter takes the form of six main sections. The first section focuses on VR/AR and Mixed Reality, which includes the development and taxonomy of this technology, how the proposed problem has been discussed in the academic field, and an overview of the current trends in the consumer market. The second section discusses wearable technology, which introduces considerations that need to be taken into the design of the modified HMD both for the wearer and observers to open the gateway for the shared awareness. The third section investigates digital fabrication as the production methods with the emerging techniques that has been suggested in the field, which will be incorporated into designing and making process of this project. The fourth section dives into wireless communications and Internet of Things (IoT) to establish the system framework for the connections between the HMD wearer and observers. The fifth section probes asymmetric game design with guidelines featured in academic and industrial fields to engage both the HMD wearer and observers into the shared experience.

2.1 Virtual and Augmented Reality

2.1.1 What is Virtual Reality (VR) and Augmented Reality (AR)?

Virtual reality (VR) is a 3D computer simulation system that immerses the user in a synthetic and interactable world (Milgram and Kishino 2). The goals of VR are to allow the user to move freely within the space, along with interact with and modify features within the space itself while receiving sensory feedback (Rheingold). Humans perceive our world based on the feedback received from sense organs and VR presents to these organs an artificial world. This enables the fulfillment of human curiosity about exploring beyond reality through computer-generated illusions that replace our most important sensory feedbacks: visual, auditory and tactile senses (Bates-Brkljac).

Fig. 1. *Reality-Virtuality (RV) Continuum* from Milgram and Kishino, 1994. (3)

Augmented reality refers to scenarios in which an otherwise real environment is augmented by means of virtual objects (Milgram and Fumio 4). Azuma (2) defined AR as a system with three characteristics: it combines real and virtual, is interactive in real time, and is registered in 3D. AR differs from VR in that it augments the current environment with a layer on top of the real world, while VR allows the user to perceive a completely synthetic world leaving oneself blind to the current world. More specifically, VR and AR can be distinguished in the reality-virtuality (RV) continuum by Milgram and Kishino (3) as shown in Fig. 1. VR is at one end of the continuum, while AR is in between the extremes and more towards to the real environment. Video-based approaches in AR use image processing or computer vision techniques to aid in understanding positions of objects, one of which is to place fiducials in the environment such as LEDs or special markers (Azuma 25).

2.1.2 From Past to Now

To gain a better understanding of the problem of isolation in VR, I investigate this technology in chronological order. The development of VR technology can be roughly divided into three main periods: the early period (1950s to 1970s), the recent period (1970s to 2000s) and the current period (2000s till now). The early period built the foundations for VR: in 1957, Morton Heilig invented *Sensorama* to combine multiple technologies to give users an immersive illusion with stereo sound, vibrations, smell and atmospheric effects of wind. He later improved *Sensorama* into the world’s first head-mounted display with stereoscopic

3D images, wide vision and stereo sound in 1960 (Heilig). The first VR head-mounted display (HMD) was created by computer scientist Ivan Sutherland in 1968. The HMD connected to a stereoscopic display from a computer with a wireframe visual of a 3D object and changed perspectives following user's head movements (Sutherland 759). Sutherland's HMD is also marked as the birth of augmented reality as the visual was overlaid on the top of the real background (Billinghurst and Kato 65).

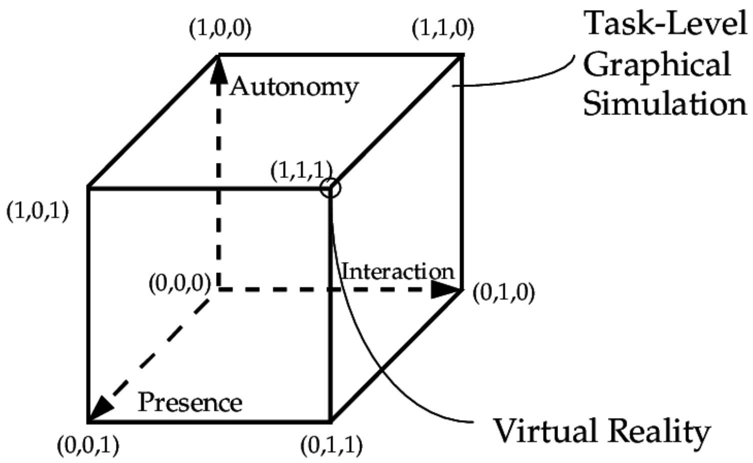

Fig. 2. *The AIP Cube* from Zeltzer, 1992. (127)

Important theories appeared in the recent period, such as the RV continuum providing an explicit taxonomy on mixed reality (Milgram and Kishino 3) and the AIP cube (Fig. 2) as a framework for describing, categorizing, comparing, and contrasting virtual environments (Zeltzer 127). More experiments around the HMD were conducted during this time period, one of which was *Super Cockpit* in the US Air Force Research Program, which projected information such as computer-generated 3D maps, infrared, radar imagery, and avionics data into an immersive, 3D virtual space for the pilot to view and hear in real time (Furness 48). The recent period also featured the first commercial wave of VR. Computer scientist and artist Jaron Lanier, who is also known as the founding father of the field of virtual reality (Bernard & Tweedie), is known for popularizing VR in the 1980s. His company *VPL*

Research is one of the pioneers to develop and sell VR products such as gloves[2], HMDs[3] and tracksuits[4]. However, VR was stuck in its early-adopter phase by the mainstream because of unaffordable costs, bad user experience, and low graphics support (Fogden).

Fig. 3. An example of a head-mounted display (Samsung Gear VR)

Current VR technology is most commonly displayed via HMDs, as shown in Fig, 3. A typical HMD has one or two small screens in front of the user's eyes and allows for stereoscopic vision with overlapped images. The fusion of disparate images can create the illusion of a three-dimensional graphic to the user. Moreover, with the movements of the user's head, new visual perspectives can be generated based on the input values received from the tracking sensor embedded in the HMD (Mon-Williams 387). The current period features the second VR commercial wave. In 2012, Oculus Rift was launched on Kickstarter,

[2] The DataGlove: https://www.britannica.com/technology/VPL-DataGlove

[3] The EyePhone: https://flashbak.com/jaron-laniers-eyephone-head-and-glove-virtual-reality-in-the-1980s-26180/

[4] The DataSuit: https://queerfragments.wordpress.com/2013/01/19/vpl-data-suit/

raising $2.4 million (Robertson). Google cardboard was released in 2014; Its low-cost VR viewer and development platform encouraging interest and development in VR applications without the requirement of a high-end PC (McAllister). 2016 was considered the year of rising consumer HMDs including Oculus Rift, HTC Vive and Sony Morpheus.

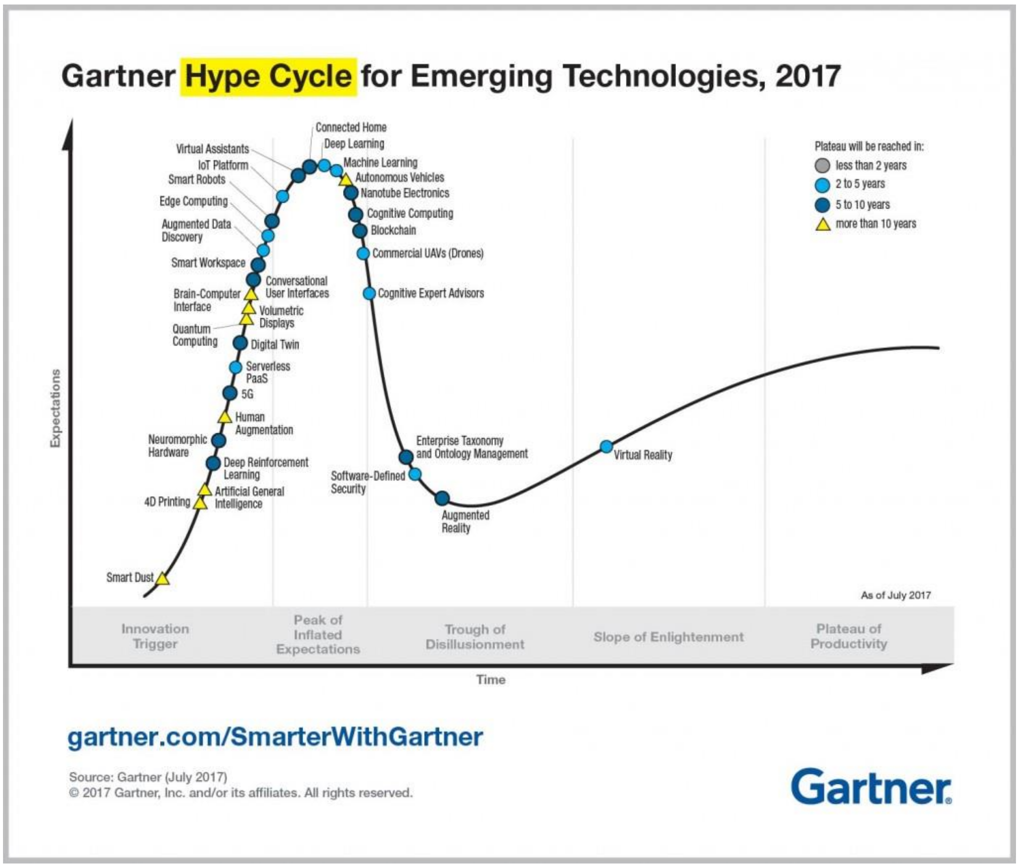

Fig. 4. *Gartner Hype Cycle* for Emerging Technologies from Gartner, 2017.

https://www.gartner.com/smarterwithgartner/top-trends-in-the-gartner-hype-cycle-for-emerging-technologies-2017/

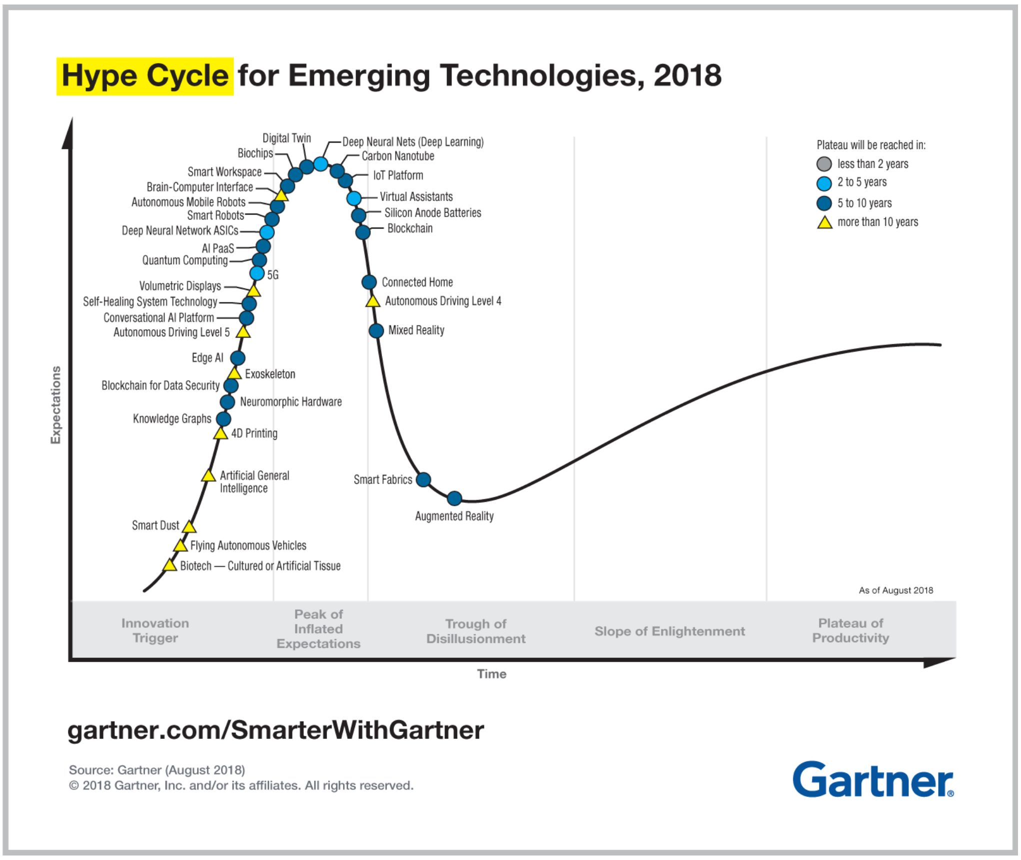

Fig. 5. *Hype Cycle for Emerging Technologies* from Gartner, 2018.

https://www.gartner.com/smarterwithgartner/top-trends-from-gartner-hype-cycle-for-digital-government-technology-2018/

Mark Billinghurst, an expert on mixed reality, discussed why the second commercial wave of VR is more successful than the first one in his presentation *Virtual Reality 2.0* (Billinghurst). He argued many factors determine technology acceptance, which include levels of investment along with availability of inexpensive hardware platforms and easy to use content creation tools. Most importantly, the current period has exhibited more focus on user experience than the past. Gartner Hype Cycle in 2017 as shown in Fig. 4 indicates that VR is already in the phase of “Slope of Enlightenment” and it will take 2 to 5 years to enter the “Plateau of Productivity”. Second- and third-generation products of VR are appearing before the mainstream adoption starts to take off (Linden 7), which I see where my thesis topic “shared awareness” is contributing to. Technologies such as the Internet of Things (IoT) platform and Augmented Reality are sliding into “Trough of Disillusionment” but might offer new opportunities around inputs and outputs as they will enter the “Plateau of Productivity” between 5 to 10 years in Gartner Hype Cycle 2018 (Fig. 5). Not only VR, Helen Papagiannis holds the similar opinion that the real impact AR will have is when it combines other emerging technologies like wearable computing, sensors, the Internet of Things and so on. Similarly, the first wave of AR focused on single user experience: “We’re beginning to see possibilities for a new type of virtual space emerging in this second wave that is shared among users, allowing coexistence and multi-user participation.” (Papagiannis 82). Hence, I start to dive into these technologies to find possible solutions for generating shared awareness in the next sections (from 2.2 to 2.5).

2.1.3 Communications in VR and Perspective Gap in Shared Mixed Reality Experiences

The primary goal of my thesis is to make shared awareness between the HMD user and other observers in a VR experience by creating communication between them. The importance of being able to share VR experiences has been raised by Biocca and Levy (127) in the first wave treatment of virtual reality when it emerged as a new medium. They argued that VR entertainment needs to be a repeatable experience; one of the approaches is to create a networked system that includes other people by incorporating design for competition or cooperation with the themes of battle, exploration and rescue (Biocca and Levy 130). Biocca and Levy highlight three competing design themes to make a more effective interpersonal communication in VR applications (147):

- Reproduction of interpersonal communication.
- Augmentation of interpersonal communication.
- Regulation of presence in interpersonal communication.

Reproduction of interpersonal communication is a theme which emphasizes the desire to reproduce the unmediated face-to-face communication by collapsing space. *Augmentation of interpersonal communication* is a theme which seeks to enhance and extend through artificial means the range of interpersonal communication, which Biocca and levy assumed to be more effective than unmediated interpersonal communication. *Regulation of presence in interpersonal communicatio*n is a theme with cultural rules to regulate interpersonal communication behaviors. In my thesis project, I choose to explore *Augmentation of interpersonal communication* because this design theme is more suitable for the situation when the HMD wearer and observers are in the same physical space.

Communication in VR has been an ongoing discussion in the academic field, particularly the topic of Social VR: it can help experience presence with real people which induces a stronger emotional response (Rubin 124). By the end of 2017, there were still less than ten percentage social VR worlds (Rubin 125). However, Social VR is focused on communication among VR users who already have access to the virtual environment, which is not directly related to my proposed problem. I am particularly interested in the problem which has been described as the “perspective gap”, where the VR experience is isolated to the person wearing the HMD (Ishii et al.). To address the problem of a VR player being unable to share their experience with others (observers), Ishii and his colleagues developed a system called *ReverseCAVE*. The system features four screens that surround the VR player with projection mapping to share the VR experience with observers.

Other researchers have also indicated the need to design more forms of interaction between users with an HMD and observers without an HMD (Gugenheimer et al.). Gugenheimer and his colleagues propose three levels of desired participant engagement to design such experiences: 1. some want to watch, 2. some want to have some form of interaction, and 3. some want to be fully part of the experience. I inherited these three levels of engagement into defining possible users in the VR experience in the chapter 4.

AR has the same problem of isolation as VR when using a single-viewer system, despite its inclusion and layering of the physical world. In addition, a see-through HMD such as *Magic Leap*[5] is as isolating as a blackout visor; this problem forces developers to reimagine the way we interact with technology (Conditt).

2.1.4 Current Trend

There is a rising trend among industry leaders in mixed reality platforms to develop shared experiences. In June 2018, *Apple* introduced a new platform *ARKit2*,[6] which allows developers to integrate shared experiences between two or more users to make AR apps more dynamic (Fitzsimmons). *Google* announced *Cloud Anchors*[7] in the same year for its platform *ARCore* with similar capabilities of shared experiences in the same physical environment (Lang). *Microsoft*'s platform *Windows Mixed Reality*[8] also featured the shared experience on their developer site (Turner et al.). Turner and his colleagues suggested that apart from developing mixed reality devices for shared communication, 2D devices such as a mobile or desktop observer will be a necessary consideration, especially in situations when using mixed 2D and 3D devices. Most recently in February 2019, *Microsoft* announced *Hololens 2*[9] at Mobile World Congress. Apart from featuring the product itself, Microsoft also introduced the ability of sharing the same experience by using a different device such as iPad (CNET). My thesis is fitting with this trend and contributing to this new wave of innovation of mixed reality that will bring more social aspects to this field.

2.2 Wearable Technology

As explained in Section 2.1, an HMD provides the VR user with access to the virtual environment. At the same time, it is one of the causes of isolation in VR. Once the wearer puts the headset on, the person becomes disconnected from surroundings and gets immersed

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[5] Magic Leap https://www.magicleap.com/
[6] ARKit2 https://developer.apple.com/arkit/
[7] Cloud Anchors https://developers.google.com/ar/develop/java/cloud-anchors/quickstart-android
[8] Windows Mixed Reality https://www.microsoft.com/en-ca/windows/windows-mixed-reality
[9] Hololens 2 https://www.microsoft.com/en-us/hololens

in the virtual space. To understand the physicality and social context of the HMD as one type of wearable device, the first field I want to explore is wearable technology. This field opens a gateway from the HMD wearer to the observers and establishes the possibilities of shared awareness. My research interest focuses on modifying an existing HMD instead of a new design for this wearable device.

2.2.1 Design Considerations

In the development of prototypes detailed in Chapter 5, I look into considerations with key elements when modifying the VR head-mounted display. Motti and Caine defined 20 key principles to guide design decisions towards human-centered aspects in the wearable domain: "Aesthetics, Affordance, Comfort, Contextual-awareness, Customization, Ease of use, Ergonomy, Fashion, Intuitiveness, Obtrusiveness, Overload, Privacy, Reliability, Resistance, Responsiveness, Satisfaction, Simplicity, Subtlety, User friendliness, Wearability" (1821-1822). Selecting from these, I have chosen the following principles as a guideline of the modified HMD:

- Aesthetics -- Improve the attractiveness of the HMD to extend its social context to the observers
- Comfort -- Allow the wearer to move freely with the HMD after adding the components
- Ease of use and Intuitiveness -- Allow the wearer to use the modified HMD as easily as a standard HMD
- Responsiveness -- Ensure the high level of responsive feedback in the modified HMD communication system between the wearer and observers
- Wearability -- Consider the active relationship between the wearer and the device (the modified HMD) in terms of engagement and satisfaction

The wearer and the observers perceive the aesthetics of a wearable device. However, as the case of an HMD is worn to cover eyes, the observers perceive more aesthetics of this device than the wearer. By improving the aesthetics of an HMD will attract the observers and invite them to be part of the experience. Moreover, Dunne and colleagues discuss the social perception of wearable devices extending beyond the “static” aesthetics -- artifacts worn on the body but cannot be interacted with into the social aesthetics -- artifacts worn on the body and can be interacted with (4160). Thus, improving the static and dynamic aesthetics of the HMD is the crucial design principle to engage the observers from the social aspect of the shared awareness.

Responsiveness provides users feedback in near real-time because users tend to be less patient when they are wearing the device on the move. Motti and Caine defined this principle mainly focus the system responsiveness for the feedback between the wearer and the device. I inherit and expand the responsiveness to the feedback among the HMD, wearer, and the observers through my communication system. High responsiveness can help the users to complete the tasks more efficiently in the game, which will then help to generate the shared awareness between the HMD wearer and other observers.

The rest of the design considerations are more focused on the HMD wearer to ensure the device can still be worn after modification. *Comfort* allows the wearer to move freely with the HMD. As the original HMD has already be considered with this principle, my main intention is to keep its weight still acceptable after adding the extra components. *Ease of use and Intuitiveness* are the design considerations to place the extra components on the HMD while not destroying the original functionalities so that the wearer can use it as a standard VR device. *Wearability* is the general consideration of the active relationship between the wearer and the HMD in terms of engagement and satisfaction. Based on the design guidelines for wearability (Gemperle et al.), I choose to employ critical elements such as accessibility and long-term use to make the modified HMD robust to wear.

2.3 Digital Fabrication

Following the established design considerations, it's crucial to find the suitable production methods to modify the HMD that supports my iterative prototyping process (see Chapter 5). Digital fabrication accelerates the process of ideation and invention by presenting the prototype with a near-professional finish (Blikstein 7). Digital fabrication has a number of implications for human-computer interaction. Computer numerical control (CNC) routing, laser cutting and 3d printing are three popular production processes (Mellis 3307-3308). Digital fabrication makes building custom physical interfaces and devices more feasible compared to traditional manufacturing (Mellis 3308). Laser cutting can work with a variety of materials and its versatility allows designers to take their inspirations from just about anywhere and even recycle existing designs (Baker 9). Digital fabrication methods such as laser cutting and 3D printing provide useful possibilities to design physical add-ons to consumer HMDs. Baker demonstrates a tutorial on how to engineer a found pattern to make a surface design that applies to the substrate by working with *Illustrator* (15). It inspired me to laser cut customized patterns into fabric to act as a fiducial marker for AR mobile applications. For the 3D printing production process, one of the powerful aspects is that it can work to extend and enhance existing objects to fulfill additional purposes (Chen et.al 73). Chen and colleagues introduce three attachment techniques: *print-over*, *print-to-affix* and *print-through* (73), which can be utilized in the modification of the HMD. Due to the reason that the fabricated parts need to work with the digital components and electronic circuits in my project, *print-to-affix* is more feasible as a technique to separately attach them using straps or adhesive, which will be highlighted in making process in Chapter 5 and 6.

2.4 Wireless Communications in the Internet of Things (IoT)

As mentioned in 2.1.3, the communication system between the HMD wearer and observer serves as a framework to generate shared awareness. The Internet of Things (IoT) as a field of study provides technical support for such wireless communications in my system. The Internet of Things (IoT) is defined as “a system of physical objects that can be discovered, monitored, controlled, or interacted with by electronic devices that communicate over various networking interfaces and eventually can be connected to the wider internet.” (Guinard and Trifa 5). Guinard and Trifa also described IoT that extends into the physical, real-time world using a myriad of small or even tiny computers (4-5). Mark Weiser predicted the vision of IoT when he defined small devices that connect to a common network and interact independently with each other as “Ubiquitous Computing” (94). However, my thesis project features a small scale of IoT system, where devices which can communicate and interact over the internet can be remotely controlled. This supports the addition of capabilities to an HMD that will bring more interactions between the VR user and other observers.

Most data networks today for IoT are based on the Open Systems Interconnection (OSI) standard; its model consists of seven layers (Rayes and Salam 35). The Web with HTTP, JSON and WebSockets are in OSI layer 7 *Application Layer* which “specifies the shared protocols and interface methods used by hosts in a communications network. It is where users interact with the network using higher-level protocols ...” (Rayes and Salam 35-36). According to Rayes and Salam, Transmission Control Protocol/ Internet Protocol (TCP/IP) simplifies into four layers: *Application*, *Transport*, *Internet* and *Network Interface* (39).

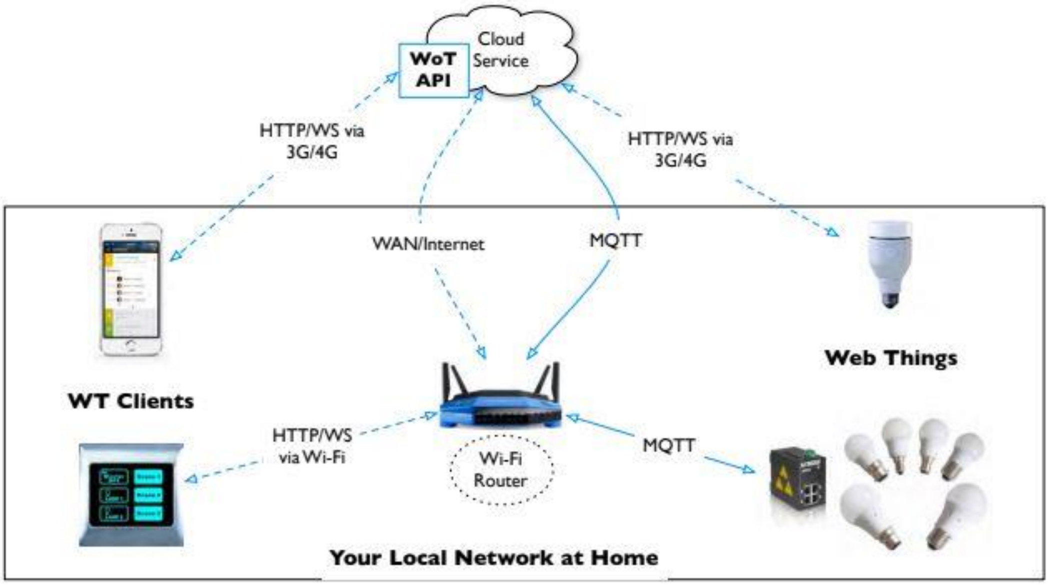

Fig. 6. *Integration pattern Cloud* from *Building the Web of Things* Dominique Guinard. 2016.

https://www.slideshare.net/misterdom/building-the-web-of-things-presentation-bsc

There are four main layers in the IoT reference framework which is in fact the TCP/IP layer: IoT device level (e.g., sensors and actuators), network level (e.g., IoT gateways, routers, switches), application service platform level (the IoT Platform), and IoT application level (Rayes and Salam 44). Based on the integration pattern in Fig. 6 by Dominique Guinard, my thesis project is building similar communications between the HMD wearer and observers through Wi-Fi, HTTP, an IoT enabled microcontroller, namely the *Particle Photon* and its platform and Cloud service[10].

2.5 Game Design

Making a playful experience to actively engage both the HMD user and other observers might be the key solution to generate the shared awareness. I am seeking to incorporate suitable game design theory to encourage and invoke the feeling of shared

[10] Particle https://www.particle.io/

awareness in virtual and physical environments. Well-designed and imaginative systems are essential for any fun game, which consist of a collection of game mechanics (Menard 32). Game mechanics are defined as “methods invoked by agents, designed for interaction with the game state” (Sicart). That being said, a game mechanic is a rule or a description that governs a single, specific aspect of play (Menard 32). A formal approach to game design was developed and presented as MDA (Mechanics, Dynamics and Aesthetics) framework (Hunicke et al.). In the MDA framework, *Aesthetics* make a game “fun” through game categories including, but not limited to, Sensation, Fantasy, Narrative, Challenge, Fellowship, Discovery, Expression and Submission. *Aesthetics* is described as “the desirable emotional responses evoked in the player when interacting with the game system”. *Dynamics* can determine how particular states or changes affect the overall state of gameplay to create aesthetic experiences, which is described as “the run-time behaviour of the mechanics acting on player inputs and each other’s outputs over time”. As mentioned before, *Mechanics* support overall gameplay dynamics by various actions, behaviours and control mechanisms at the level of data representation and algorithms.

2.5.1 Asymmetric Gameplay

Besides basic game design theory, Gugenheimer and his colleagues developed insights for designing asymmetric co-located VR experiences that specifically address the problem of isolation in VR, which is highly relevant to my thesis topic. They designed a proof-of-concept named *ShareVR* with the goal of increasing the enjoyment, presence and social interaction for HMD and non-HMD users. Based on the testing of *ShareVR* and user studies, they gave four guidelines that are essential when designing a co-located asymmetric VR experience:

- Leverage Asymmetry
- Design for the whole living room
- Physical engagement is fun in moderation
- Design for mixed reality in shared physical space

They described the goal when applying asymmetry in visualization and interaction into design is to leverage the advantages of each individual visualization for the HMD user and observers instead of bringing them to the same level (4029). This principle guides me to design my early prototype *Invisible Destination* which is trying to find a way to leverage asymmetry between HMD user and observers in a physical format. *Design for the whole living room* is to encourage the designers to keep in mind participants that are in the same physical space beyond those observers who are engaging with the HMD user. Hence, I created a diagram to better define the possible users in the Methodology chapter. *Physical engagement* and *Design for mixed reality in shared physical space* are about encouraging the introduction of physical props and elements into the design, as experiences take place in both virtual and physical reality.

Following these guidelines, I decided to investigate primarily "asymmetry" in game design. Symmetric games are when all players have the same strategy set and earn the same payoff. In contrast, asymmetric games are defined as games with different strategy sets (Kim 29). In asymmetric games, players are fundamentally different from each other in the asymmetric abilities (Knox). The players have different goals and are given different rules, which may include interacting with different objects in different ways to reach different achievements. In VR, the HMD wearer and observers are naturally given asymmetric abilities because of the observers' lack of access to an HMD and its accompanying experience. The benefits of incorporating asymmetry in game design are in improving replayability and reducing complexity with more straightforward rules (Knox). A few existing VR games have been designed through an asymmetric interaction approach, such as *The Playroom VR*[11],

[11] The Playroom VR https://www.playstation.com/en-ca/games/the-playroom-vr-ps4/

Black Hat Cooperative[12], *Ruckus Ridge VR Party*[13], and *Keep Talking And Nobody Explodes*[14]. These games will be discussed further in the next chapter.

A literature scan did not yield a significant amount of game design theory that specifically focuses on asymmetry. However, there are asymmetric design guidelines in the game industry that have been developed by designers and developers. One example is by Burgun:

- Few characters
- Elegant design in general
- Low execution barrier
- Tutorial Mode

Featuring fewer characters makes it easier for players to learn and experience all characters in the game, and the full e game experience in general. Avoiding the situation of choosing a certain character is also suggested to apply to improve the playfulness (Burgun). *Elegant design* and *low execution barrier* mean designing for simple mechanics for players to get hands-on with the game quickly and easily. Thus, for the game design part of my thesis, I decide to make the game mechanic as simple as possible to maximize playability.

2.6 Summary

Overall the aforementioned wearable technology, digital fabrication, wireless communications in IoT and game design are four fields I found in the literature with possible solutions that incorporated within my project to generate shared awareness between the HMD wearer and observers. The next chapter will scan horizontally through existing projects created by others which inspired me to turn my design ideas more concrete.

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[12] Black Hat Cooperative https://store.steampowered.com/app/503100/Black_Hat_Cooperative/
[13] Ruckus Ridge VR Party https://store.steampowered.com/app/443800/Ruckus_Ridge_VR_Party/
[14] Keep Talking and Nobody Explodes https://keeptalkinggame.com/

3. Related Works

This chapter gives an overview of related VR projects that either focus on solving the problem of isolation in VR or try to increase the shared awareness between the HMD wearer and other observers. Towards the end of this chapter, I discuss artworks focusing on HMD modification. Each related work contains my own analysis and how it inspired me to incorporate elements into my design to gain a better understanding of how my thesis stands in these fields.

3.1 Inhabitat

Fig. 7. *Inhabitat* from Haru Ji and Graham Wakefield. 2017. https://artificialnature.net/

Inhabitat, created by Haru Ji and Graham Wakefield, is one of an evolving series of art installations that surrounds humans with biologically-inspired systems that are experienced in mixed reality. *Inhabitat* offers a virtual ecosystem that is populated by artificial organisms whose rules can be rewritten while participants interact within them, and it includes a head-mounted virtual reality and projection-augmented sand sculpture. As shown in Fig. 7, the artists have built in a feature to directly engage not only the HMD wearer but also other observers. VR helps to provide the HMD wearer with an immersive experience into the internal perspective of the ecosystem. Other observers can manipulate the ecosystem outside the VR space by interacting with the sand sculpture shadows, which results in causing organisms to become vulnerable to extinction.

Inhabitat provides two perspectives: one from the HMD wearer with the perspective of the organism living in the artificial ecosystem, the other from a "godlike" perspective given to observers. The artists designed the experiences for the HMD wearer and other audiences with interactions and different perspectives between them both objectively and subjectively through systemic interactions and the sensation of immersion (Ji and Wakefield 4). I see this project as a strong example that generated shared awareness between HMD wearer and other audiences and addressed the problem of isolation in VR because both types of participants can be part of the experience to understand the concept of the artificial ecosystem.

The other aspect of this project that influence my project is its exploration of non-human factors in the user experience. The way that the artists incorporated the non-human creatures' behaviors/communications in the artificial ecosystem inspired me to consider about the animal's perspectives and behavior into the game design (see *Rabbit HMD* in Section 5.2).

3.2 Flock

Flock is a co-located and multi-user VR experience made for a group of people. The artists, Tim Fain and Julien Mier, described it as a gamified sandbox, an interactive music video and a ritualized LARP (Live Action Role Playing Game). Each participant wears an HMD, headphones and a pair of feathers attached to their arms. The participants are playing the roles of birds, and they will have their representative birds' avatars in VR. *Flock* encouraged participants to call like birds and to flap their wings instead of speaking to each other. The more insects the participants "eat" in VR, the bigger and more colorful their birds' avatars will grow.

However, this project belongs to another research field, which is social VR, as discussed in the previous chapter. The proposed problem of isolation in VR is less relevant as each user has access to an HMD. However, *Flock* offers many other features that improve the engagement of participants in a VR experience which I would like to incorporate in my design. First, in my opinion, the whole experience becomes a performance with the design of LARP. The players were physically dressed up with a pair of wings that align with the characters and game mechanics in VR, which enhances playfulness and engagement. On top of that, LARP provides an additional perspective to the other observers. If there were passersby without an HMD, they could still watch the experience with an awareness of the concept because the players were acting and behaving like birds. It inspired me to come up with the idea of introducing the feature of dressing up as a part of play into the game experience.

3.3 Shooting Game

Shooting Game, a hackathon[15] project at Shanghai (Jiading) developed by E−GO, simultaneously demonstrates two parallel worlds by blurring the boundary between the virtual and physical environment and renders the artwork in a profound sense of immersions. The artists introduced participants onto a platform surrounded by projections on all four

[15] A hackathon at Shanghai Interactive Festive of Theater in Jia Ding http://www.shiftfestival.cn

sides. The participants then started a lighthearted shooting game, where the system applauded each time a paperman target was hit. Meanwhile, in the outside world, paper targets were transformed into running children. Observers standing around were able to hear the children's' scream and see them dropping dead with blood onto the ground. The VR player remained oblivious to this, until at the end of the game when the screen finally showed a list of names of the children who were shot dead, all real shooting victims from wars, while video of the shooting round was played back.

This project provides two different perspectives with distinct visual contents. The artists designed visualizations both for the HMD wearer and other observers, although it did not make shared awareness between them. In my opinion, *Shooting Game* critiqued the un-shared awareness between the HMD wearer and observers by using the gap between virtual and real worlds to make an ethical statement. It motivated me to consider current events with moral debates into the game context even though my thesis is more focusing on the technical and design parts, which is one of the reasons that I decided on simulating animal testing in the scientific lab as the core theme.

3.4 Keep Talking and Nobody Explodes

Keep Talking and Nobody Explodes is a co-located VR game developed by Allen Pestaluky and collaborators, where one VR player is trapped in a virtual room with a bomb that needs to be defused in a limited amount of time. The other players need to give instructions by deciphering a 23-page manual containing the information to defuse the bomb. The game builds tension through vocal communications between the HMD player and non-HMD players because the bomb scene remains exclusive in the VR experience and is hidden to others.

This project smartly integrates asymmetry in the game design with a distinct and simple game mechanic, so that the technical development becomes less tedious. The game challenges the ability of the HMD player to describe the visual of the bomb and also challenges the ability of the non-HMD player to find the right solution based on the vocal cues. I see this game as a successful and efficient example to engage non-VR users into the VR game experience in the same physical space with shared awareness. The developers maximize the limitations of an HMD and leverage it into player abilities to create repeatable playfulness. It inspired me to step back from the technical development and focus more on the game mechanics and player experience.

3.5 The Playroom VR

The Playroom VR, developed by Japan Studio, features a collection of six asymmetric mini-games, most of which are designed for a group experience, either cooperative or competitive. Only one player wears the HMD and goes into VR while other players can play through looking at TV screen using game controllers like normal video games. *Cat & Mouse* is one of the competitive games where the VR player, a cat, needs to catch other players who are mice trying to steal cheese in the game. The VR player can only catch the mice when leaning forward so other players need to hide by staying still. The VR player wins by catching all of the mice while other players win by stealing all of the cheese on the floor. A cooperative game featured in *Playroom VR* is *Ghost House*, where the VR player scans the room with a flashlight, while other players must guide the VR player to the location of the ghost by vocal communication. There are many other fun features that have been incorporated into the design of *The Playroom VR* to improve playfulness:

- The VR character's voice and movements change in response to the microphone and sensors on the HMD

- The design of the VR character aligns with the appearance of the HMD

Compared to *Keep talking and nobody explodes*, it has a more complex technical system with an essential requirement of using the *PlayStation* camera to be able to track the movement of the VR user. Both VR player and non-VR players can see the representations of each other in the game experiences such as *Cat & Mouse* and *Monster Escape*. *The Playroom VR* mainly gives me the inspiration of keeping a consistent design both in the game and the physical HMD to improve shared awareness.

3.6 Ruckus Ridge VR Party

Fig. 8. *Ruckus Ridge VR Party* from Foreignvr. 2016.
https://store.steampowered.com/app/443800/Ruckus_Ridge_VR_Party/

Ruckus Ridge VR Party is another co-located game developed by *Foreignvr* that features a series of VR mini-games designed with uses asymmetry principles. Similar to those previously mentioned games, the VR player wearing the HMD plays against other TV players with traditional game controllers or smartphones. As shown in Fig. 8, The VR player has the first-person perspective in the game environment while other players play with the top-down perspective from the TV screen. In the game, the VR player is surrounded by a field of boxes and the non-VR players are hiding in the boxes. The goal for the VR player is to defend themselves by shooting any suspect boxes. The top-down view from the non-VR players' perspective shows an indicator of which direction the VR player is facing towards to so they can find opportunities to move forward.

The shared element of *Ruckus Ridge VR party* and RABBOT is incorporating puzzle features with asymmetry in the game mechanics. It provides possible solutions to leverage the design to position the VR player in 3D and limit non-VR players to 2D. RABBOT takes a similar approach by emphasizing the ability of non-VR players to control the game environment that the VR player is immersed in. The design of the indicator can be another useful approach to improve the non-VR players' awareness in the same game environment.

3.7 Augmented Headsets

Fig. 9. Augmented headset from Hiroto Ikeuchi. 2018.
https://www.instagram.com/_ikeuchi/?hl=en

As mentioned in the previous chapter, modifying the HMD is one of my research interests and I want to take this approach to improve shared awareness. There are other projects being shared on open source platforms such as *Thingiverse* or personal blogs, but I choose to talk about the novel approach by artist Hiroto Ikeuchi. His works focus on the concept of the "materialization of imagination through plastic models" (Ikeuchi). He handcrafted futuristic objects and accessories into complex and beautiful high-tech-looking garments by using recycled electronic gadgets, cameras and smartphones inspired by science fiction and manga. Ikeuchi's works highly inspired me in terms of cyberpunk aesthetics and production methods. His approach is to take parts of existing plastics models and to modify them based on their original shapes and functionalities. As shown in Fig. 9, the shape of a VR HMD can be recognized in the center of this artwork with the same position that was originally designed to wear on the body. Concerning wearability, I have made a more streamlined HMD, despite Ikeuchi's works being a significant aesthetic influence on me. My own method will be to print small sized 3D parts to work with a microcontroller that can be attached to the HMD.

3.8 Summary

To conclude, the design of my prototypes is inspired by these aforementioned related works in different respects. *Inhabitat, Flock, shooting game* and Ikeuchi's augmented headsets are the projects I came across at the ideation stage of my thesis. The design decisions of roleplaying, cyberpunk, human and non-human perspectives are revealed in my early prototypes (see Chapter 5). The rest asymmetric games were part of my later research when I decided to emphasize the game experience in the process of developing my final project RABBOT (see Chapter 6) after I found its rich context when experimenting with users experience in my first prototype *Invisible Destination*. Overall, through researching and analyzing these related works, the design of the shared awareness between the HMD wearer and observers is getting into shape and clearer in my mind.

4. Methodology

The methodology of this project employs Research Through Design (RTD) by iteratively developing several prototypes. RTD is a research methodology where the design process itself becomes a way to acquire new knowledge—in other words, doing design as a part of doing research. RTD emphasizes artifact-led, practice-based research with an emphasis on developing design methods, conceptual frameworks, and theories, as well as products (Gaver). It takes advantage of the unique insights gained through design practice to provide a better understanding of complex and future-oriented issues in the design field. John Zimmerman and collaborators mentioned that the documentation of progress and evolution of RTD projects should preferably cover the whole process, from problem framing and the idealized preferred state to the outcome (316). Specific attention should be paid to detailing how theories from other disciplines have been integrated into the process and how the resulting artifact helps to refine or challenge the general theory through reflection on its application. Prototypes play an essential role in RTD methodology—they can illustrate or instantiate abstract theoretical concepts and demonstrate the possibility of a new combination of elements.

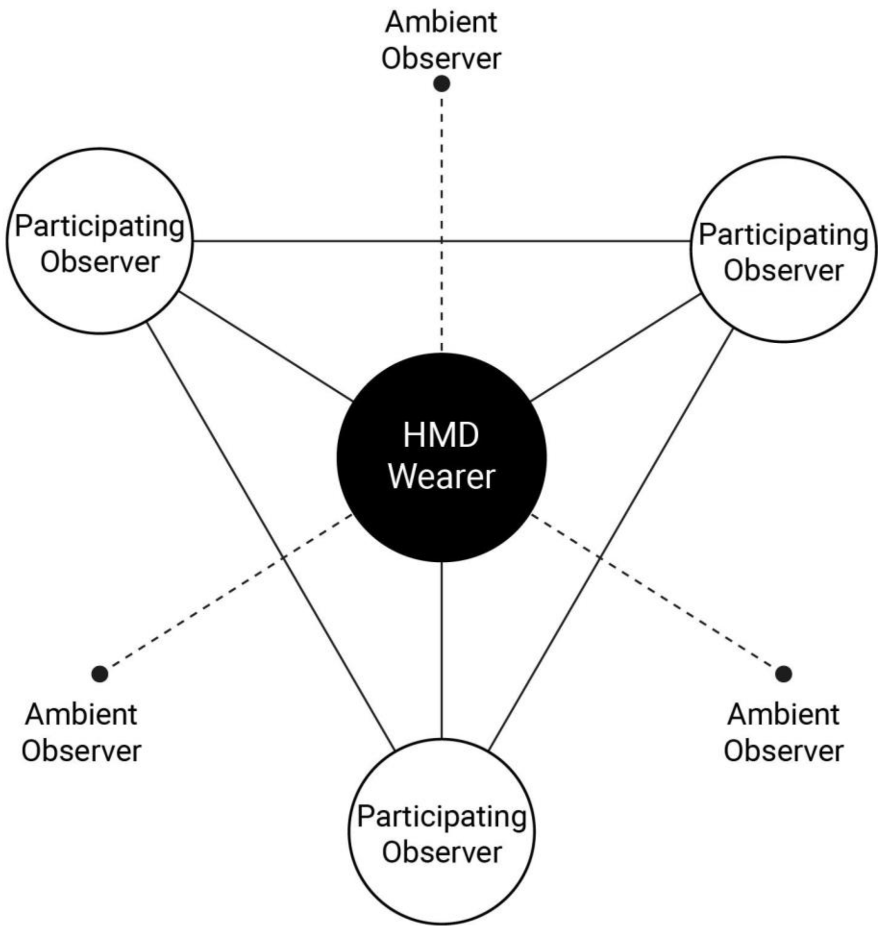

Fig. 10. Possible users in a VR experience

In my research and design process, I struggled with opportunities and constraints, with implications of theoretical goals/constructs, and with the confrontation between these and the empirical realities in the world in the generative process of ideation, concept development and making that brought prototypes into existence. The whole design process is part of my research from problem framing and identifying the idealized state to the outcome. I started my thesis by gaining an actionable understanding of a complicated situation: the isolation of the HMD wearer in VR. Through reading and studying literature around this situation, I framed it by defining the possible users in a VR experience as shown in Fig. 10:

- The head-mounted display wearer (big black circle in the middle): who is completely immersed and has no connection outside the VR experience
- Participating observers (white circles at the outer ring): who are in the vicinity of the VR experience, interested in engaging with the wearer, and also have shared awareness with other observers.

- Ambient observers (small black dots): who are not actively engaged in the experience, such as a passerby or remote telepresence player.

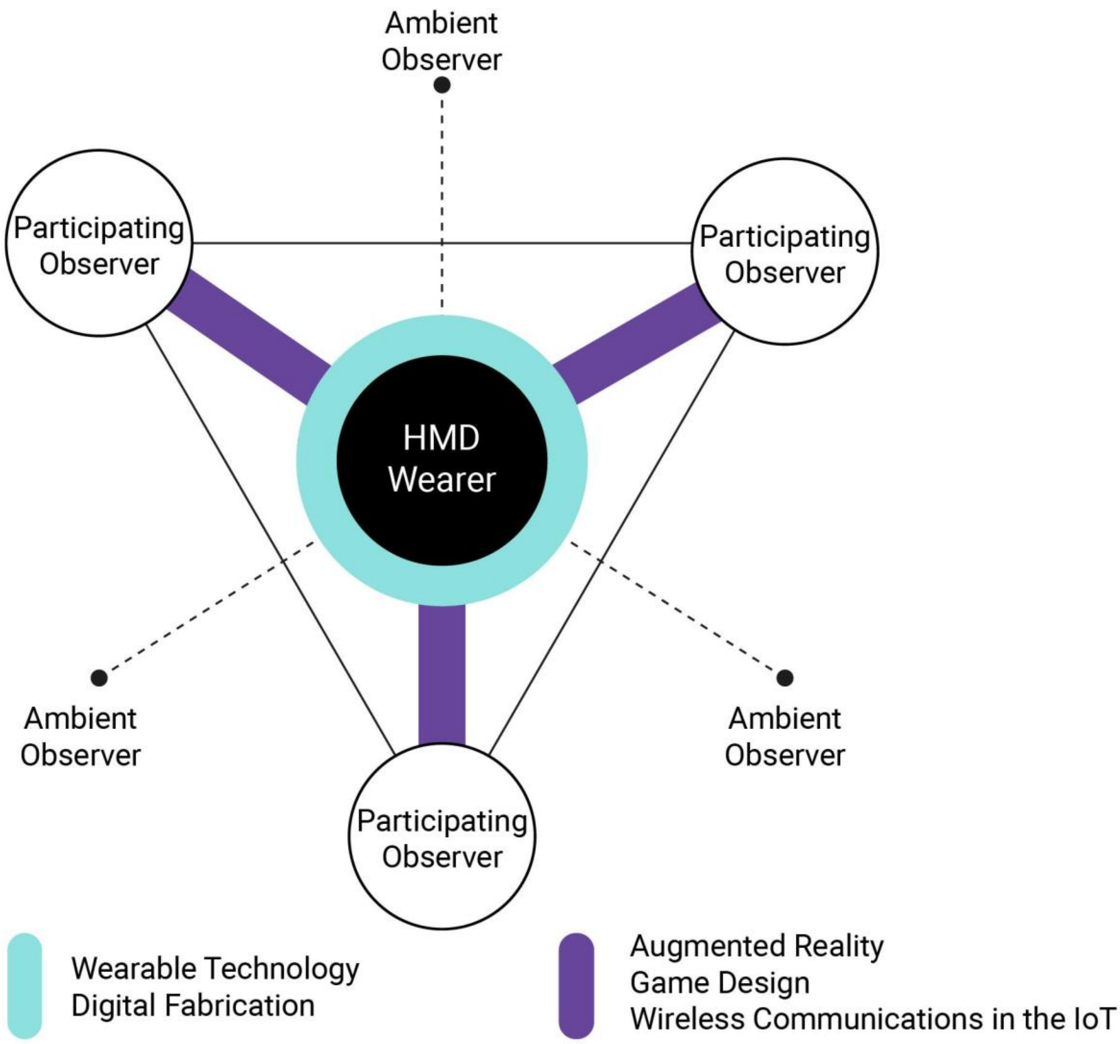

Fig. 11. Conceptual framework

To explore possible solutions of generating shared awareness and to determine idealized preferred design decisions, I went back and forth between research on literature and related works and design development. Overall, my conceptual framework is as shown in Fig. 11. Wearable technology and digital fabrication help me to open the gateway from the HMD wearer to other observers, which conceptualize the idea of modifying an HMD as one of my prototypes *Rabbit HMD* (see Section 5.2). Augmented reality, game design and wireless communications serve as the bridge between the HMD wearer and participating observers, which reflects on the rest of my prototypes, as will be discussed in detail in Chapter 5. These prototypes were all shared with classmates and professors in a classroom critique environment where I was able to receive feedback to inform each iteration. These prototype iterations contributed to the development of my final project, RABBOT, which serves as a means to test my main research question of shared awareness between the HMD wearer and other observers. To evaluate my final project, I conducted formal user testing by using the methods of on-site observation and questionnaires to gain qualitative data from participants.

5. Iterative Prototyping Stages

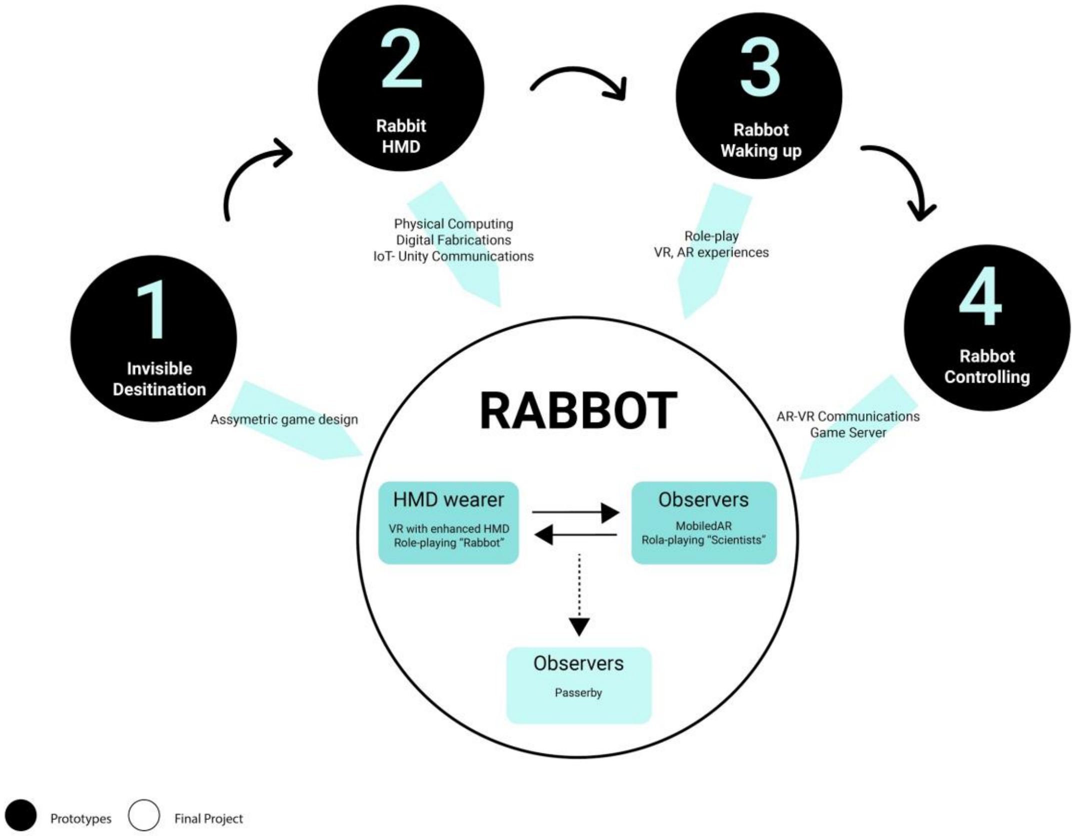

Fig. 12. Prototypes Map

This chapter introduces a series of iterative prototypes, each starts with a detailed description and process, ends with the results and my reflections. As the prototypes map shown in Fig. 12, the four prototypes contribute different aspects to the final project RABBOT with different design challenges. *Invisible Destination* is a physical game focus on the target users' asymmetric experiences. *Rabbit HMD* is a modified VR headset in the explorations of different materials with digital fabrications, physical computing and communications between IoT platform and Unity3D. RABBOT *Waking Up* brings the roleplaying feature into the VR and AR experience that working with *Rabbit HMD.* RABBOT *Controlling* takes in consideration with important features from previous prototypes but more focus on the backend development such as building a game server to support communications between VR and AR apps. As mentioned before in Chapter 4, the feedback I receive to inform each iteration from these prototypes were from my classmates and professors in a classroom critique environment. These prototype iterations served to inform the development of RABBOT.

5.1 Prototype 1: Invisible Destination

5.1.1 Description and Process

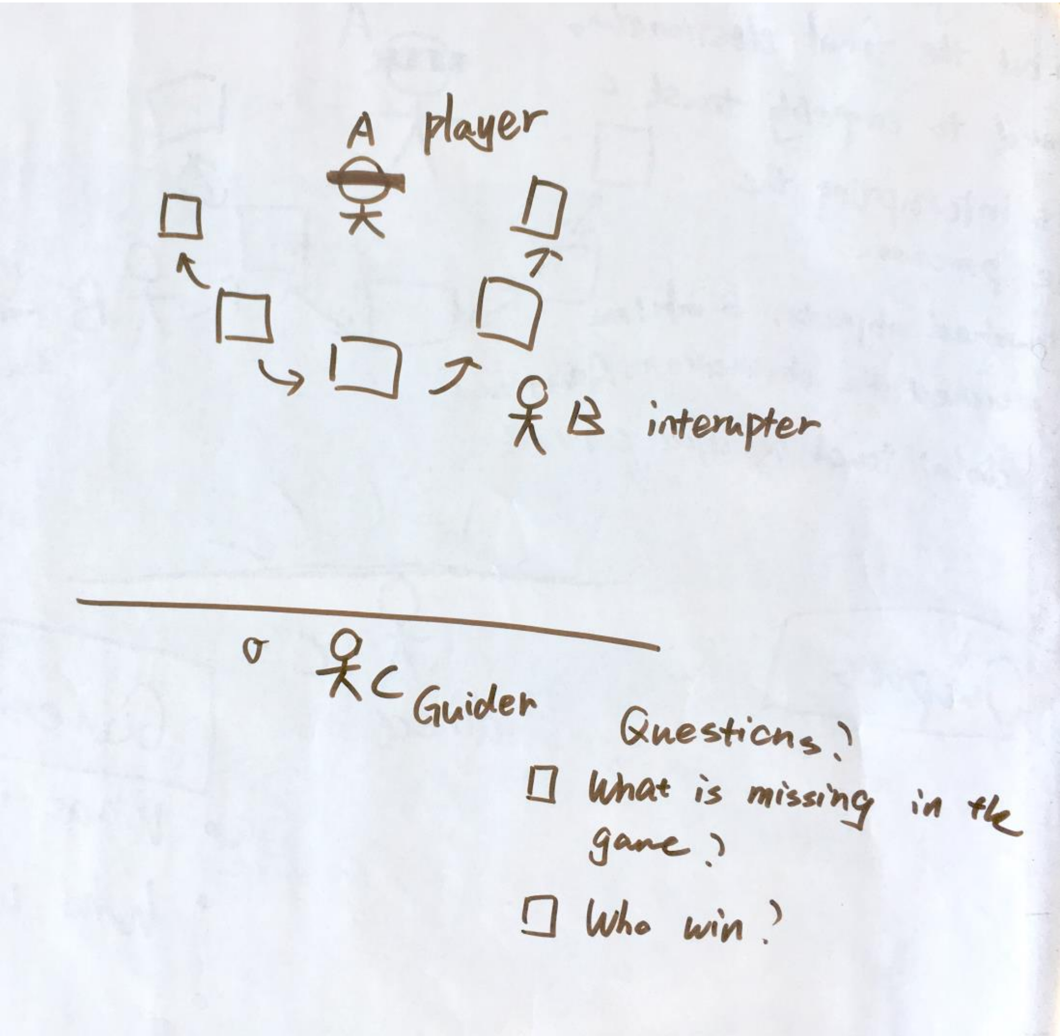

Fig. 13. Design sketch of the Invisible Destination

Invisible destination focuses on user experiences to explore possible interactions between HMD wearer and other observers by conducting a physical asymmetric game with group of three classmates. As shown in Fig. 13, Person A is a player who gets blindfolded and needs to follow the vocal commands made by the commander to get to the destination. Person B is an interrupter, who can make sounds, move chairs around and touch person A. Person C is a commander, who need to make clear commands to person A and help him/her to reach the destination. Person A and C wins by reaching the destination within 3 minutes. Otherwise, Person B wins. The instructions of how to play this game are as following:

- Person A – Player: You will be blindfolded and you need to reach out to the destination by the commands made by the commander, you can completely trust him/her and they will make you safe.
- Person B – Interrupter: You can make sounds, move chairs around and touch person A. Your goal is to try your best to prevent Person A from reaching the destination.
- Person C – Commander: You need to make clear commands to person A and help him/her to reach the destination. Your responsibility is to make person A safe and don't make him/her stumbled and fell down.

In the ideation process of designing this prototype, we had the group discussion in the class to discuss some prototype ideas. I wrote about my thesis title, short description and prototype ideas on a poster and my classmates gave me the suggestions by post-it notes, I select the useful approaches as following to design *Invisible Destination*:

- Role Play
- Concept testing to get ideas of interactions people would want
- Asymmetric design
- Think of physical interactions between the person in and persons out of VR

5.1.2 Results and Reflections

Invisible Destination was played by my classmates in four rounds in class. The following are the feedback and the on-site observation:

- Most participants tried VR before and it's reminding them of wearing headset but not knowing what happened outside of the VR.

- Most participants can figure out a strategy quickly to move forward.
- Vocal cues/commands from the commander are the most helpful part.
- The lost of vision is difficult for most participants.
- More constraints and rules to would be more difficult for the participants.
- Some participants wish they can simulate the voice of the commander to confuse the player.
- Most participants worried they were doing too much to interrupt and gave fewer interruptions towards the end of the game.
- Secret code to communicate with the player
- Clarifications of the directions with the player at the beginning of the game.
- A more clear and straightforward way to guide the player.
- Body configurations

I do not usually involve both physical prototype and digital prototype in my design process. However, I do think this approach is very helpful before going further to develop a digital prototype. As a designer and developer, it's common to limit on my own assumptions of what my users will do in experience and it's also very easy to be single-minded on the technical side but forget about the actual experience.

In this prototype, I use the asymmetry to design the game experience by incorporating the theory of cybernetics (see appendix C.a) and information communications with a sender, a receiver and noise. Person A is playing the role of the HMD wearer who has no control of the physical world and only has limited access to interact within the virtual world. Person B is playing the role of the audience who can interact with the HMD wearer in the virtual environment like moving objects around, making sound and haptic interactions. Person C is playing the role of the storytelling cues in the virtual reality for the player to finish the whole experience. *Invisible Destination* contributes to the final prototype RABBOT in a way that the combination of competitive and cooperative gameplay among three players has been inherited through character setting and game mechanics.

5.2 Prototype 2: Rabbit HMD

5.2.1 Description and Process

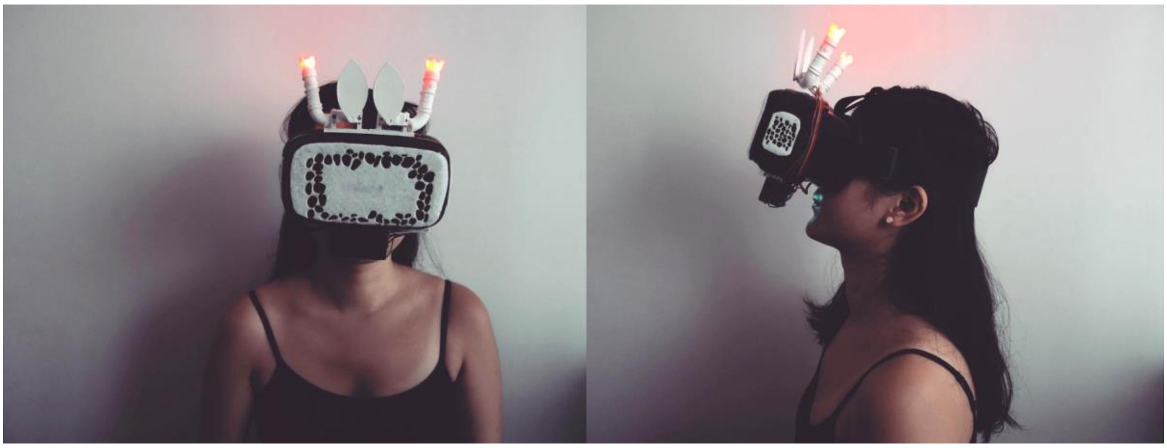

Fig. 14. Rabbit HMD

Rabbit HMD (as shown in Fig. 14) is a prototype mainly focused on the physical modification of the VR headset for both HMD wearer and other observers by incorporating 3D printing, laser cutting, wirelessly networking and physical computing. This prototype uses an existing VR mobile viewer to explore different materials and technologies. The purpose of this prototype is to improve the overall aesthetics and capabilities of a normal HMD. Hence, it will enhance the engagement of other observers by interacting with the HMD as well as the fun of looking at the player who is wearing the HMD. The image targets are designed to be placed on three directions so each angle of the headset can trigger a 3D representation on the AR app.

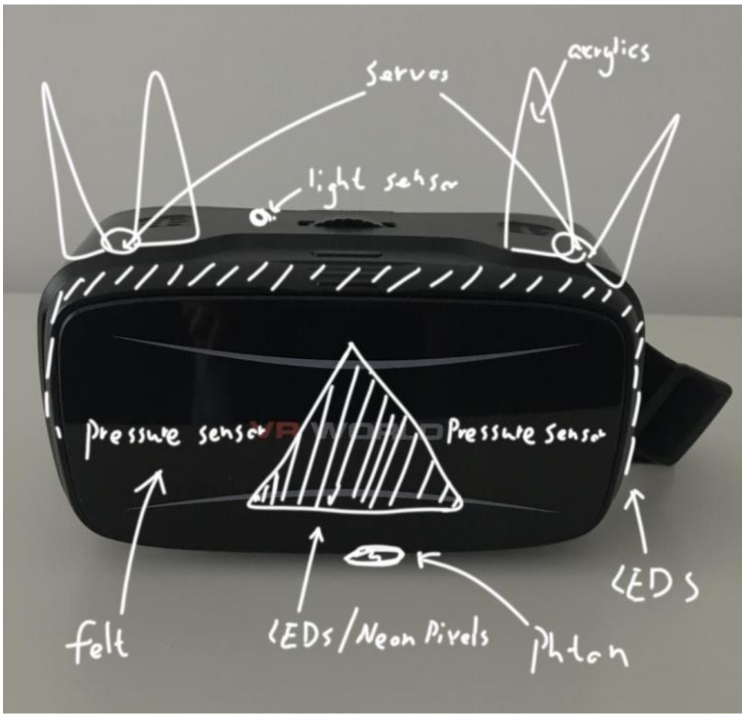

Fig. 15. Initial sketch for Rabbit HMD

My initial goal for this prototype is to explore a various range of materials as the sketch shown in Fig. 15. However, due to the problem of the power supply and limited materials, I decided to work with two LEDs, two servos and a DIY pressure sensor in the end as the circuit diagram shown in Fig. 16.

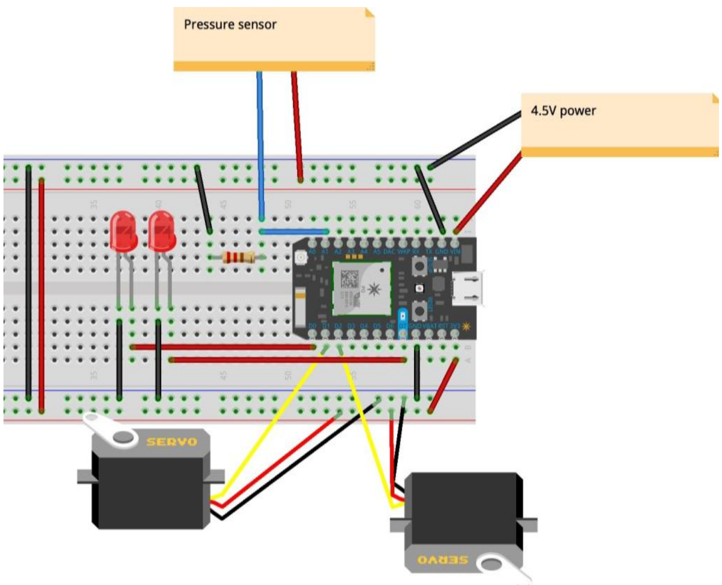

Fig. 16. Circuit diagram

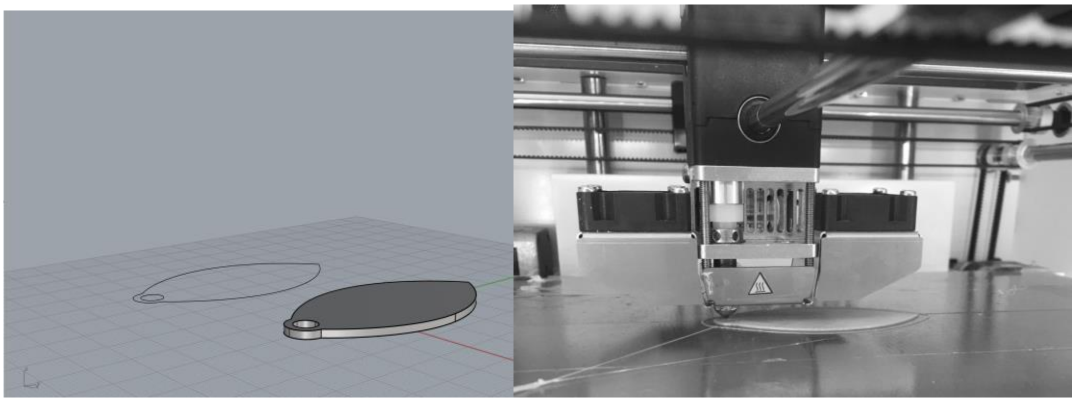

Fig. 17. 3D design in Rhino and 3D printing servo attachments

The 3D printed components include attachments (Fig. 17) for two 9g servos and light diffusers for two LEDs. They were printed with Ultimaker 2+ with 0.4mm PLA filament and assembled with screws and glues onto the headset. The AR markers (Fig.19) were designed in Adobe Illustrator for three different angles to place on the headset which is designed to trigger three different 3D objects. They were cut on 0.15mm felt fabric sheet on Boss 2436 laser cutter. The pressure sensor (Fig. 18) was made in a sandwich structure (Hartman 56) using a pressure-sensitive electronic textile from Eeonyx. It was attached at the bottom of the headset to get inputs from the HMD wearer.

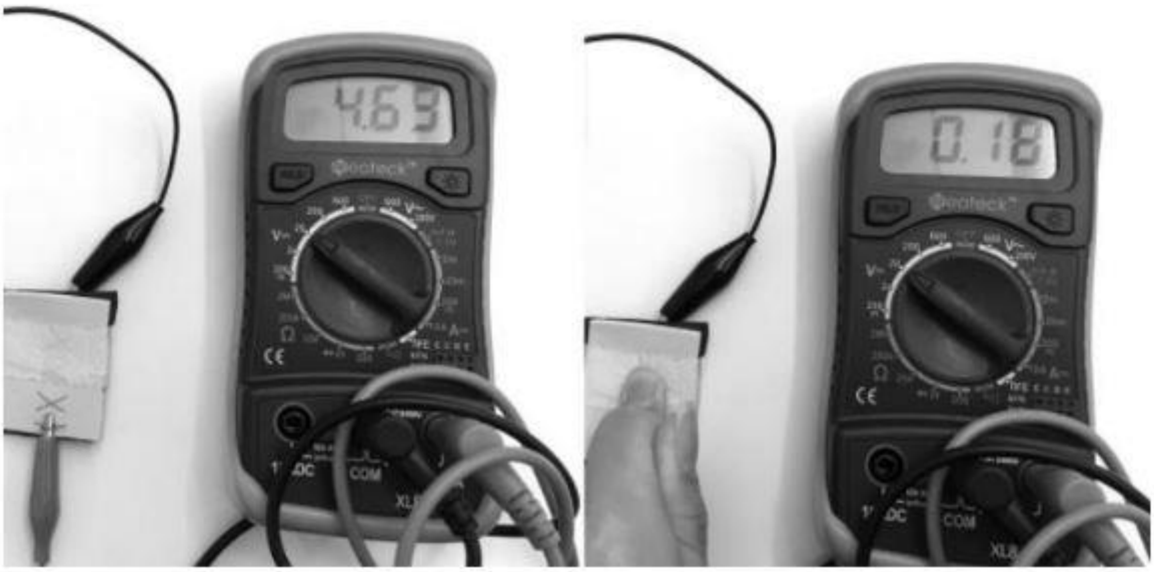

Fig. 18. Testing with DIY sensor

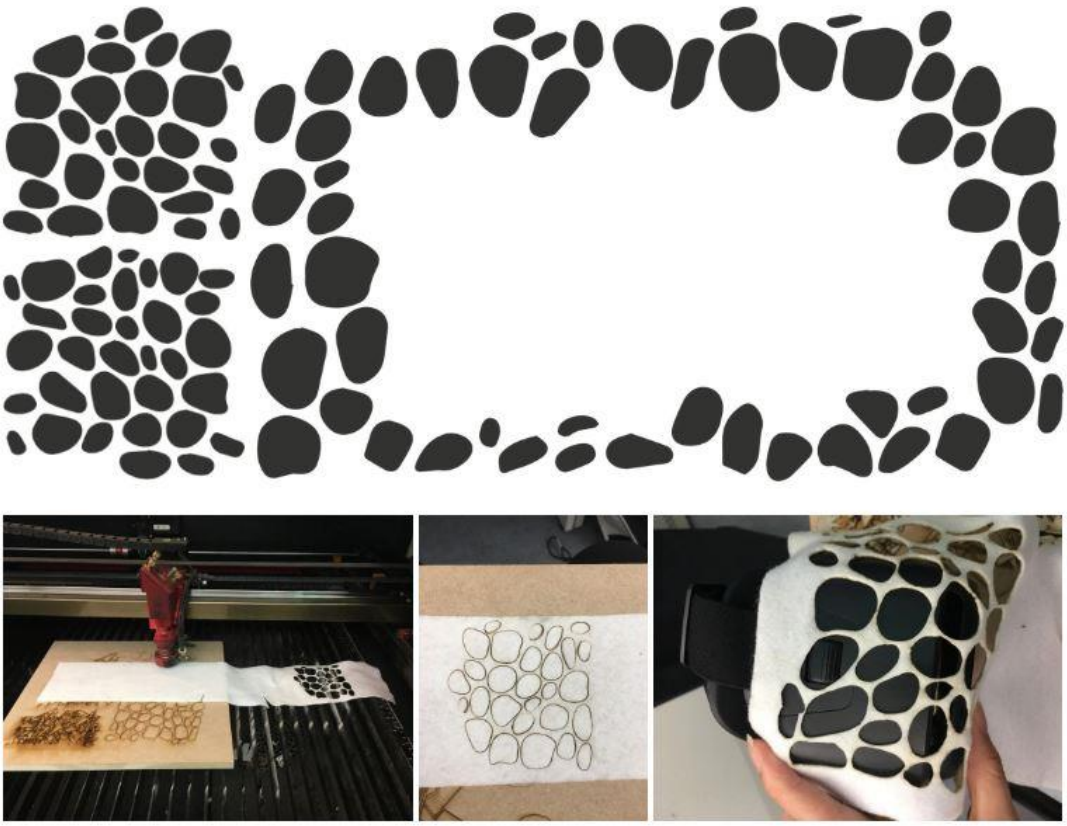

Fig. 19. Marker Design and laser cutting

For the power supply, my initial plan is using coin cell batteries for the consideration of wearability, as they are small and lightweight. However, after several attempts, I determined that the coin cell batteries have significant current drop which will not be ideal to power up a microcontroller. So, I decide to work with AAA batteries instead for this prototype. The position of the battery pack is designed at the bottom of the headset, which is convenient to be turned on/off and to be replaced with new batteries if needed. The connection wires for the LEDs and servos go from two directions alongside the edges of the headset to the microcontroller and power supply.

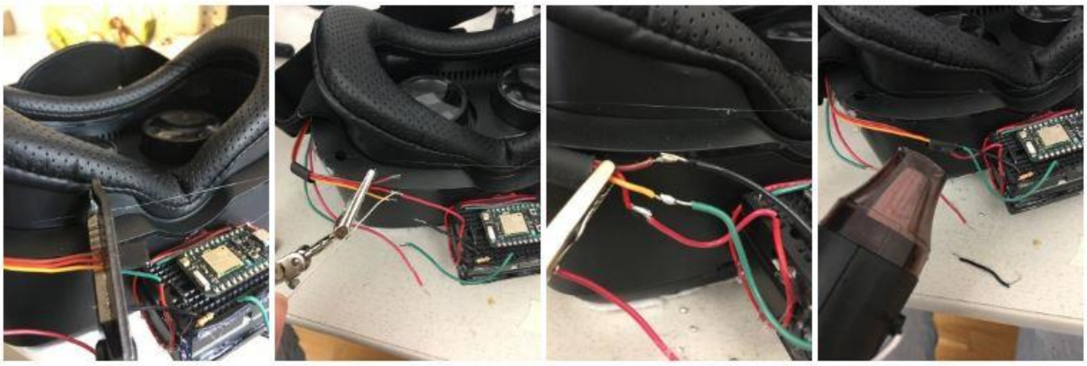

Fig. 20. Assembling wires

For software development, I use *Particle Cloud API* to build communications with *Unity3D*. The *Particle Photon* microcontroller is programmed through *Particle IDE* and it can subscribe and publish to any customized event. In Unity3D, I write scripts to connect to *Particle Cloud API* that can read the JSON file (sensor values) and send HTTP request (event trigger) to the microcontroller. The other technical specs to build the AR app are as following:

- MAC OS: High Sierra 10.13.5 (17F77)
- iPhone OS: 11.3.1 (15E302)
- Xcode: 9.4 (9F1027a)
- Vuforia: 7.1.35
- Unity 3D: 2018.1.4f1

Fig. 21. Multiple image targets test in AR

Fig. 22. Rabbit HMD from three angles

5.2.2 Results and Reflections

I received feedback on the *Rabbit HMD* in class which included the following:

- I would prefer more instructions from you. How do I use the app?
- The headset is not heavy at all and it's quite comfortable to wear.
- I prefer the small movements of the ears and I feel like the big movements are too robotics.
- The buttons on the AR app are too small, they are difficult to touch

Speaking to the feedback that I received, it's important to know the users would prefer more instructions. It's also interesting to know most of the people who tried this prototype feel the ear's movement is very robotic, which inspired me to come up with the concept of robotic rabbit - RABBOT. I then started to work with the design of a fictional background story which can both be instructions for the participants but also immerse and position my participants in a game set up to further introduce the idea of human-animal perspectives.

Rabbit HMD built a fundamental system framework for the communications between HMD and the game from the observer's side. It contributes to the RABBOT with initial attempts to work with different materials and wireless system structure. In this prototype, however, I haven't brought the VR app to the HMD wearer yet. The goal for *Rabbit HMD* is to test the wearability of the enhanced HMD. It leads me towards to better design the 3D components for the next iteration and also establish the decision and confidence of working with a better headset. One of the considerations that has been incorporated into the next iteration is to replace the small buttons with a 3D rabbit model. Instead of touching on the buttons, the observer can touch the specific parts of the rabbit model to interact with the corresponding parts on the headset.

5.3 Prototype 3: RABBOT - Waking Up

5.3.1 Description and Process

RABBOT - *Waking Up* is a prototype that works with the *Rabbit HMD* and a VR app featuring the rabbit's perspective. It is also the next attempt to bring back roleplaying to the HMD wearer and observers incorporating a fictional background story to improve the engagement.

For this prototype, I start with the research on rabbit vision to figure out what color and angles that a rabbit can see. Rabbits can discriminate between the wavelengths we call “green” and “blue.” (Krempels). Although rabbits may not perceive green and blue the way humans do, they can tell them apart. This means rabbits have limited color vision, probably conferred by two different categories of cone cells (blue and green). Hence, this finding establishes the color theme of the VR scene and I start to create the rabbit’s vision in *Unity3D* with the following technical specifications:

- MAC OS: High Sierra 10.13.5 (17F77)
- iPhone OS: 11.3.1 (15E302)
- Android: 7.0
- Xcode: 9.4 (9F1027a)
- Vuforia: 7.1.35
- Unity 3D: 2018.1.4f1
- Android JDK: 1.8.0

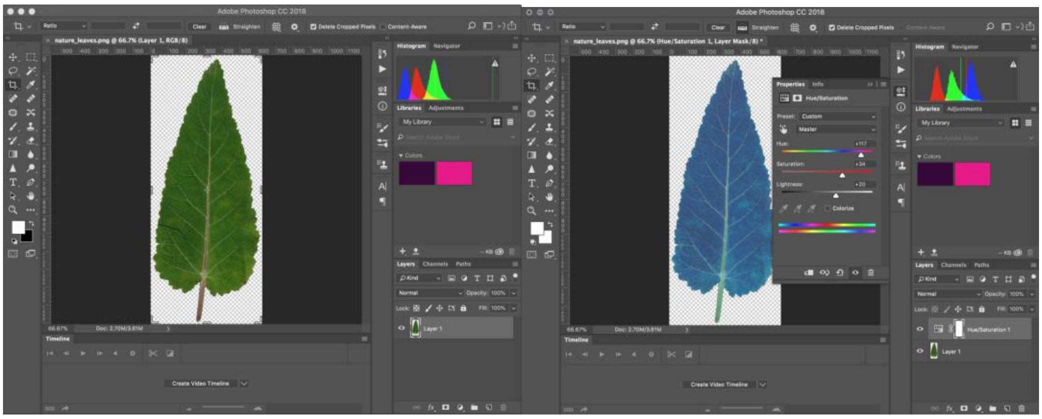

Fig. 23. Creating textures in Photoshop

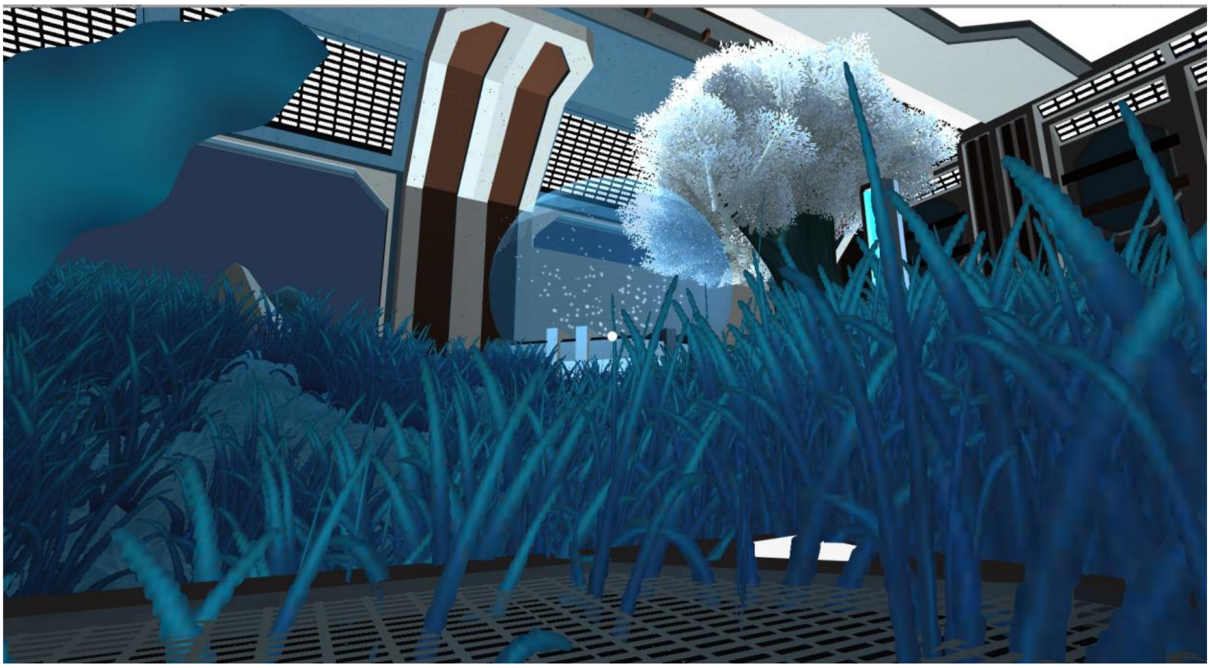

Fig. 24. VR scene in Unity3D

I improved the AR app by replacing the buttons with a 3D representation of a rabbit and design the fictional background story to be read out loud to the HMD wearer and observers before the experience:

> Today is 26th July 2038, My name is Yiyi Shao, I’m the chief scientist at AniBot Lab. Welcome welcome! It’s an exciting day to the public our new project RABBOT. We implanted two robotic ears and eyes to our test subject. It’s still the first stage of our experiment, but we saw a remarkable success. Now may I invite our guest to wake up RABBOT 1.0.

The HMD wearer is roleplaying the *Rabbot* and can only turn the head around with no other interactions in VR. The other observers are roleplaying the guests that are visiting the lab to see the *Rabbot* waking up by tapping on the AR app to control the physical components on the headset.

5.3.2 Results and Reflections

I shared RABBOT - *Waking Up* for the first time in a group of people with my classmates and professors in the class and received the following feedback:

- It’s tricky to point towards to the image target, the VR user is always moving.
- The sound is too low, I can’t hear anything.

- I wonder If there is any interaction I can do in VR.
- If I were a rabbit, I would prefer to see my pink noise, furry feet and paws when I look down.
- Wow, I feel like I am so small like a rabbit.
- I can see some shadow of trees is pink.
- I wonder if a rabbit can turn their neck at such a big angle.
- I found the graphics in VR are a bit rough.
- I feel it's a bit blurry in VR but when I look far it will become better.
- Your headset can't fit me, I can't see it well.
- I found the rabbit is too cartoonish

In RABBOT- *Waking up*, the communications between VR and AR haven't been made yet, but the HMD wearer already start to try to wonder the interaction in VR. Based on the feedback, the next iteration would improve the overall graphics quality both for the VR and AR app. One of the important findings both from my on-site observation and feedback I received is the problem of triggering the image target. As the VR user would wander about the virtual environment once putting on the headset, the AR observers found it's very tricky to launch the control panel. This problem is creating an interesting dynamic between the HMD wearer and AR observers, which brings me back to think about using asymmetry in the game design and come up the main game mechanics in the next prototype.

5.4 Prototype 4: RABBOT - Controlling

5.4.1 Description and Process

RABBOT-*Controlling* is an asymmetric game sketch containing AR and VR mobile apps with a local server that can provide interaction between people inside VR and people outside the VR. The main game mechanics are the body movements of the HMD wearer (VR user) and the participating observers (AR users) because an image target is designed to place in front of the VR headset. While the VR user is moving their head around in VR, the AR users need to point their mobile phones towards the image target to be able to launch the control panel that can move the object in the VR scene. During the demonstration, two projectors were screen-mirroring the AR and VR apps.

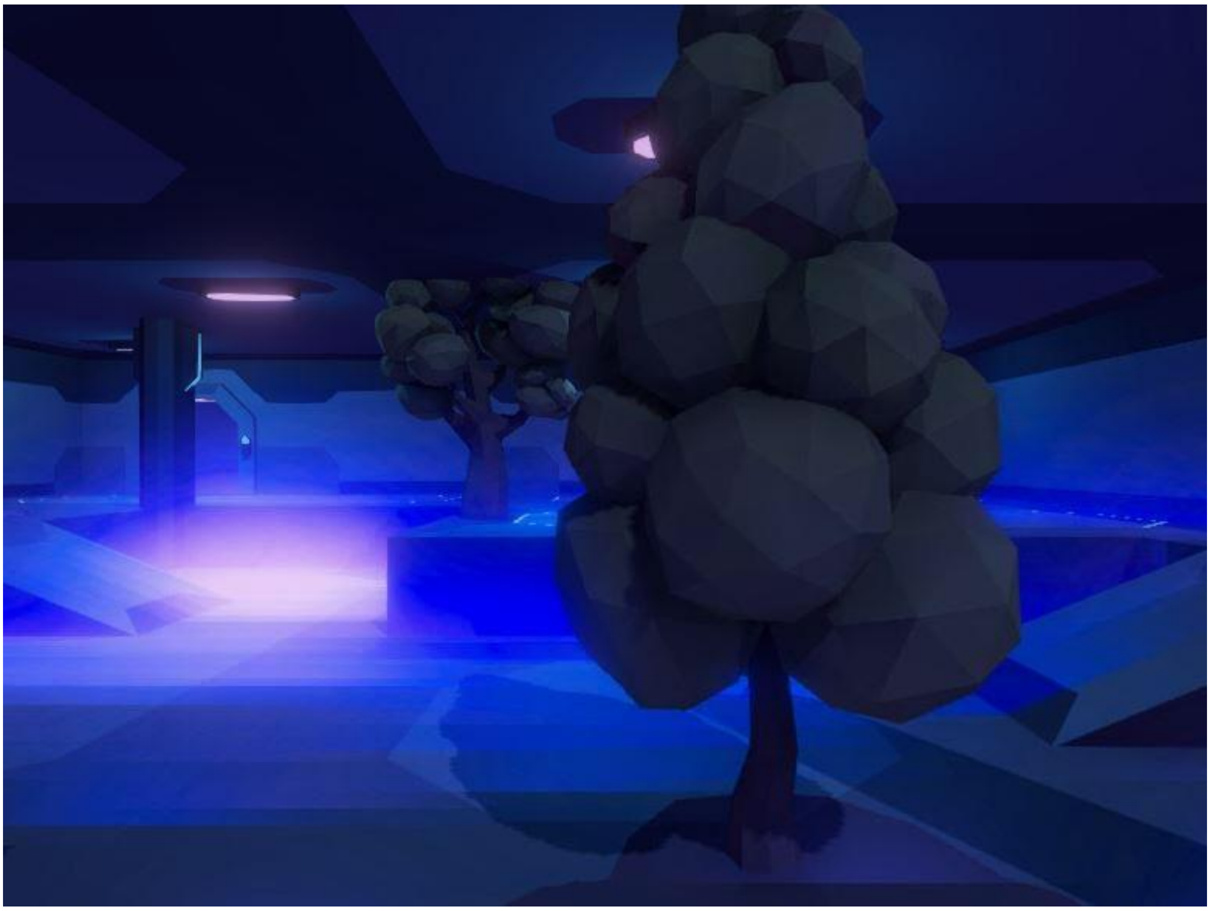

Fig. 25. VR scene in Unity3D

I start with this prototype by improving the overall graphics quality. The first improvement is the VR app scene for the reason that the early VR prototype has a big lagging problem after switching from *Google VR* to *Gear VR*. I redesigned the game scene (Fig. 25) and the main character (Fig. 26) to be low-poly and also optimized the graphics setting in Unity 3D to better support mobile VR. I made some aesthetic choice such us placing fog in the VR scene, which is designed as millions of nanobots flying in the air to work with the game story. I also add post-processing effects such as *bloom* and *color adjusting* to make the graphic smoother and align with the cyberpunk theme. The main character *Rabbot* is designed in low-poly style as well to be cohesive with the rest of the design. Based on the *Gear VR* example package in Unity3D, I improve the VR user experience in terms of adding an instruction of how to interact with the game object at the beginning.

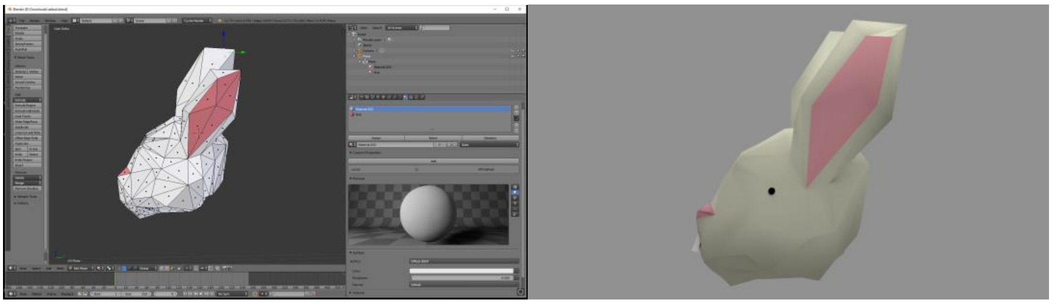

Fig. 26. 3D modeling RABBOT in Blender3d and the final visual after rendering out

To make the interactions between AR and VR app, I first experimented with the *Networking* manager that comes natively with Unity3D. It can set one of the players to be the game server and other players to be the clients, which turned out to be working fine but not stable enough and does not support the latest version of *Unity3D.* I then decided to use a plugin called *Socket.IO*, which works with *Node.js*. That way, the game server can run separately on a computer, which provides more capability if employing to the cloud later on. For the purpose of a more stable WIFI connection under an enterprise network at OCAD University and to customize a static IP address for the game server, I set up a travel WIFI router connecting to the OCADU-embedded network working as a hotspot to provide connection to my devices and apps. The final designs of AR and VR app are as shown in Fig. 27 and 28. The following are technologies and equipment used during the demonstration:

- One travel router
- One Samsung S6 with *Gear VR* headset
- Two iPhones
- Two projectors
- One laptop for running the server
- One *Apple TV* and one *Chrome Cast* for mirroring the devices
- One extension cord

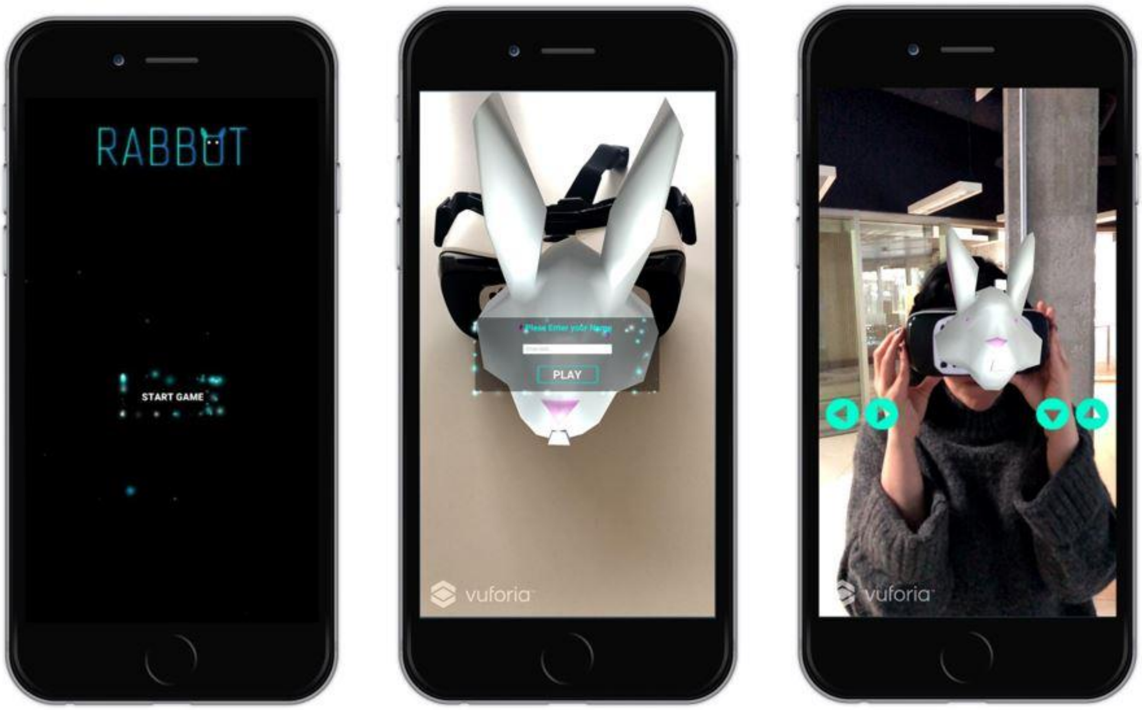

Fig. 27. AR App Design

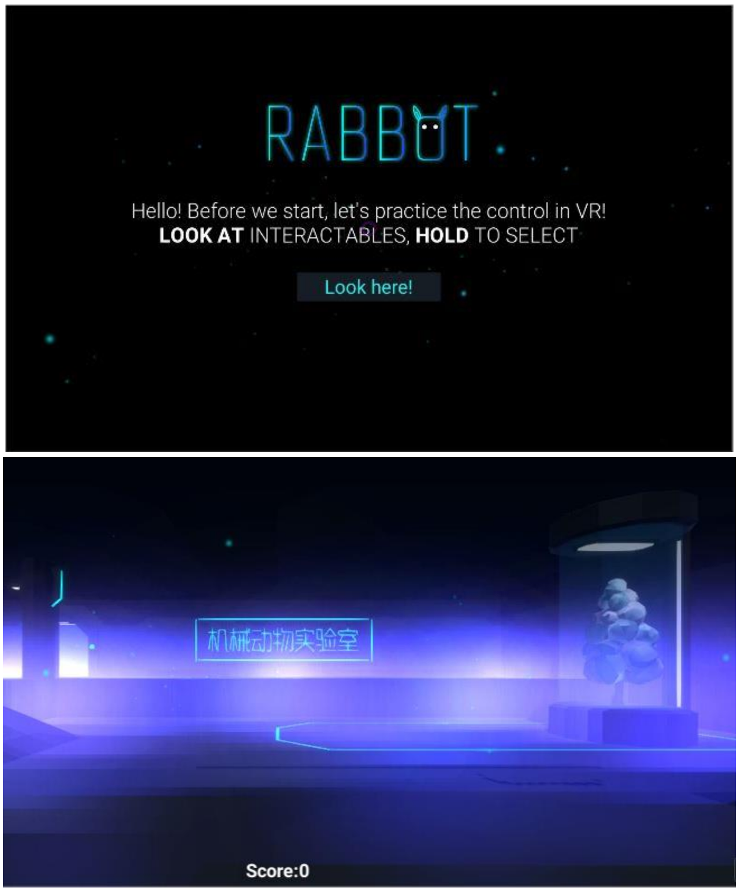

Fig. 28. VR App Design

5.4.2 Results and Reflections

I demonstrated this prototype to my classmates and professors and received the questions and feedback as following:

- Is this game competitive or collaborative?
- Should add some indicators to both of the users.
- The iPhone screen is too narrow for me to interact with.
- What are the physical components on the headset do?

Overall the feedback I have received during the demonstration helps me for the improvements of final project RABBOT in terms of game design and user testing. The following will be my next steps for the consideration:

1. Competitive vs. Collaborative

The initial idea is a competitive score system between the VR user and AR users. For this prototype, I have not decided which one to incorporate into the game design. However, one of the conceptual ideas is to bring different roles/controls (bad and good scientists) to the AR users so it will bring different endings to the game. This will be considered as one of the main aspects to design the final project RABBOT and test out through later user testing.

2. Indicators for AR user and VR user

One of the challenges that the VR user has experienced from both the feedback I received and my observation while demonstrating is the loss of space recognition and the positions of AR users. This is part of my concerns when designing the scoring system in an asymmetric puzzle game to leverage the game experiences for each user. For the next steps, it's worthwhile to add some indicators for VR users and AR users to locate the position of the object/other players. In addition, adding more constraints to the AR user can possibly be another approach because as for now the AR users seem to have the upper hand.

3. Physical components for the headset

Physical components such as motors and LEDs are part of the game experiences. On the one hand, it will make the experience look more interesting for the aesthetic purpose which aligns with the cyberpunk style and to tell more backstory of RABBOT, the other hand it will bring more haptic and tangible feedbacks to the VR user.

5.5 Summary

The iterative journey of the prototyping process paves the way for my final project RABBOT. Each prototype features with the design decisions that worked and didn’t worked with new inspirations raised from feedback that given by my classmates and professors. By thinking of their essence to their dregs, I finally proceed to design my final project RABBOT in the next chapter.

6. Final Project: RABBOT

This chapter introduces the final prototype RABBOT, and it is created based on the challenges and opportunities identified in my prototyping process. The final output is an asymmetric game featuring the VR app that playing by the HMD wearer, the AR app playing by the observers and the modified HMD to enhance the player experience. The main mechanics are the body movement associating with the image target, which adopted from RABBOT-Controlling. The modified HMD was improved with a new design to attach the digital components and microcontroller with electronic circuits. This chapter starts from the first section on the system overview with a close explanation of how the communication system works between the HMD wearer and the participating observers. The second section interprets the final game design of RABBOT with character's control and goal. Subsequently, the third section presents the making process of improving modified HMD. The fourth section introduces the user testing process. Finally, the fifth section concludes this chapter with the results and reflections.

6.1 System Overview

As shown in Fig. 29, the system is built based on communications between the HMD wearer and observers both for software and hardware. Derived from the early prototype, the personal WIFI router is running to provide a stable signal. For the software, as shown in the top half of the diagram, the WIFI router assigns my laptop with a fixed IP address that is running a Node.js server for the game. In Unity 3D, both AR and VR apps are embedded with Websocket using a plugin called *Socket.IO.* As a result, the apps are communicating with each other through WebSocket in the format of exchanging data in the JSON files. For the hardware, as shown in the bottom half of the diagram, the WIFI router provides with internet access to the *Particle IoT Cloud* via Particle API. This enables the AR user to toggle the LED and servo events via HTTP request developed in Unity3D. Additionally, the dashed arrow in the diagram represents the communication from HMD to the AR user that can be made in the same method but it has been removed because it is not required by the game design.

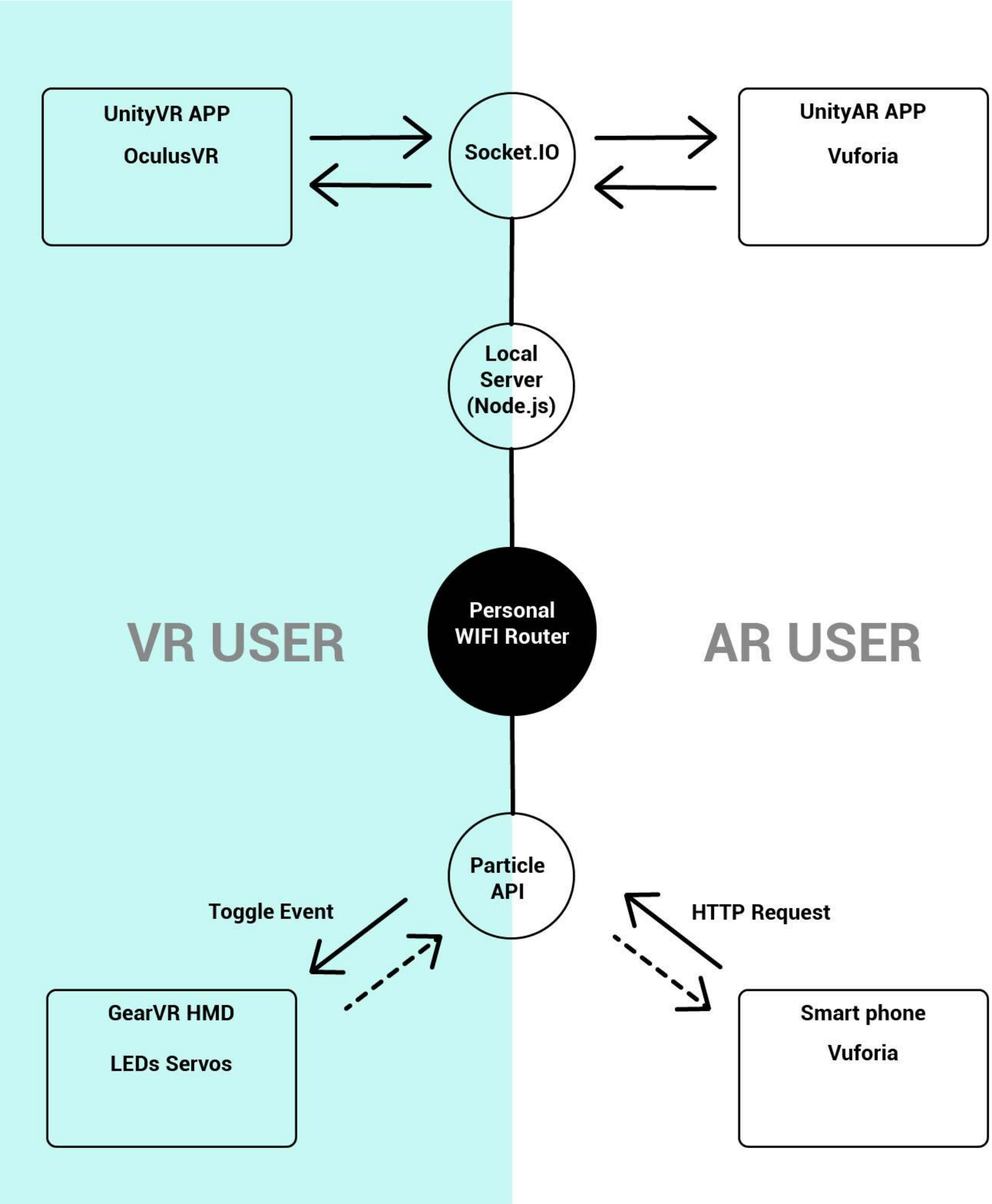

Fig. 29. System overview diagram

6.2 The Game

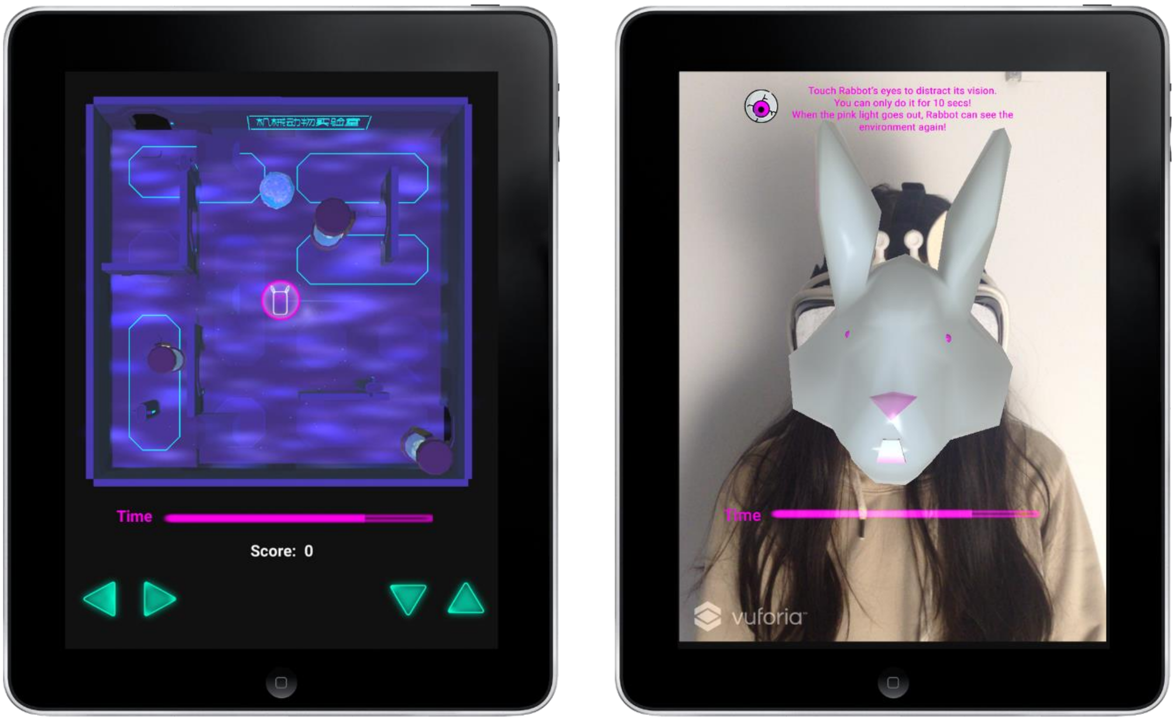

Fig. 30. The final game interfaces for participating observers

RABBOT is designed under the core theme of cyberpunk (see appendix D.1). Based on the early prototype RABBOT-*Controlling*, I decide to keep using the game story and have three characters in the game: *Rabbot*, *Scientist A* and *Scientist B*. The game is happening in *AniBot Lab*, where the scientists are working on combining cyborg technologies with live animals. *Scientist A* and *Scientist B* are training animals to complete some complex tasks by remote-controlling with the new inventions on neurological technology, *Rabbot* is one of the testing subjects.

The game features both collaborative and competitive. Scientist A and Scientist B are working together against the Rabbot, the game specifications such as goals, ways of controls and points system are as shown in table 1. By comparing the final scores of Rabbot and scientists, the game determinants the winner with higher scores. As shown in Fig. 30, I designed the supportive role-playing items such as costumes and name cards to improve the engagement and level of fun both for the participating observers. As thus, the whole experience will become a performance that presented to the ambient observers. However, these items are prepared for the thesis show and haven't been tested with the participants yet in section 6.4. More design details of RABBOT game can be found in appendix C.

Table 1. Game Specifications

Character	Goal	Controls	Points
Rabbot (VR player)	Find the ball	Look at the ball and activate by holding the touch panel on the headset	Get 10 points by holding 5 secs. Get -10 points by not finding the ball under 10 secs.
Scientist A (AR player)	Control the light in the lab room and help *Scientist B* by disturbing Rabbot	Chase after Rabbot to make its 3D representation reveal, turn the lights off in VR and toggle the components on the headset by touching the Rabbot's eyes and ears	Share points with *Scientist B*
Scientist B (Tablet player)	Move the ball around to hide from Rabbot and not collide with the walls	Control the ball by using arrows	Get 10 points by eating stars in the lab room. Get -10 points by hitting the walls

Fig. 31. Costume and items design for roleplaying

6.3 Making Process

The headset was designed by taking consideration of all defined users because the HMD wearer can feel the physical components that triggered by certain behaviors in the game while the observers enjoy the overall appearance of the HMD. Based on the early prototype Rabbit HMD, I improve the 3D parts and design a case that can hold both the microcontroller and battery. One of the significant improvements is the LED attachments, I came across the design of LED solderless holder[16] uploaded by "Roipoussiere" on *Thingiverse*, which provides good support for a 5mm LED. I incorporate it into my design and add extra support from both sides for the ¼'' diameter fabric wires. Then I design the hollow "eyes" that can be placed on top of the LED basement and functioning as LED diffusers. To achieve the best lighting effect, I replaced the normal LEDs with super bright neon ones, so they are more visible compared to the early prototype.

The other significant improvement is the case, I decide to use the rechargeable 3.7V 1000mAh Li-Po battery instead of the AAA batteries to reduce the weight, which needs to with the Photon battery shield. Some additional design considerations including adding the switch to the case to be able to turn on and off the microcontroller and adding a hole for the LED indicator on the microcontroller for debugging. In order to achieve a seamless design for the wearability of the HMD, I measured every component for references when designing the case. It is beneficial that the high-fidelity 3D models of the microcontroller and battery shield are available on the internet, it saved me much time to figure out the position for the USB port, LED indicator and to place the screws (Fig. 32). When in the assembling process (Fig. 33), the most time-consuming part is soldering especially for the wires that are going into the case. I used a small piece of protoboard to extend the Pins from the microcontroller

[16] Roipoussiere. "5mm LED Holder Solderless." *Thingiverse*, 23 Oct. 2013, www.thingiverse.com/thing:170562

and place it under the battery shield. For the aesthetic consideration, I choose to use the fabric covered wire for the exposed part of the circuit.

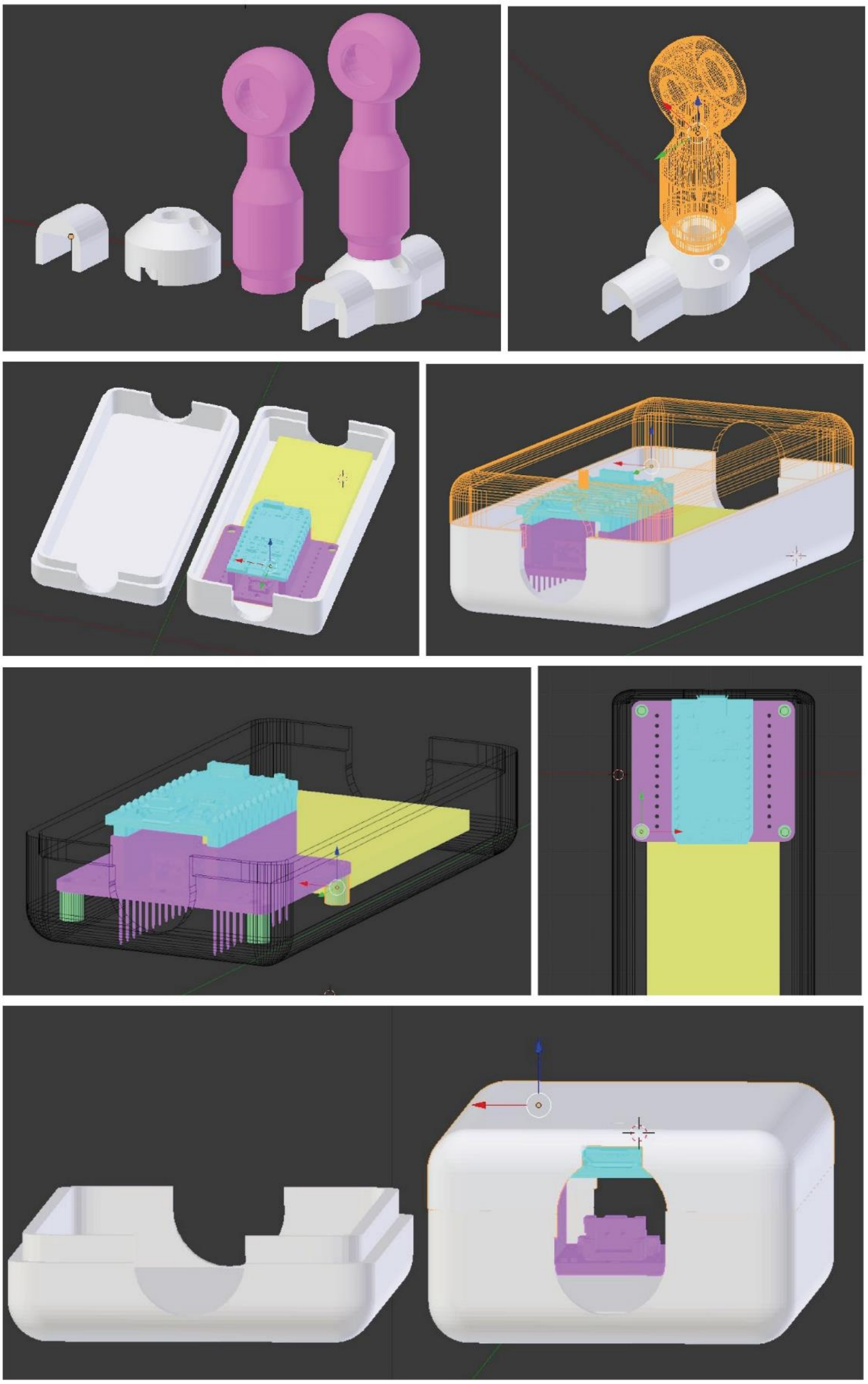

Fig. 32. A collection of the 3D design process

Fig. 33. A collection of 3D prints and assembling process

Fig. 34. Final product

6.4 User Testing

To evaluate shared awareness as well as the overall design and experience of the RABBOT, I recruited eighteen participants in total to playtest RABBOT. These participants included undergraduate and graduate students from OCAD University and Ryerson University. Participants were recruited as groups of three people who already knew one another with the expectation that their social connections would allow them to feel comfortable to play with one other. They were randomly assigned to particular roles by choosing folded papers from a table to be the *Rabbot* (VR player) and *Scientists* (non-VR players). Afterwards, the participants filled out questionnaires regarding their different roles. Some participants requested to play the game once more by swapping among them, so the people who experienced with both VR and non-VR roles filled out both questionnaires. In the end, I received twelve responses from non-VR players and ten responses from VR players.

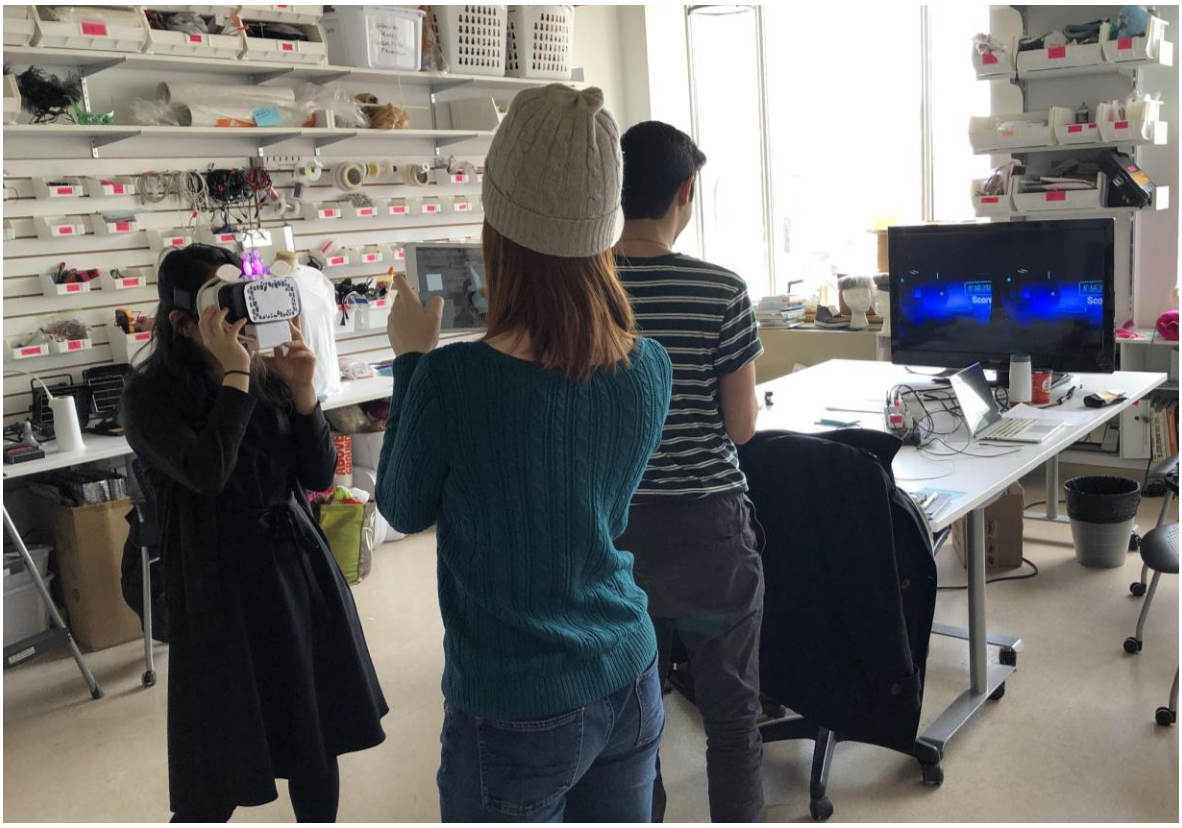

Fig. 35. Participants play-testing RABBOT

In their responses, 9.1% of participants reported one or fewer prior experiences with a head-mounted display, and 90.9% reported previous experience of a few times or regularly. Overall, 95.4% of the participants reported that they had ever watched someone else experience virtual reality with an HMD; they mostly described it as a “funny” experience. 80% of the VR players would like to interact with other people around them in the same physical space, while all the non-VR players would like to do so.

6.5 Results and Reflections

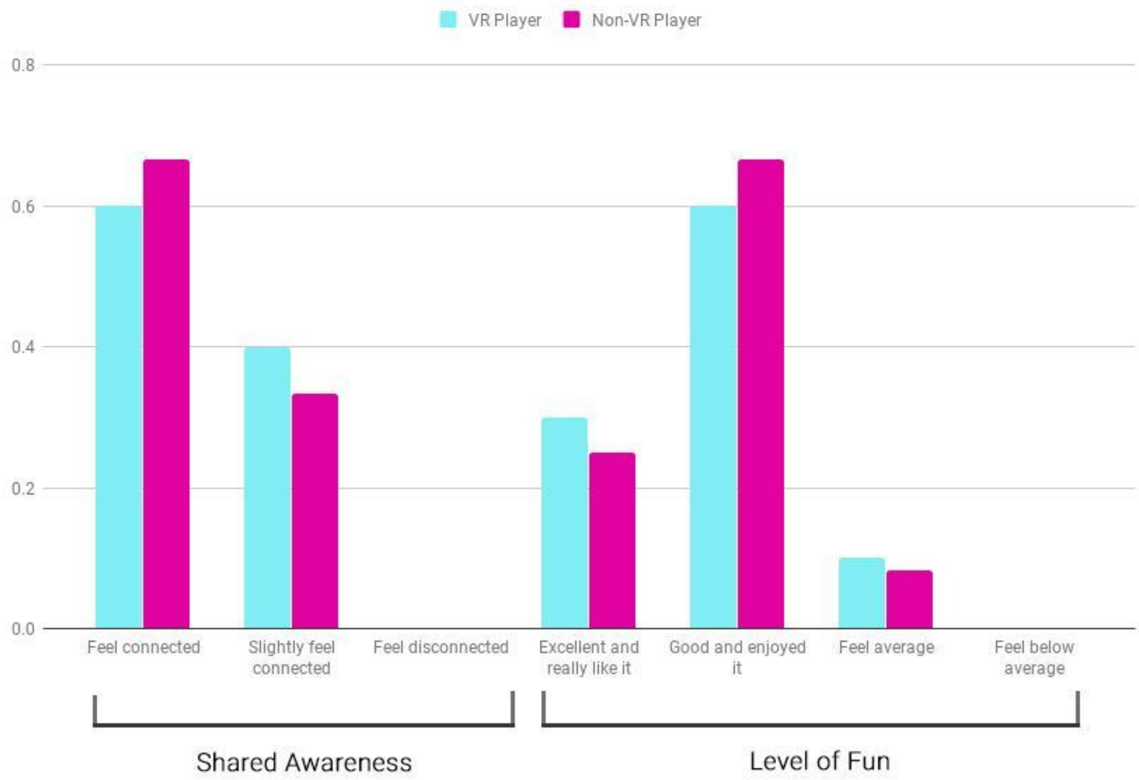

Fig. 36. User testing data analysis

Responses (see appendix B) from participants of their experience on RABBOT indicates that 0% feel “disconnected” from one another (Fig. 36), which shows that shared awareness has been generated between the HMD wearer and participating observers in the same physical space. 66.7% of non-VR players and 60% of VR players reported feeling "connected". 33.3% of non-VR players and 40% VR players felt "slightly connected". The data of shared awareness for HMD wearers are consistent with that of participating observers but, overall, participating observers feel more strongly about the degree of connection than the HMD wearers. Additionally, Fig. 37 shows that 80% of the participant observers considered the interaction with people in VR and the awareness of what's going on in VR as the "most interesting" part of RABBOT. Additionally, 25% of the non-VR players and 30% of the VR players rated the experience with the top level of fun ("excellent" and "really like it"). 66.7% of non-VR players and 60% of the VR players rated it "good", and they enjoyed it. There is still some space to improve shared awareness, but the methods I have incorporated seem to be appropriate directions for research on overcoming the isolation of HMD wearers in VR.

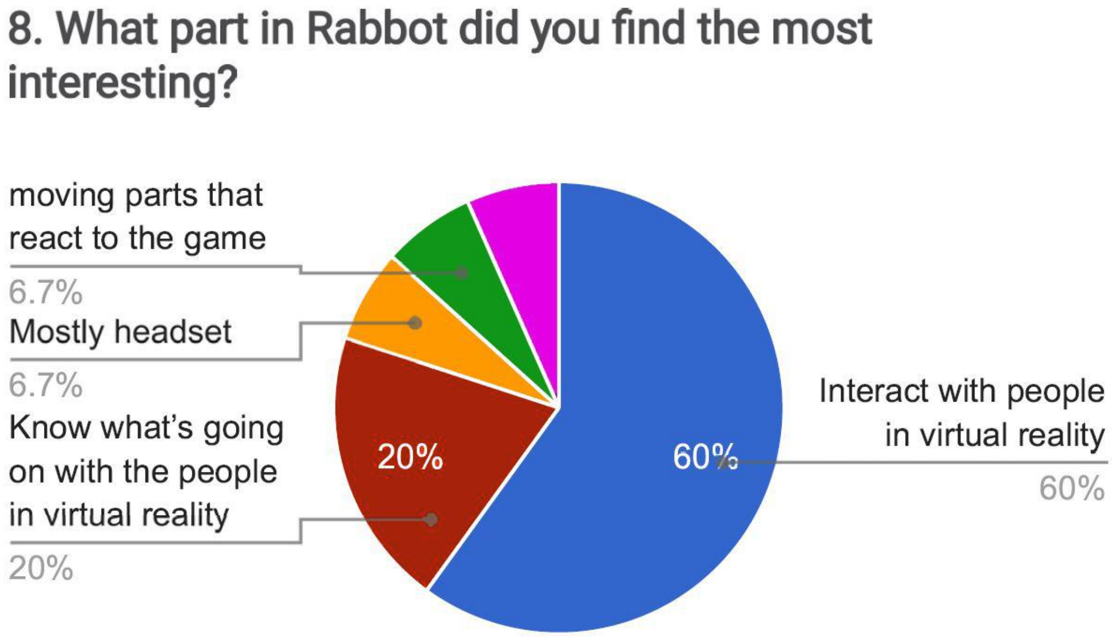

Fig. 37. Response from non-VR player regarding their experience on RABBOT

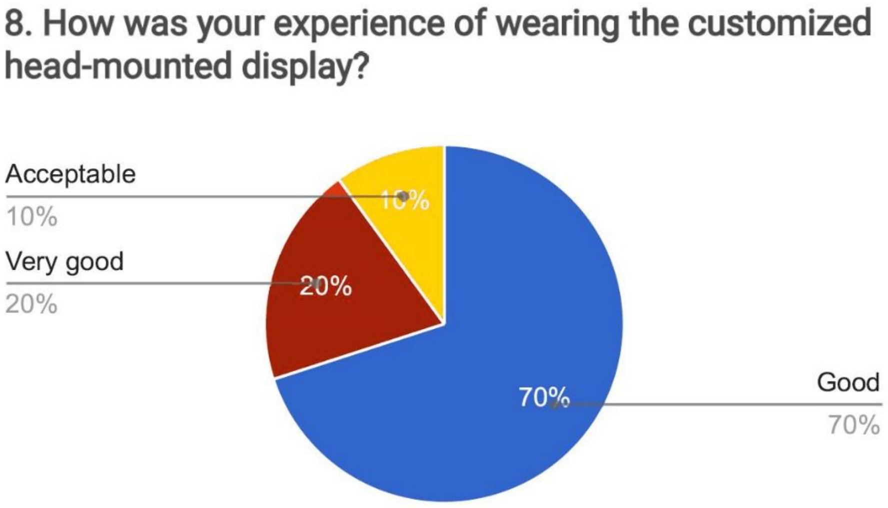

Fig. 38. Response from VR player regarding their experience on the HMD

Fig.38 shows that 70% of the VR players reported it was “good” to wear the modified headset, 10% of them found it is slightly heavy but still “acceptable”, by which I see the modification of the HMD as a success. My observations on the participants are as follows:

- Overall. the score system makes the *Rabbot* (VR player) too easy to win; one of the reasons is that the movement speed of the ball is too slow so RABBOT can catch it very easily
- The general engagements of *Scientist A* (AR player) are less than *Scientist B* (Tablet player)
- The effect on turning off lights in VR scene is not sufficient to disturb RABBOT (VR player)
- The ball size is too big which makes it difficult for the Scientists to win
- Laughter is frequent while participants play the game
- Most participants who play *Scientist B* (Tablet player) were able to figure out that they could move to some places within the game, such as the corner in the lab room, and by remaining there and not moving they could win the game
- The mobile phone in the HMD tended to overheat, which crashed the VR game several times
- Participants like the visual and graphic elements of the game
- One participant commented, “Your game is really cyberpunk”

My false assumption was that there would be active interactions between *Scientist A* (AR player) and *Rabbot* (VR player), which turned out to be a passive relationship. During user testing, most AR players did not move and chase after the image target on the headset as much as I had thought. The overall engagement of the AR player was lower than that of the tablet player. However, one of the comments from participants is that RABBOT presents a very novel way to incorporate AR into gameplay that can be controlled both physically and digitally. The lower engagement of AR can be improved by adding more ability to *Scientist A*, such as a separate scoring system or adding more image targets. Overall, the feedback (see Appendix B) I received from user testing provides a great deal of potential for the future development of this project.

7. Conclusion and Future Orientation

7.1 Contributions and Limitations

To conclude, this thesis project challenged my ability in terms of programming libraries, tools, and frameworks to combine several emerging technologies to solve the complex problem of isolation in VR. The RABBOT game still needs much more polish, such as a better score system, more interactions for the AR player, more explicit instructions for each player and better level design to improve the puzzle, but at this stage I consider it a success with regard to addressing this complex problem.

My ultimate goal was to see if it is possible to help generate shared awareness between HMD wearers and other observers. Based on the results of user testing of RABBOT, such shared awareness has been generated. Comparing to the related projects that have been discussed earlier in Chapter 3, the most novel approach of RABBOT that helped to generate shared awareness is modifying the HMD which inspired from Ikeuchi's works. Additionally, incorporating augmented reality, wireless communications and physical body movement to the asymmetric game design, proved to be useful to solve the problem of isolation in VR. However, in my opinion, the most critical part is to weave every design decision into the game and that will help to improve shared awareness more efficiently. My suggestion to others who are interested in related topics is that they should start the game design in their early stage of development.

Through my findings from this project, I want to encourage other artists, designers, and researchers to pay more attention to the relationships between HMD wearers and other observers when designing and developing a VR experience -- apart from the situation when this type of experience is specifically designed to isolate one user. Part of my thesis is focused on designing mobile VR/AR game experience, which contributes to the mass adoption of VR and AR because it provides more accessibility at a lower cost.

Furthermore, the design principles of shared awareness in VR can be applied to design many topics, no matter if the theme is serious, critical or playful. As a case study example, the asymmetric game experience RABBOT was designed in a cyberpunk-style to comment on the future of the human-animal relationship in science and technology. I posed open questions through the game setting of RABBOT: What will the future relationship between human and animals be with the rapid development of new technologies and disciplines? Will it help to reduce the gap between human and animal and push towards more collaboration?

7.2 Future Work

Fig. 39. Install for thesis show

As shown in Fig. 39, I decorated the environment to align with the game design of RABBOT for the final thesis show, which including the choice of color for ambient lights and furniture, the LED lab sign and warning board on the electronic cabinet to provide additional background story. From my onsite observation, I like how RABBOT can often make people laugh when they are playing this game together especially with a close relationship between them, such as family members and friends. The conversation of a better way of playing the game between the visitors can usually last even when they were walking out of the space, where I see the shared awareness in RABBOT can improve the social interactions amongst the players.

Future possibilities for this project begin with the game design improvement. These include more interactions between two scientists, such as doing the same type of action at the same time; some visual haptic feedback, such as a change of color when colliding into walls; the function of starting the game at the same time, and so on. More social elements can be added on the AR app, such as the feature of taking photos of VR player and sharing on social media. Speaking to the physical improvement to the modified headset, these can include an extra part such as a small fan on the cover of the headset to solve the overheating problem, experimenting with more materials to reduce the weight, and more image targets around the player's head or any place of the body. The communications system and game server can be certainly improved into a more stable version after more debugging and possibly employing the Cloud instead of running on a local machine. Additionally, RABBOT could also possibly lead to another research direction -- the future relationship between human and animals, which can be incorporated into the game context.

As RABBOT has a lot of potential, I want to build a team and bring this project to the consumer market. The idea will feature DIY attachable add-ons that can work with any existing VR headset and an AR/VR multiplayer game experience that allows people to be able to play with their friends and family in their own living room. As for me, this is not the end of RABBOT, it's a new beginning.

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Appendices

Appendix A. REB Approval Statement

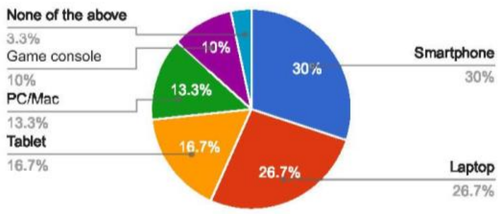
This project has been reviewed and received ethics clearance through the Research Ethics Board at OCAD University.

Appendix B. Questionnaires and responses

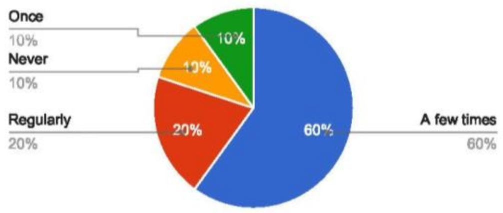
B.1.VR Player

10

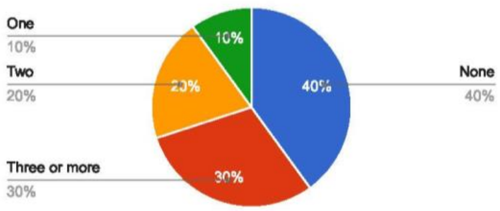
1. What, if any, of these devices, do you own and use regularly?



2. Have you experienced virtual reality with a head-mounted display before?



3. How many modern day virtual reality head -mounted display brands can you name?

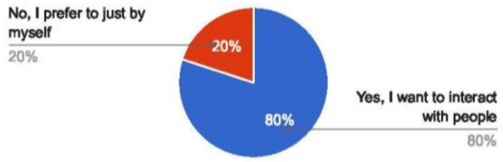


4. Have you ever watched someone else experience vi

Yes

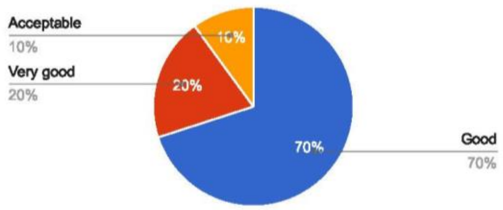
5. If you answered YES in Question 4, What was that experience like?

6. When you in a virtual reality experience, would you like to interact with other people who are around you? (Skip this question if you never try virtual reality before)



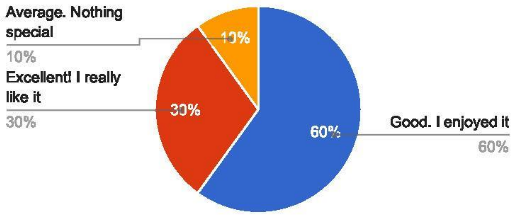
7. What part in the virtual reality experience did you find the most interesting?

8. How was your experience of wearing the customized head-mounted display?

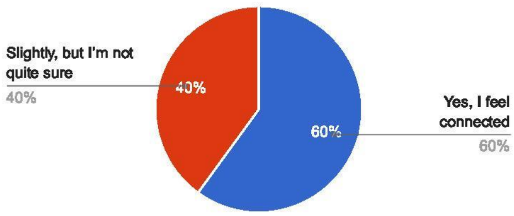


9. Regarding the previous question, can you give us more feedback on why?

10. How would you rate the level of fun in the VR experience?

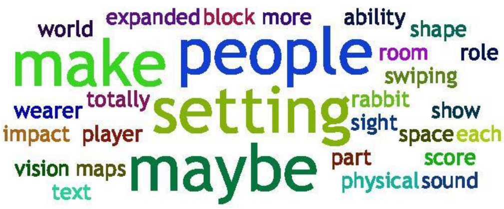


11. Did you feel connected with the people outside VR?

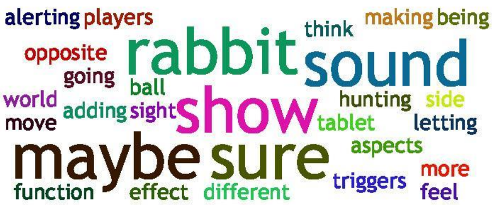


Do you have any suggestions on how to improve or expand the VR experience?

What other ways can you imagine interacting with other people around you in the physical world through the VR game?



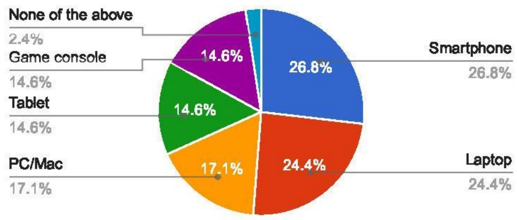
What other ways you would like the head mounted display that you are wearing to communicate your experience with other people around you?



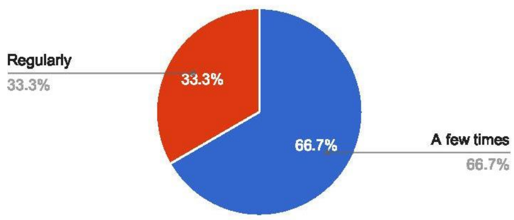
B.2. Non-VR Player

12

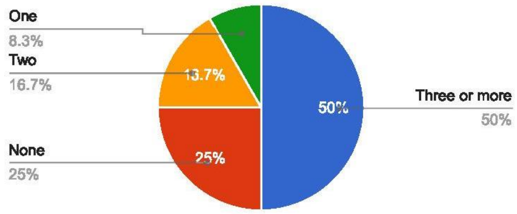
1. What, if any, of these devices, do you own and use regularly?



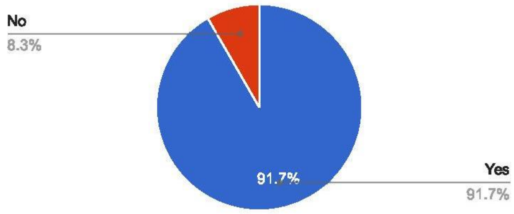
2. Have you experienced virtual reality with a head-mounted display before?



3. How many modern-day virtual reality head-mounted display brands can you name?



4. Have you ever watched someone else experience virtual reality with a headmounteddisplay?

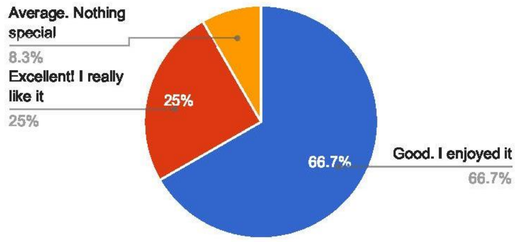


5. If you answered YES in Question 4, What was that experience like?

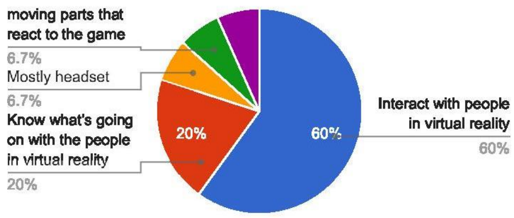
6. When you in a virtual reality experience, would you

Yes, I want to interact with people

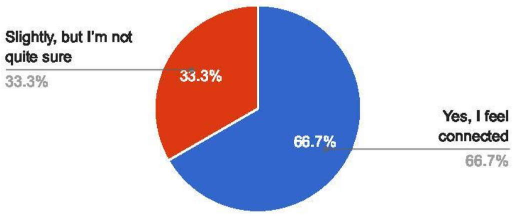
7. How would you rate the level of fun in Rabbot?



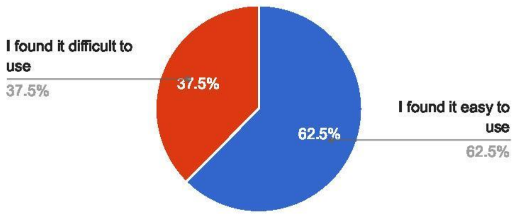
8. What part in Rabbot did you find the most interesting?



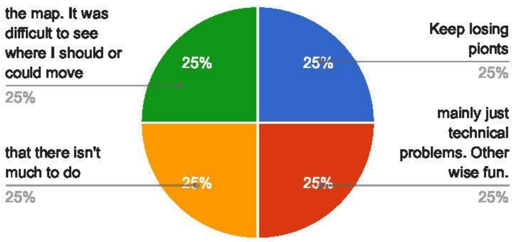
9. Did you feel connected with the people in the virtual reality?



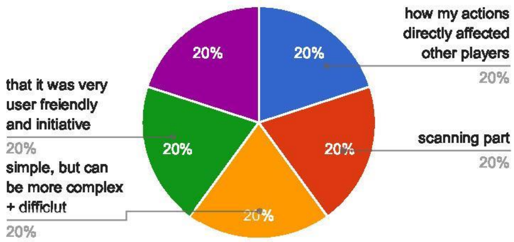
10. How did you find the augmented mobile app to use and why?



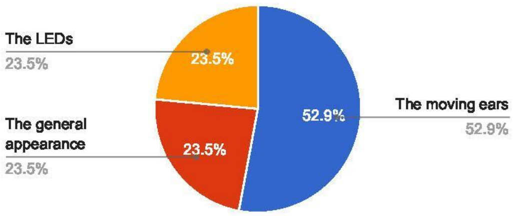
I don't like



I like

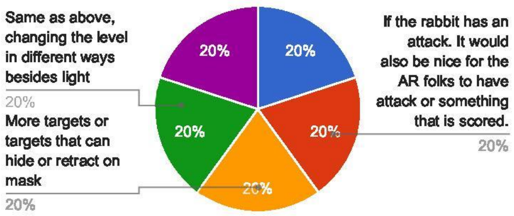


11. Which part of the customized head-mounted display did you find the most interesting?



Do you have any suggestions for how to improve or expand the augmented reality experience/app?

What other ways in which you can imagine interacting with the VR user through the AR app?



Appendix C. Game Design Documents

A character-based roleplay AR/VR asymmetric puzzle game

Core Theme/ Idea

AniBot is a research lab working on combining cyborg technologies with live animals. The scientists are training animals to complete some complex tasks by remote-controlling. RABBOT is one of the testing subjects and trying to escape from AniBot Lab.

Characters Bios

Rabbot: The VR player character. The most strong rabbit in the lab. *Rabbot* was chosen to be the testing subject for project A0611. *Rabbot* was implemented by scientists with two computer eyes and robotic ears so that the scientists can remotely control the vision and audition. As always, *Rabbot* wants to escape from the Anibot Lab and rescue other rabbits.

Scientist A: The AR player character. *Scientist A* is workaholic, trying to do as many experiments as possible and keeping adding computer-generated illusion to affect *Rabbot's* vision to help *Scientist B*.

Scientist B: The tablet player character. *Scientist B* is a neurologist, who invented the system to control *Rabbo*t's behaviours.

Core Mechanics

The main game mechanics are the body movements of the VR player (*Rabbot*) and AR player (*Scientist A*) as an image target was placed in front of the VR headset. *Scientist B* is controlling the object in the VR scene. While *Rabbot* is moving their head around in VR, the AR player (*Scientist A)* needs to point the mobile phone towards the image target to be able to disturb Rabbot.

Assets Needed

2D

App logo

AR Interface

3D

The head for *Rabbot*
Face or feet for *Scientist A*
Face or feet for *Scientist B*

Sounds
VR
- Background music
- Selecting sound
- Selected sound
- Getting piont sound
- Counting down sound (final 5 secs)

AR
- Background music
- Moving object sound
- Getting piont sound
- Counting down sound (final 5 secs)

Animations
AR
- *Rabbot* nose twitching
- *Rabbot* ears moving
- Object position indicator

VR
- Nanobots flying in the air (particle system animation)
- Selecting animation
- Selected animation
- Scientists position indicator

Victory or Goals
Each round of game lasts for 5 mins. By comparing with the final scores of *Rabbot* and scientist, the higher one is the winner of the game.

Character	Goal	Controls	Points
Rabbot (VR player)	Find the ball	Look at the ball and activate by holding the touch panel on the headset	Get 10 points by holding 5 secs. Get -10 points by not finding the ball under 10 secs.
Scientist A (AR player)	Control the light in the lab room and help Scientist B by	Chase after Rabbot to make its 3D representation reveal, turn the lights off in VR and toggle the components on the headset by touching the Rabbot's eyes and ears	Share points with Scientist B

	disturbing Rabbot		
Scientist B (Tablet player)	Move the ball around to hide from Rabbot and not collide with the walls	Control the ball by using arrows	Get 10 points by eating stars in the lab room. Get -10 points by hitting the walls

Player Start

VR

- Instruction for interactions in VR
- Game story intro
- Mission assign: find the object
- Ready to play the game

AR

- Instruction for trigger image target
- Game story intro
- Mission assign: remote control or help to escape
- Ready to play the game

Appendix D. Cybernetics and cyberpunk

The final field I am looking at is cybernetics, in which intersections with VR will be discussed to contribute to developing communication in shared awareness between the HMD wearer and observers. Cybernetics will inform the function and processes of the interactive game system in my thesis, along with the culture and aesthetic context that I am incorporating through my design.

Cybernetics was originally defined in 1948 as "the science of control and communication in the animal and the machine" (Weiner). It refers to control systems and dynamic communication technologies, among humans, animals, and machines. Cybernetics as the science of proper control provides a means for examining the design and function of any system (Pask 15). The artist Roy Ascott combined cybernetics into arts and coined the term “Telematic Art” which used computer networking as its medium. The cybernetic system in telematic art can provide the capacity to attract and enhance the visitors’ interactions between themselves as much as with the art (Cubitt 27).

D.1 Cyberpunk, Hacker Culture and Maker Culture

Cyberpunk is a dystopian world that Bruce Sterling described as a “combination of low life and high tech” (xiv). It features a world with advanced technological and scientific achievements in which cybernetics are prominent. Referring back to the main topic of my thesis, virtual reality is an important element in cyberpunk. Magazines like Mondo 2000 were highly influential for the worlds of Cyberpunk and VR, featuring novel-length stories on sensory rearrangement and chemical/technological augmentations of experience in cyberspace.

Mondo 2000 also compares how people were speculating about VR and what VR can do now, which speaks to my central research question of the "Why" to make shared awareness in VR. “Reality isn’t enough anymore” is the slogan that highlights the dissatisfaction with reality from *Mondo 2000*.

Cyberspace plays a central role in cyberpunk culture, which talks about the network as if it were an actual place—a virtual reality that can be entered, explored and manipulated (a networked virtual reality). Some other essential elements in cyberpunk are hacking, cyborg and data communications, which have influenced a subculture of hackers. In *A Cyberpunk Manifesto*, cyberpunks are the people who are “programming the last virtual reality” and “stuffed with electronics” (Kirtchev). To me, cyberpunk is an aesthetic choice to keep consistency for physical making, mixed reality application developing and game scenario setting.

I'm interested in hacking existing HMDs and using open-source hardware, which more speaks to maker culture. Maker culture has an intersection with hacker culture and it's a technology-based extension of Do-It-Yourself (DIY), which revels in the creation of new devices and tinkering with existing ones. There is an increasing interest in maker culture from HCI researchers because of playfulness and material aesthetics (Tanenbaum 2604-2607).

In issue 03 of *Mondo 2000*, an article titled "Flow like a dragonfly sees like a bee: a drug-free expansion of the senses", Nick Herbert talks about how to learn to experience other sentient beings like bees. He compared the optical difference between humans and bees from a scientific point of view and developed methods such as using polaroid plastic sheets and glasses to experience bee sight. He criticized at the end of the article, "Why was such a flagrant phenomenon-amounting to an entirely new human sense overlooked by hundreds of generations of artists, explorers and curious laymen?" and questioned, "What other hidden human senses are awaiting discovery by alert sensory adventures?" These interesting open questions made me think more about the relationship between human and animals, it will be discussed further in the next section.

D.2 *The Relationship and Collaboration Between Human and Animals*

Since VR can provide its user with a different perspective, the relationship between human and animal in science and technology becomes the core theme I want to incorporate in the game design. Cyborgs are cybernetic organisms with both organic and biomechatronic parts (Clynes and Kline 27). Cyborgs are commonly thought of as mammals. It also applies to any organism that has been enhanced with the integration of artificial components or technology (Kline 331-332). One of the first cyborgs was a laboratory mouse that was has been implanted with an osmotic pump that gave with continuous chemical injections according to a self-adjusting at a biological rate controlled feedback (Clynes and Kline 27).

More recently, in 2002, laboratory animals were remotely controlled to accomplish complex tasks by being implanted with stimulating electrodes (Talwar et.al 37). Even insects such as cockroaches can be remotely controlled by a mobile app after just attaching a $150 *The RoboRoach Bundle* to its back (Gent). The stimulation won't hurt the cockroaches, they can still live and behave like normal after the experiments according to the description on the product details from *BackyardBrains* website. Hence, I want to bring some Through my thesis, I hope to stimulate discussion via through the mixed reality game experience as a via creating a mixed reality game experience as a case study example: How will the future relationship between human and animals will head to with the rapid development of new technologies and disciplines? Will it help to reduce the gap between human and animal and push towards more collaboration?

Appendix E. Thesis Blog

https://yiyishao.org/blog/