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Development of a Virtual Pet Game Using Oculus Rift and Leap Motion Technologies

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Abstract

Recent emerging technology with a Virtual Reality (VR) aspect is very research-driven as well as successful in commercial devices. Within it, the most advantageous technology is the Oculus Rift headset because of its light-weight, low-cost and high quality, which has potential to bring novel VR theory into practice. Furthermore, Leap Motion has emerged as a high precision bared hand tracker which supports VR integration. Thus, the combination of these technologies is promising in many application areas. Gaming is one of these, particularly the life simulation game genre because gaming not only bridges users to familiar technology but also gives them full immersion into the synthetic world. Among the many successful simulation games, the digital pet raising game genre has proven itself in the gamers' community as well as in relation to advances in motion controller games. This has motivated the development of a virtual reality pet game.

So, this research envisages to develop a prototype of a pet-raising game using the Unity game engine based on Leap Motion and Oculus Rift technologies. The prototype contains a variety of pet interactions including feeding, cleaning, throw-catch, tricks training, etc. to enhance the hand motion controlling of Leap Motion as well as playing with first person perspective to give full immersion in terms of VR. After that, the importance of game evaluation is justified via quantitative research approaches, aming to investigate into the interactive technologies like Leap Motion. Kinectimals game based on Xbox Kinect technology, was selected to compare two games in terms of motion controlling similarity. Two experiments which are similar procedure on the developed game and Kinectimals, are conducted in order to collect objective measures such as duration, task and failure rate; plus participant's subjective reporting following three questionnaires, the After-Scenario Questionnaire (ASQ), IBM computer usability satisfaction questionnaire (CSUQ) and NASA-Task Load Index (NASA-TLX). Those questionnaires included standard questions and additional questions which are specific design for the prototype.

Comparing to Kinectimals, the game achieved a high acceptable score in terms of workload, information and interface quality satisfaction. The final prototype received much positive feedback without simulator/motion sickness during long term playing and interface design. Moreover, beside the rich content game playing, some hand gestures including fist, face-up hand, throw-grab activities were the most reliable using Leap Motion. However, hand tracking issues were identified due to the lack of robustness, particular in dynamic gestures. As a result, main contribution is to make VR more accessible to ordinary people via gaming as well as how to apply the immersion into a specific game genre. In spite of some games/applications based on

these technologies combinations, the serious experiments verifying their feasibility are limited, which makes this research worth to carry on. The experiment's findings it is hoped contribute to promoting the pet game genre within a VR setting, in particular immersion role and motion controlling.

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Chapter 1 Introduction

1. Background

Virtual Reality (VR) refers to the computer-generated world which immerses users to believe that it is realistic through familiar physical laws or the use of human senses. The key roles of VR environments are to simulate human sensory including vision, auditory, tactile, taste and smell. After several decades of research, VR has finally reached the point where it can be deployed with a light-weight, cost-efficient headset with the emergence of the Oculus Rift in 2012. Following that, many promising devices also emerged onto the scene such as the Sony PlayStation VR (Sony 2010b), the HTC Vive (Steam 2013), etc. Based on significant mobile trends, VR is also now invading smartphone development with the emergence of a mobile VR branch, which focuses on the (even more) portable and light-weight. For this see the Samsung Gear VR (Oculus 2014a), the Google Cardboard (Google 2015) etc. However, it should be mentioned that mobile-based VR has to wait for years to reach PC-based VR quality.

As mentioned for the immersion in VR, natural interaction plays a vital role while voice command and motion controlling are the most commonly used ways of implementation of that. The list of popular motion controllers includes the PlayStation Move (Sony 2010b), the Nintendo Wii Remotes (Nintendo 2006), the Leap Motion (LeapMotion 2012), the Microsoft Kinect (Microsoft 2010a), all of which giving diverse options for fully 3D motion tracking.

VR applications areas can vary from education, healthcare to simulation, architecture and of course, video games. In order to make users involved into new technology, games are an appropriate choice because of their fun and goal-driven tasks. Within this, simulation games, and in particular pet games, are ideal to propose many interactions with the virtual environment, leading to this project's potential.

2. Aims

This research is a development-driven project, which builds a prototype game, aiming to employ player interaction and navigation in VR via a pet game's activities. The Oculus Rift is utilised to simulate VR vision while the Leap Motion is chosen for hand controlling within game. The proposed/developed virtual game world takes the concept/enrvironment of a modest house within which the player is asked to raise a puppy and advance daily life activities so that a human-pet friendship can be built. Finally, testing is conducted in order to evaluate the feasibility and value of the built prototype towards the research question, "How is the usability of the prototype virtual reality pet game via Oculus Rift and Leap Motion technologies?". The results aim to promote a pioneer pet game in terms of VR using these emerging technologies.

3. Objectives

Based on other pet games references, primary functions are proposed, e.g. feeding, cleaning, caring, throw-catch, training, etc. VR immersion drives the game development to diverse pet activities, emotional states, as well as navigation and interaction with the surroundings. To enhance the hand controlling, a set of hand gestures are proposed for the caring of the pet and menu interaction, e.g. thumb up hand, swiping hand, fist hand, grab gesture, etc. The mapping of these gestures with the possibility of pet activities helps to build game features and apply these into required missions. A series of quests targets directly the learning of players of controlling as well as participating with the game in many mini-games with their dogs.

Afterwards, to validate this prototype, player feedback is collected via an experiment. A quantitative method is considered to observe the effectiveness and satisfaction of the prototype by comparing to another pet game in the commercial domain, called Kinectimals, with a similar controller approach. Two research objectives are the comparison of the two games in terms of workload, satisfaction scale and common menu interaction features; examining the performance of tasks including hand gestures, pet caring, feeding, cleaning, navigation, hidden camera, pet appearance, etc. Independent observations, log data recording plus questionnaire-filling are methods used to approach and satisfy these objectives. Three standard questionnaires used are the After-Scenario Questionnaire (ASQ), IBM computer usability satisfaction questionnaire (CSUQ), NASA-Task Load Index (NASA-TLX).

4. Chapters

This thesis is comprised of six chapters which are presented in the traditional method. The first chapter clarifies research overview as well as motivation, aims and objectives in order to give readers general viewpoints of this thesis.

Following that is the Literature Review section which mainly focuses on aspects of the Virtual Reality (VR) research area from the definition, classification and its history to its immersion and presence. Immersion is a key characteristic (of VR) which drives a further literature review to virtual characters, interaction and navigation in a synthetic world. Each category covers vital variables, advantages and drawbacks of other studies to identify gaps, reasons and most importantly issues to focus on for further study. Applications in VR review at the end of the second chapter showcase the potential of this specific field, not only in games but also in other areas.

Chapter 3 covers the methodology for this research based on relevant literature in the previous chapter. Through technology reviews of Oculus Rift and Leap Motion separately, this thesis evaluates and justifies the possible combination of these technologies via other studies' experiments and implementation methods. After that, testing approaches are presented in order to verify the final product from quantitative to qualitative methods pilot test, questionnaire preparation and the setup of a testing environment.

The next chapter describes the game prototype design consisting of game flow, levels, missions, HUD and the player controller. The final section covers some techniques of implementation in Unity, plus identifies issues and their solution.

Experiment results play a vital role to presenting the research findings via data, tables and charts. Within the scope of this research, quantitative method approaches are used with statistic tests organised into demographics correlations. There is a comparison of the two games results, the developed prototype and Kinectimals. Consequently, discussion of data analysis results is presented linked to hypotheses.

The final chapter 6 remarked the research aims and then contributions from the experiment results as well as eventually proposing further investigations.

Chapter 2 Literature Review

1. Definition Virtual Reality

Virtual Reality (VR) has been a technology headline from the mid of the 1980s, as one with the potential to usher in the new age of computer/human experience. VR is to simulate an external physical world by virtual objects and synthetic environments which can be interactive. The purpose of its build is to isolate users from the real world and then make them believe in the virtual world without the need of the physical objects by immersion. To enhance immersion in terms of VR, a head-mounted display (HMD) is the first regard as it provides first-person perspective. HMDs simulate 3D vision by generating a sequence of images of the synthetic environment, following the user's head movement. The specification of image creation in HMDs is via stereoscopic view, which is an illusion of depth for binocular vision. This method presents two offset images for the point of view in a separate manner for the left and right human eyes. Besides the visual 3D image simulation, other immersive features are navigation and interaction with the virtual environment, which both play a vital part of believability in virtual reality world.

2. Classification

Reality-Virtually continuum has been mentioned from the 1990s (Milgram et al. 1995) as a way to classify variants of Virtual Reality from reality to virtual environment, with authors making a distinction into Augmented Reality (AR), Augmented Virtually (AV) and Virtual Reality (VR). AR completely mimics properties of the real, existing world with physic constraints (such as gravity, time, material, etc.) but superimposes computer-generated imagery over real-world objects whereas AV, is a virtual world, integrating some physical elements from the real world. Within a VR system on the other hand, the synthetic world simulates properties of the real world in order to make the user believe the realistic nature of their completely artificial surroundings. Moreover, Mixed Reality (MR) refers to both AR and AV because the common aspect between them is integration of virtual and reality elements. The below figure demonstrates this classification clearly.

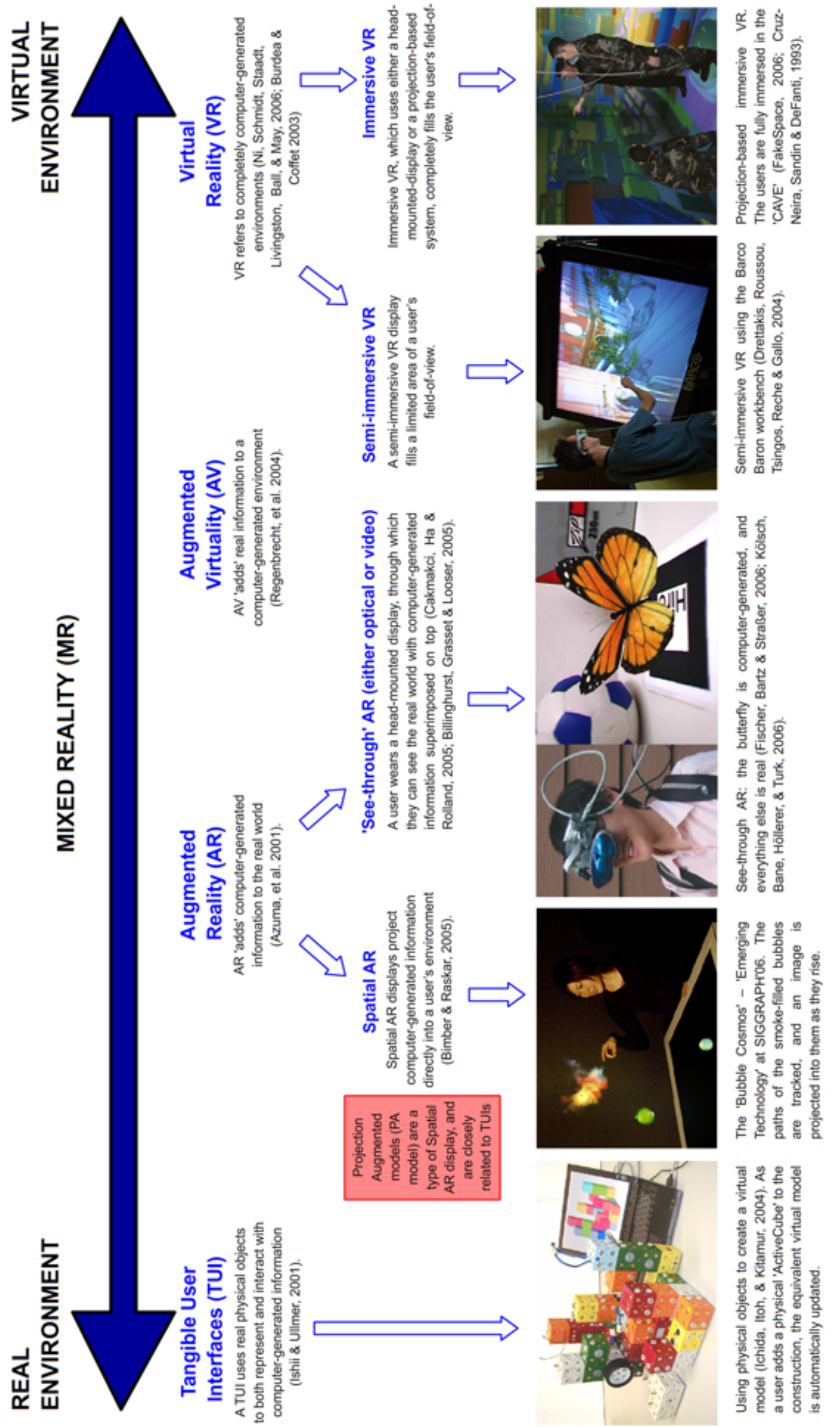


Figure 2-1 Real Environment to Virtual Environment (Wikipedia 2016)

AR is divided into two categories including "see-through" AR and monitor-based AR, according to Milgram et al. (Milgram et al. 1995). "See-through" devices are typically a headset put on the user's head to display augment information, whereas monitor-based advances eliminate this. In 2005, Bimber and Raskar (Bimber and Raskar 2005) introduced Spatial AR, which used projectors to show augment models without wearing any devices.

In terms of optically augmented headsets, Google Glass (Muensterer et al. 2014) is an example which was released in 2013, but currently stopped by Google. Consequently, Google invested into a start-up company which has developed Magic Leap (MagicLeap 2010). Also, Microsoft has introduced HoloLens (Microsoft 2016), using AR's HMD concept.

VR is classified into three categories based on the level of immersion. HMD is fully immersive while semi-immersive VR is presented on large projection screens, with non-immersive displayed on a desktop-based VR system (Gutiérrez et al. 2008).

Non-immersive VR in the early 1990s had some advantages compared to immersive VR because it overcomes challenges of VR that technology at the moment cannot achieve. Non-Immersive VR systems concentrate on the sense of presence, which also displays a 3D environment but using a monitor, mouse and keyboard (Robertson et al. 1993). As a result of this, it needs less complex computation and accuracy tracking, avoiding jitter/lag which can destroy the presence factor.

3. History

In the 1960s, the father of the VR system was Ivan Sutherland, an American computer scientist, who published a paper called "The ultimate display" (Sutherland 1965), mentioning the future of virtual world development. Consequently, in 1968, he invented a head-mounted display (HMD) with two perspective views as well as a tracking head movement system to support image processing in the HMD. Additionally, he also developed "Sketchpad", which was the ancestor of computer aided drafting (CAD) programs for the development of 3D models.

VR continued to be developed in 1970s and 1980s, including a movable VR system in a truck (Lippman 1978), a virtual object interactive system called "VideoPlace" (Krueger et al. 1985), virtual interface environment workstation (VIEW) of NASA research centre (Fisher et al. 1988). VIEW combined a wide-angle display helmet, glove-like received tactile input, speech recognition, gesture tracking devices and 3D audio; however, it is still limited by the CPU power, the weight of the HMD and the unreliable touch feedback of a glove. Mid of the 1980s, although there was not a fulfilled VR system, the medium began its journey towards commercial and industry application.

The early 1990s saw a boom of VR development which was inspired by Rheinghold's book (Rheingold 1992). Consequently, a development of a CAVE system (Cruz-Neira et al. 1993) which allowed humans to walk freely inside a room and observe their hand/body as well as other users in the multi-user system. Users in CAVE environment put on a lightweight stereo glass instead of a heavy HMD, which contributed to three dimension views with multiple projection screens in the room. During the last decade of 20th century, the most successful VR example was of a 3D stereoscopic HMD and interactive glove.

Stepping into the 21st century, technology enhanced the commercial aspect and realism of an efficient VR system. Tracking and display technology are important to look at this juncture. The tracking system has a broad range of devices including a mechanical tracker attached to human body; optical extensions using an infrared video camera to detect markers on the arm, hand, joints; active infrared which attaches infrared on a user's body and emits light to record; the popular means of tracking at the end of 1990s and early 2000s, electromagnetic using magnetic to track the user's head. The tracking system contributes to additional position and orientation information in order to reduce the latency by synchronizing computer-generated images with the real events occurrence. In terms of body interaction tracking, successful prototype haptic devices are Phantom or Haptic Master with 6DOF in the case of single-point force feedback; CyberGrasp, CyberTouch (haptic glove) belonging to exoskeleton and vibrotactile research (see more in haptics section). On the other hand, display technology, Boom, Retina display, Panoramic screens and the most noticeable, HMDs because of its full immersion. Although VR studies have their limitations, it plays a central role to bring novel theory into the commercial.

In the industry, based on the advanced power of the PC, VR hardware has been increased significantly with new generations of light weight and low cost devices including the Oculus Rift of Facebook (Oculus 2016), Play Station VR of Sony (Sony 2016b), HTC Vive and Steam VR of Valve (Steam 2013) recently emerging. Almost all commercial devices emphasise on HMDs. Mobile VR is an emerging technology because of its accessibility and portability, including the Gear VR of Samsung (Oculus 2015) and Google Cardboard (Google 2015). Their evaluation will be observed in the methodology chapter.

4. Immersion

4.1. Immersion and presence

In terms of the VR spectrum, immersion and presence properties are the key characteristics to be recognized from a physical and psychology point of view, respectively (Slater and Wilbur 1997). Immersion is a capability of the perceiving of human sense, particularly in sight, hearing and tactile stimuli from the real world. It refers to the object level of sensory that a VR system provides. In comparison to the involvement of immersion, the sense of presence relates to psychology terms, the high awareness and acceptance of the synthetic world, which in another word is the subjective sense. For example, being in a stadium watching a boring match is a presence but not an involvement. Martin Usoh and Slater remarked the sense of presence based on an experiment of daily behaviours in a familiar environment (Martin Usoh and Slater 2013). These two terms, immersion and presence, are different but a combination of these can make a successful VR system.

According to game design, Ernest Adams divided immersion into three main categories: tactical, strategy and narrative immersion (Adams 2004). On one hand, tactical immersion performs a rapid response based on given human interaction; whereas strategy immersion relates to mental problem-solving such as playing chess; finally, the narrative one is story-based and can encourage users to immerse themselves into an interesting story.

4.2. Immersion benefits

Where a VR system tries to mimic the real world or persuade users to believe so, immersion is definitely a key to opening up this aspect. Immersive VR gives users a unique experience by looking at a stereoscopic world and realising the changes of view following their head's movement and then picking up a virtual object with their real hands.

As a result, immersive VR brings potential benefits such as spatial understanding. Because the human brain processes images received from the human eye from the 3D world into a 2D image by stereopsis, motion parallax, occlusion, etc.; immersive technology stimulates the same process with stereo images and head tracking. Another benefit of higher level of immersion is a decrease in information clutter by many separate windows, icons, notifications, which is also referred by Bowman and McMahan (2007). In addition to immersive benefits, Gruchalla (Gruchalla 2004) investigated individual components of immersion (stereoscopy, head tracking, the field of regard, etc.) effects on the efficiency of a particular task and compared between the high-immersion system and the low-immersion one, this time using a CAVE approach. The results indicated that not all components of immersion contribute to the user's task performance; therefore, full immersion is potentially not always necessary.

4.3. Immersion factors

In terms of factors impacting on immersion, Fan Dai (1998) suggests numerous factors as follow: psychology, stereoscopic, the field of view, low resolution and feedback. To begin with, psychology such as "lag" or jitter - a status where computer-generated imagery mismatches the real user's gaze - plays a vital part in the consciousness of immersion in the synthetic world. To solve this delay issue, rendering time (FPS) and tracking systems have to be considered. In particular, this circumstance of the tracking algorithm can be overcome by predicting the position/orientation of the user's head. Other psychology problems refer to a complexity of computation in collision detection and physic simulation, which are also necessary in virtual 3D world building.

Secondly, a 3D image is formed by 2 separate 2D visual images and the process of mapping these images into the retina of human eye is called stereoscopic vision. However, the human brain always has alternative strategies to estimate the depth of object (depth cues), not only based on stereopsis cues but also motion parallax ones too. Motion parallax is based on monocular vision estimating the disparity between 2 views related to the object's motion (direction and velocity). In addition to this, depth cues (Yao et al. 2014) also include curvilinear perspective (straight lines converge as they extend into the distance), relative scale (objects get smaller when they are farther away), occlusion (closer objects block the view of more distant objects), aerial perspective (distant objects appear fainter than close objects because of the refractive properties of the atmosphere), texture gradients (repeating patterns) and lighting (highlights and shadows). Although vision technology using HMDs is designed to provide a comfortable view for users, the challenge here is with a disparity in collimation in the real world and HMDs.

Thirdly, FOV is a visual range which is observed by the human eye. Within it, the fusion field intersects between the left and right eye, called binocular vision; while the range observed by only one single eye is called monocular vision. The binocular region offers 3D images whereas monocular region displays in 2D only. The combination of the visual field of both eyes is 130^o vertical and 190^o horizontal, which is illustrated in the below figure.

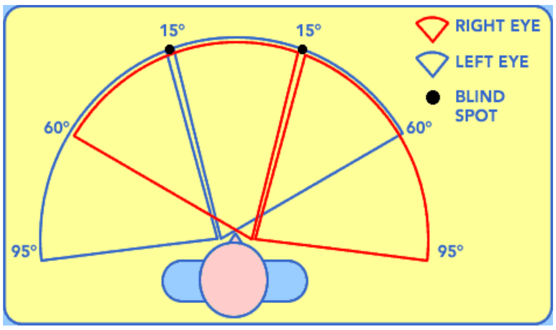


Figure 2-2 Human vision field of view

According to resolution, graphical display technology, Cathode-Ray Tube (CRT), Liquid Crystal Displays (LCD) and Plasma Displays are all options for HMDs (Gutiérrez et al. 2008, p.125).

Last but not least, the cognition of the VR world depends on responses from user's interaction. Beside visual feedback, stereo audio, haptics, force, smell and taste feedback which belong to human sense, are also all important. The more senses demonstrated within the virtual environment, the more immersive that VR system can potentially be. However, currently, technology succeeds in 3D sound, and there is limited success in the rest of human senses, particularly in the combination of all of them.

4.4. Feedbacks

4.4.1. Vision

Vision technology is the heart of a VR system while HMDs would offer a full immersion consisting of stereoscopic, FOV, depth of field and the persistence of view. The first two terms are mentioned in the previous immersion factors. The depth of field (DOF), which relates to focus and depth cues, is the focus range of the eye between the nearest and furthest of the object; the rest of vision is out of focus (blur). The natural human eye contains this strategy, which contributes to the better experience of depth perception. Another concept related to the human eye mechanism is the persistence of vision. A series of discrete images repeated at a certain speed is perceived as continuous by short-term visual memory. This process applies to the refresh rate on the computer displayed screen where a lower rate leads to an obvious flicker. These human factors must be covered in order to understand the mechanism of the human eye and brain, with that knowledge then to be applied to HMDs simulation.

4.4.2. Sound

Spatial sound, which gets signals from the auditory cortex in a human ear system, is constructed by the human brain to make a human believe that the external sound happens from physical objects, however, its process is inside the brain. Pinna is a part of the ear which interprets the sound signal. Using electronic and mechanical technologies, "head-related transfer function" (HRTFs) (Vince 2004, p.63) is a process which modifies the signal sound to simulate the spectral shape in a human head and pinnae. HRTF is a basic pre-process which is mostly used in stereo-headphones. In a VR system, the spatial sound has to meet three requirements (Gutiérrez et al. 2008, p. 142): 3D localization (3D positioning sound sources), acoustic simulation (reflection properties on the wall), plus balance speed and efficiency.

4.4.3. Haptic

Regarding haptic feedback, it is classified into force feedback (hardness and weight) and tactile feedback (surface contact geometry, temperature, smoothness). In terms of tactile, it is divided into three main categories including touch, pressure and vibration sense (Vince 2004, p. 64). Touch receptors which help spatial discrimination, are found in lips and fingertips while pressure receptors are related to the hairy area of the skin. Vibration is detected by both touch and pressure receptors. Based on many impacts of this sense into real world perception, Burdea (1999) noticed the key role of haptic feedback in VR simulated system. From the 1990s, the haptic interfaces research field has been divided into vibrotactile (simulated vibration-like frequency, amplitude, waveform, duration by electric current), tactile (including electrotactile, thermal, mechanical), kinaesthetic (single-point force feedback, exoskeleton and haptic surface) (Gutiérrez et al. 2008).

4.4.4. Taste and smell

Olfactory (smell) sensation correlates with the human's mood and emotional state by memorization of concepts of virtual objects. There are two types of smell simulation: individual user nose detection or using devices out on the user's neck; whereas a multi-user system develops a spray gun in a room like a CAVE system. The smell sense in VR is still not fully explored but there are several applications such as Sensorama, InStink, Dollars and Scents, Scent Reminder, Scent Air, Aromajet (Gutiérrez et al. 2008, p.157).

In terms of taste, it is comprised of sensory fibre monitor food attributes (texture, temperature, odor) by five distinguished human taste classes (sweet, sour, bitter, salty, umami). Age, sex, diet and anxiety factors all contribute to affect human tastes, which remains an open research question in VR world.

4.5. Equilibrium

Equilibrium is a balanced system which is controlled by the vestibular in the human inner ear. It has a role to inform the human brain whether they stand upright or lean to one side and whether they stay or move, in another word, their relationship to the ground. Fully six degrees of freedom simulation in a VR environment is important to achieve equilibrium. The confliction between equilibrium signals and motion cues from a visual VR system causes motion sickness, which has symptoms like sweating, nausea and/or loss of balance. Hence, the VR system's objective, which is to simulate the human sensory system, need to consider the eye fatigue and disorientation factors in equilibrium as well as the avoidance of long periods of adaptation. This motion sickness was reported from the earlier stages of virtual environment development (Kolasinski 1995).

In conclusion, the goal of the immersive virtual environment is to let user involve into a virtual world as a real one and observe the presence in mind. The research literature review on immersion is conducted to understand and evaluate VR components and then further narrow the research scope. As a result of this, development of immersion and presence in VR is affected by main elements consisting of the virtual environment, navigation control, interaction with virtual objects, which will all be studied in the next few sections.

5. Virtual Environment

5.1. Definition

Virtual environments mimic the physical world, simulating a variety of properties such as physical laws etc.; in other words, the capability of shifting a subject into the different environment without physically moving the user. As aforementioned, immersion features are central to the paradigm in a simulated world. Not only HMDs support but also the design of virtual elements in the simulated society takes into account to improve the immersion.

5.2. Virtual characters

Virtual inhabitants may be human characters, animals or creatures, which can be interactive. To create the realistic society, the role of virtual characters, which are capable of understanding, emotion, behaviour, reaction to other virtual characters, must be considered. If a simulator has intelligence, personalities and social skills, it would enhance the virtual community. To be more specific, the representation of virtual characters is a 3D model with skin. Locomotion such as walking must be observed by the character's animation. Moreover, character-object interaction refers to object's characteristics and its context, which divides into two approaches: object behaviour and reflected animation. Artificial intelligence for autonomous characters is a plus to the artificial crowds, especially decision making following different situations made by users. Decision making is based on four factors which include the perception of changing environment, the capability of reasoning behaviours (even unpredicted events), memory/knowledge and current emotions (effect on physical response, facial expression and gestures). The autonomous virtual character is mentioned in the "Stepping into VR" book (Gutiérrez et al. 2008, p.92).

5.3. Virtual body

Slater's research has showed the strong association of virtual body with presence (Slater et al. 1995), which was confirmed by another piece of research work four years after that (Usoh et al. 1999). The more customized the avatar is to adapt to the human, the better immersion. To conclude, VE research, in general, helps to shape in mind how to synthesise a virtual environment, 3D characters as well as maintain the immersion and users' belief. In particular to this project, a personalized human hand avatar and the main character's actions (i.e. dog) will be implemented to enhance the VR properties.

6. Interaction

There are a wide range of computer interactions from the traditional methods consisting of the mouse, keyboard, joysticks, etc. to user-friendly interactions including body language and verbal command. Within it, natural interaction is mandatory to implement as VR has been defined "Immersion-Interaction-Imagination" (Burdea and Coiffet 2003).

In general, there are three basic approaches (LaViola Jr and Marks 2010), including mapping 2D input devices (e.g. keyboard, mouse, game controller, joystick, etc.) to 3D elements in the virtual world, stimulating the real world using physical props (e.g. steering wheel) and fully 3D tracking of users' motion (e.g. PlayStation Move, Nintendo Wii Remotes, Leap Motion, Microsoft Kinect, etc.). Related to common tasks for 3D interface, there is navigation, selection, manipulation and system control (e.g. menu, voice commands, gestures, tools, etc.).

HCI research is a reasonably large topic in the virtual reality field. A cross-dimensional VR interface was proposed in Transection (Lee et al. 2015b) with a virtual keyboard interaction or 2D pop-up window in 3D space through the Leap Motion and the Oculus Rift HMD. This experiment proposed a practical application, maintaining the immersion while relieving simulation sickness, despite the small scale of the experiment. Regarding menu design, a piece of more recent research (He and Yang 2014) examined three different types including a palm-based menu, an object-tracked menu and as screen fixed menu. The results illustrated that a screen-fixed menu was the most satisfactory for general cases while the palm-based one had advantages in some specific cases. The object-tracker menu was the worst scored option because it was hard to stay in human view when people had to change the direction of view. In terms of object manipulation, (He and Yang 2014) also compared double-hand and single-hand interaction. Double-hand in menu manipulation was more natural but difficult in doing gestures in the air, whereas single-hand was easier and like familiar touch screen action. Although this research is related to AR context, it is useful to refer to for VR design too.

In summary, following these categories of interaction in VR, this specific pet game project will exploit navigation, object manipulation (e.g. virtual hand, ray casting) and system control (e.g. menu, gestures), which will be introduced in the prototype implementation chapter. In particular, the hand gestures will be discussed in more detail in the next chapter.

7. Navigation

Because of the first-person perspective in fully immersive VR, the user's navigation is critical to engage with the virtual world. Within a piece of research in 1999, Usoh et al. conducted an experiment to compare three different kinds of locomotion in the synthetic world including real walking, virtual walking and flying (Usoh et al. 1999). They concluded that real walking was the highest of presence but expensive whereas virtual walking was better than flying and was a potential option for locomotion. In terms of walking in place, there was an experiment using the Nintendo Wii combined with HMDs (Williams et al. 2011), resulting in spatial orientation as normal walking and much better than a joystick. Recently, with advanced psychological technology, Clemente et al. assessed successfully the influence of navigational control and a bigger immersive screen on the sense of presence in VR using EEG brain activities signal responses (Clemente et al. 2014).

Following (LaViola Jr and Marks 2010), navigation is consisting of two components which are movement and path-finding. Out of many kinds of travel techniques, gaze-directed steering is the most common technique to determine where to move. Increasing the immersion during locomotion tasks needs more reliable information about the users' future path, vision guides locomotion. Instead of traditional movement using the mouse or joystick, locomotion path prediction was a promising solution using head tracking data including six degrees of freedom from position and orientation (Nescher and Kunz 2013). This study proposed a high robustness but also high latency, for short term path prediction in seconds based on the facing of direction. They also found that gaze behaviour via eye tracking could be useful, which was examined in the previous research (Hollands et al. 2002), however, it exposed some limitations on the tracking system which require future research. Another experiment suggested a different approach using human body gesture via Microsoft's Kinect (Roupé et al. 2014), succeeding in enhancing navigation as well as spatial perception. Likewise, an interaction pedestrian simulation (Orlosky et al. 2015) used the Myo device to measure muscles' activities via swing arm for walking detection, which promoted the cognitive abilities' study through navigation and interaction.

On the other hand, many studies figured out a strong positive relationship between the degree of freedom (DOF) belonging to navigational control and simulator sickness. For example, an experiment from the University of Florida (Stanney et al. 2003) is important to mention here for this. This research also suggested reducing the exposure duration and limiting the streamlined 3 DOF of navigational control, aiming to decrease the simulator sickness. To balance between subjective presence via locomotion and simulator sickness in HMDs, another experiment (Llorach et al. 2014b) was conducted in order to compare between groups of participants moving in the virtual world using the game controller and a position estimation system, indicating a lower level of sickness with a new proposed position system. This research qualified a low-cost Inertial Measurement Unit (Llorach et al. 2014a), put inside a Oculus Rift DK1 in order to measure real-time position tracking.

To reduce the motion sickness in HMDs, there are two approaches using positional tracking consisting of inside-out and outside-in devices, where the Oculus Rift DK2 utilises an outside-in positional tracking camera. To conclude, the capability of navigation to explore the virtual world contributes significantly to the immersive role. Within the scope of this project, face direction, the speed of movement and DOF reduction will be applied as well as simulator sickness relieving.

8. Applications

According to VR applications, many fields will take advantage of VR with evidence from Second Life (Hartley et al. 2015), particularly distance learning education. Turning current simulator training systems into VR immersive ones is a current potential investment which can improve the trainee's skill with limits of failure, particularly in terms of areas without real training programmes (e.g. spaceship simulation, surgery simulation, combat training for military, pilot training, etc.). Role playing games are advanced with VR (Samoylova 2014). Moreover, in terms of therapy, playing the game in a rehabilitation environment can help disabled people (Rossol et al. 2011) or address obesity and diabetes (Rizzo et al. 2011). Architecture design and museum exhibitions may also be enhanced by virtual reality application.

Trending VR applications, nowadays, have optimised for high resolution and other techniques contributing to vision immersion, particular HMDs. However, it is necessary to balance human equilibrium system to avoid simulator sickness when users wear the helmet. This issue has resolved in Oculus Rift DK2 and promising to bring benefits for mobile VR term because VR applications in the smartphones have drawbacks in vision as well as controlling. In the near future, mobile VR may take its advantages of mobility and ease of use to debut a new chapter of VR widespread games and applications.

Human senses, on the other hand, have described clearly in previous sections, are vital to increase the immersion. Current vision and audio techniques seem to reach the acceptance level but the others including tactile, taste and smell. Based on current technologies, applications are limited in the immersion and controlling which is the most challenge need to do more researches.

Applications design also contributes to enhance the immersion of VR, which are limited current applications with many different approaches. Some knowledge and results of other studies has been reviewed within this chapter will be examined again in the prototype demo.

9. Conclusion

As mentioned, this chapter covers all aspects of Virtual Reality theory which ranges from classification, history to main characteristics including immersion key. Understanding the immersion benefits, factors and feedbacks is important to apply into project development, particular in terms of balance equilibrium of human system. To clarify the immersion, virtual environment, interaction and navigation sections are considered from other studies to examine the weaknesses and effects of these features into game design. Other virtual surroundings including virtual characters intelligent and the customized virtual avatar (body/hand) contributed to the immersion increase. Moreover, natural interaction is vital in the artificial world including object manipulation, menu gesture controlling and navigation. In terms of navigation, face direction, the speed of movement and DOF reduction aspects are considered to reduce the simulation sickness caused by movement during VR playing. In conclusion, following other studies and literature review, the balance between the immersion and technologies' limitation is vital to select carefully the devices to research on. The next chapter will continue to investigate on the current technologies.

Chapter 3 Methodology

1. Oculus Rift

1.1. History

Even though VR systems are evident in research labs for more than 20 years, the commercial products with this technology have been limited. In recent years it has been possible to combine vision and auditory VR requirements into a reasonably lightweight product. The Oculus Rift has arisen as a possible solution as it solves some of the earlier disadvantages of HMDs (e.g. the simulator sickness). The Oculus Rift was started by Palmer Luckey (Luckey et al. 2014) and fund-raised from Kickstarter in 2012 and then bought by Facebook in 2014. During its development, a development kit 1 (DK), DK2 and the consumer version (CV) were released in 2012, 2014, March 2016 respectively, bringing the novel into practical with relatively affordable price and seemingly high quality.

1.2. What is Oculus?

The Oculus Rift is a headset which simulates a computer graphics world in stereoscopic vision, which is reviewed in the figure 3-1. Comparisons between the two Oculus Rift versions aim to investigate its improvement (Desai et al. 2014), particularly in low-persistence techniques and positional tracking (Lang 2014). The below table gives the detail of this comparison.

Table 3-1 Comparison Oculus Rift DK1 and DK2

	DK1(2012)	DK2(2014)
Resolution	640x800	960x1080
Display	LED	OLED
Field of view	110^o	100^o
PPI	251	441
Refresh rate	60Hz	75, 72, 60Hz
Positional tracking	No	Yes
Low Persistence	No	Yes

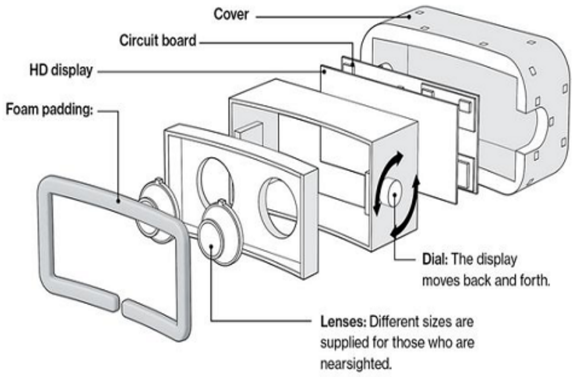


Figure 3-1 Oculus Rift, an inside view (Desai et al. 2014)

1.3. Advantage

The biggest advantage of this innovation is relieving simulation sickness. From the Oculus Rift DK1, a head tracking system included three sensors consisting of the gyroscope, accelerometer and magnetometer, combined to determine the three axes of a human head (Desai et al. 2014) which reduces the simulator sickness. Three axes of human head is illustrated in the figure 3-2. Positional tracking camera in DK2 also contributed to collecting reliable data for head movement, relieving cyber sickness, together with a high refresh rate and low-persistence techniques. In addition to this, a trick reported by the Oculus development team, which contributes to this synchronization, is "timewarp" (Yao et al. 2014).

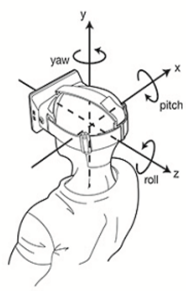


Figure 3-2 Oculus Rift three axes

1.4. Disadvantage

There is a limitation of the DK2 device in so far that the gyroscope drifts over time leading to issues with a fixed point reference in a game or application (e.g. cockpit). Likewise, the Oculus Rift suffers the optical lens system issue to provide an image at a comfortable distance for accommodation. The issue is stretching image namely pincushion distortion, result in barrel distortion shader is needed to solve this ((Yao et al. 2014); (Watson and Hodges 1995).

1.5. Discussion

Amongst the many low-cost HMDs, the Oculus Rift was a pioneer with the first release of DK1 in 2012 which received many positive responses from many researchers in the case of immersion properties ((Young et al. 2014) (Llorach et al. 2014b). While DK1 studies reported many cyber sicknesses (Tan et al. 2015) (Llorach et al. 2014b), its second generation was much improved (Goradia et al. 2014) (Polcar and Horejsi 2015) (Collins et al. 2015). Besides, there were many studies (Xu et al. 2015); (Fominykh et al. 2014); (Creem-Regehr et al. 2015) enhancing the Oculus Rift which made it a reasonable choice in terms of research.

Other reasons to propose that the Rift is more qualified than others HMDs are its light weight, low cost and up-and-coming widespread in the commercial world. There is today a promising new generation of applications and games in VR because of not only the high-resolution and relief from sickness, but also because of support of the platform/medium by many independent developers. Its limitation is high hardware specification requirements. Regarding VR devices, many competitors such as the Sony PlayStation VR (Sony 2016b), HTC Vive (Steam 2013), Samsung Gear VR (Oculus 2015), Google Cardboard (Google 2015), etc., each has its own advantages and drawbacks. Apart from the Sony PlayStation which is not released yet (at the time of writing this), the Gear VR and Cardboard have their disadvantages relating to the mobile platform they are aligned to, though HTC Vive seems to be another valid option with a soon to be released date (Wareable.com 2016). While two devices are competing in display technology, HTC Vive makes advantages of haptic feedbacks on its controller while Oculus Touch is much more user-friendly. The HTC Vive supports the very large and popular Steam VR platform which targets the large Steam community whereas the Oculus has the advantage of earlier testing ground for experiences (e.g. Oculus Social, Oculus Arcade and Netflix).

2. Leap Motion

2.1. History

David Holz developed technology for the Leap Motion in 2008, started a company in 2010 and then published the first product in 2012 called The Leap (LeapMotion 2012). Later in 2014, Leap Motion released device version 2 with support for VR tracking, particular for the Oculus Rift. Subsequently, with the Orion version in Feb 2016 optimised for VR and high reliability, the Leap Motion improved further.

2.2. What is the Leap Motion?

The Leap Motion device belongs to the category of the in-air motion controllers, i.e. using bare hands to interact with virtual objects. This device has the capability of hand and finger tracking (e.g. position, orientation, velocity, etc.) at a sample rate of 30 FPS to 115 FPS. Tracking is processed by sensors including two monochromatic IR cameras, three infrared LEDs, building a field of view of about 150^{o} – a hemisphere extending 0.6 meters in its range (LeapMotion 2015b). All sensors are wrapped into a small rectangular box 0.5 by 1.2 by 3 inches, connected by USB to the computer. The below figure gives the details of Leap Motion devices infrastructure.

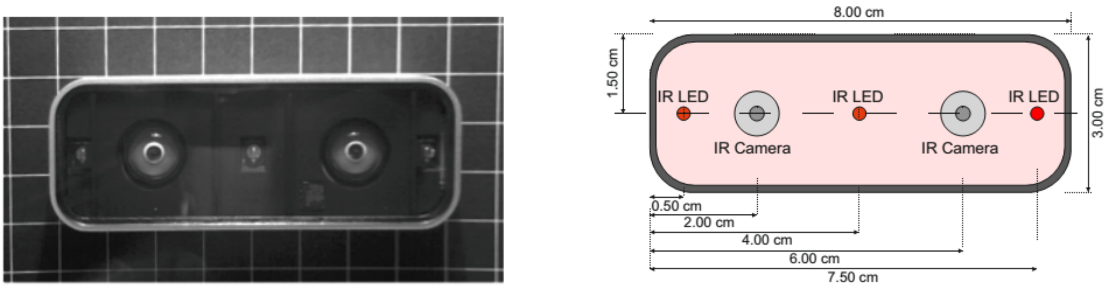


Figure 3-3 Leap Motion inside view

In terms of hand information retrieving, the Leap Motion provides hand information (i.e. palm normal direction, palm position, hand direction, confidence level) and finger information (i.e. tip position, finger direction, separated types of fingers such as thumb, index, middle, ring and pinkie finger). Some supported gestures consist of tapping, circling, screen tapping and swiping (built-in in version 2.3), which was however eliminated from Orion version. The Leap Motion desktop mode involves the device put on a table surface to detect hand like in the figure 3-4. Leap's coordinate uses the right-handed convention whereas the Unity's coordinate is left-handed one, see the figure 3-5 for more detail.

Figure 3-4 Leap Motion three axes

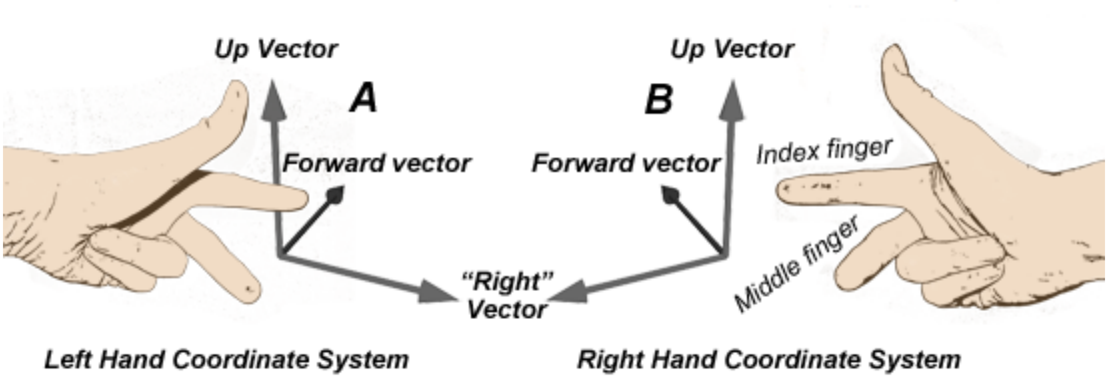


Figure 3-5 Left Hand vs Right Hand Coordinate System

2.3. Advantages

The impressive benefit of Leap Motion is the high precision in tracking individual fingers. It offers 0.2mm position accuracy for static measures and 1.2mm for dynamic (Weichert et al. 2013). Compared to the Kinect (Microsoft 2010a) sensor which provides 1.5cm and 0.4mm respectively (Khoshelham and Elberink 2012), the Leap Motion can offer higher precision performance (Bracegirdle 2014).

2.4. Disadvantages

Another study measured the reliability of this device resulted in the inconsistency of sample frequency and limited in sensory space (Guna et al. 2014). The work argues that within a range of 250 mm above the controller's surface, there was significant dropping in the precision tracking. Dynamic measures revealed a low performance, whereas the static scenario was more reliable with a standard deviation of less than 0.5mm. Comparing the Leap Motion with mouse controlling in pointing task demonstrates a decrease in performance following the long-term task (Coelho and Verbeek 2014). However, it should be noted that this research also presents qualitatively positive feedback in terms of 3D perception.

2.5. Discussion

Through many investigations on motion trackers, there is a wide range of valid options which can be categorised into wearable and touchless devices. The first group has physical contact with human body (e.g. Wii (Nintendo 2006), PS Move (Sony 2010a), GloveOne (GloveOne 2016), Myo (Myo 2016), etc.) whereas the touchless devices recognise bare hands or the body (e.g. Microsoft Kinect (Microsoft 2010a), Leap Motion (LeapMotion 2012) etc.). Among a variety of natural interface options, touchless trackers take advantages of VR immersion, whereas the others (i.e. GloveOne) enhance VR with haptic feedback. Within the scope of the work presented here, the Leap Motion is selected as a more optimal choice because of its immersion, high accuracy and detailed individual finger tracking with low latency (as aforementioned).

3. Oculus Rift and Leap Motion combination

3.1. Evaluation

Depending on what is described above regarding the Oculus Rift and the Leap Motion, against other similar devices within this field, the combination of these two technologies is a strong option which is worth carrying out an implementation with. The current motion controller list, which is appropriate for an Oculus Rift device, includes a wide variety of devices such as the Leap Motion, the Microsoft Kinect, the Nintendo Wii and the PlayStation Move. The Leap Motion and the Kinect have been more popular compared to the others because of SDK support, particular for PC applications. For example, Kinect, with a combination of this with Oculus, is discussed in research on virtual contents avatar (Lee et al. 2015a). Likewise, a commodity system with Wi-Fi connection called SpaceWalk (Greuter and Roberts 2014) is built using Oculus Rift and Kinect2, however, the performance is limited because of the Oculus DK1 drawbacks.

Regarding the Rift and Leap Motion mix, an early stage investigation of a case study in 2014 measured a small group of participants (Araullo and Potter 2014). This research involved playing two games using the Oculus Rift and two games using the Leap Motion, and identified several issues of developing the natural user interface. Additionally, TranSection (Lee et al. 2015b) promoted game-based technologies by the evaluation of enjoyment and simulator sickness. Despite of the small sample size, Lee et al.'s research showed a positive feedback from the players, with a score of 4.17 out of 5 (fun level) and 83% players replying that they would like to play the game again. Moreover, Blaha and Gupta researched a bouncing game where you break bricks (developed in Unity3D), aiming to restore 3D stereoscopic vision for amblyopic patients (Blaha and Gupta 2014). Another piece of research, which was presented at the CHI 2015 conference, developed an interactive pedestrian environment simulation to evaluate the cognitive ability using the Oculus Rift for 3D vision, the Myo (Myo 2016) for walking in the virtual world and the Leap Motion for virtual object interaction (Orlosky et al. 2015). On the other hand, in order to observe the immersive experience of cultural attractions, Webel et al. developed an application called Virtual Siena Cathedral (Webel et al. 2013) which utilized the Oculus Rift and the Leap Motion devices. Besides many academic studies, the Oculus Rift and the Leap Motion technologies also offer novel possibilities for many developers in the game industry, with some games already released on or available from the Leap Motion VR store website (LeapMotion 2016a).

When it comes to debating the hardware requirements, compared to other VR systems with a natural user interface, the Oculus Rift and the Leap Motion achieve a competitive price. The hardware system requirements are in the table below (LeapMotion 2016a), which are considered selecting the development platform.

Table 3-2 Comparison between the Oculus Rift and Leap Motion hardware requirement

	Oculus Rift DK2	Leap Motion
Graphics card	NVIDIA GTX 970 / AMD R9 290 equivalent or greater	
Processor	Intel i5-4590 equivalent or greater	AMD Phenom™ II or Intel® Core™ i3/i5/i7 processor
Memory	8GB+ RAM	
USB	3x USB 3.0 ports plus 1x USB 2.0 port	USB 2.0 port
HDMI	1.3 video output	
Platform	Windows 7 SP1 64-bit or newer	Windows® 7+ or Mac® OS X 10.7+

In conclusion, comparing the Kinect against the Leap Motion, it is clear that each has its own advantages and shortcomings, which are discussed in the previous section. For this virtual pet game context, some hand gestures, which require detailed tracking of individual fingers, are more appropriate for a Leap Motion than a Kinect device. Furthermore, the software development kit (SDK) is more supportive for the Leap Motion, with clear Unity documentation. Moreover, the Kinect, which requires a wide space of movement, can interfere with the lack of "see-through" ability of the Oculus Rift, risking the player as there is limited awareness of surroundings.

3.2. Unity implementation

This section provides details the Unity implementation of the aforementioned technologies including the Oculus Rift and the Leap Motion. To build an application or game in the

Unity platform, the Leap Motion and the Oculus SDKs need to be installed. Until March 2016, the Leap Motion had two versions, a desktop version and the Orion version (beta) which is friendly to VR development. However, the Orion version is beta version only, resulting in instability for testing, and did not qualify for the experiment within the scope of this project (plus its timescale). Regarding the Oculus Rift SDK for DK2, there is a PC SDK version 1.3.0 (28-Mar-2016) and an Oculus runtime 0.8.0 for Windows, which is also integrated with the Leap Motion SDK version 2. Additionally, the Unity game engine supports VR from version 5.1 or above. In conclusion, the compatibility of Unity, Leap Motion and Oculus Rift has to be revised carefully before development because of the frequent updates of many and different SDKs.

Aiming to diversify their applications, the Leap Motion provides C# API for the Unity plugin which is written in LeapCSharp.NET3.5.dll (for the Leap Motion SDKv2). This API plays the role of connection between the developer's scripts and the Leap Motion library (LeapMotion 2015b),which is written in C++. It is loaded depending on the platform from the file name Leap.dll. All these files have to be put in Plugins folder of the Unity assets in order to load at runtime.

The LeapCSharp.NET3.5.dll covers basic information about the hand, arm, fingers, frame, gesture, etc., with their coordinates, directions, and transformations. In addition to this, the primary difference between the Leap Motion non-VR and VR version is the Unity coordinates (LeapMotion 2015b) when the Leap mounted VR option is hanging in front of players' eyes, instead of placed on a desk. As a result of this, the "LeapUnityExtensions" script supports the conversion between Leap and Unity coordinates. The difference between these two system are demonstrated in the figure 3-6 and 3-7. Moreover, the figure 3-8 shows the range of human hand in front of the eyes, which need to be develop in Unity application.

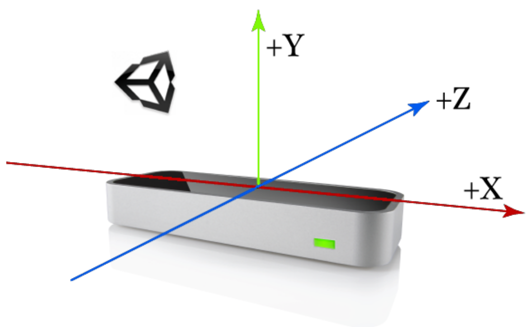


Figure 3-6 Leap Motion coordinates (LeapMotion 2015a)

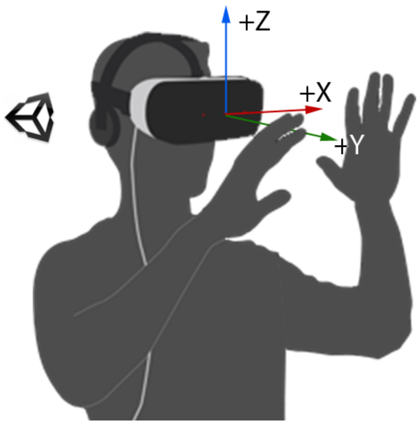


Figure 3-7 Leap Motion with VR coordinates (LeapMotion 2015a)

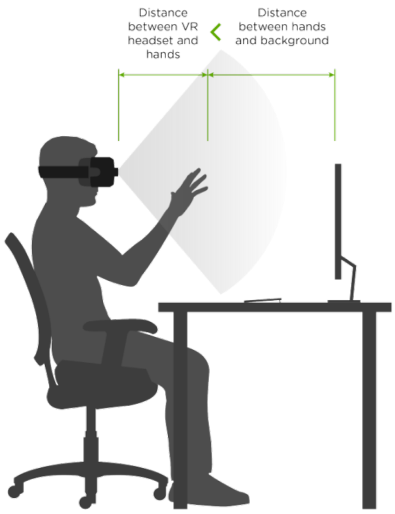


Figure 3-8 Leap Motion and HMD recommended distance (LeapMotion 2015b)

According to the Leap Motion website, Unity Core Assets (LeapMotion 2014) version 2.3.0 includes a number of pre-made hand prefab assets, which ranges from human rigged hands to robot hands and from graphical to physical models. Moreover, the "HandController" script plays a role as an interface between the Unity application and the Leap Motion service, managing the tracking of frame data and translating it into both the physical and visual hand models.

On the other hand, the Oculus team released an Oculus Utilities Unity package (Oculus 2014b), which contains two prefabs called "OVRCameraRig" and "OVRPlayerController", simulating the human eye and human body movement in 3D space (respectively). In particular, the "OVRCameraRig", which replaces the Unity camera, utilizes two 3D rendering cameras separated by a distance of 64mm as inter-pupillary distance.

4. Testing

4.1. Testing approaches

In academic research but also in general, research methods play a critical role for the justification of the validity and reliability of each study, including qualitative and quantitative research. During an iterative process, rejecting or refining a theory based on new findings is crucial, with qualitative methods focusing predominantly on the generation of categories of data collection, abstraction and also explaining phenomena, whereas quantitative research typically tests pre-built hypotheses with the employment of statistics.

In terms of game research, this is a multidisciplinary field (Lankoski and Björk 2015). Within the book of Game Research Methods press in 2015, Lankoski and Björk proposed different approaches. In particular, the qualitative approach on game studying, which is independent of the players, includes formal analysis, time analysis and game component analysis; whereas the same approach on the gamers themselves could be reviewed to refer to observation or interview methods. In contrast, quantitative studies related to the players' behaviors has a wide range of research designs including psychometrics, correlation, experimental and quasi-experimental design, which is generalized to two categories of observational and also experimental study.

On the other hand, following the guidelines of game analysis belonging to the MIT game study course (Fernandez-Vara 2016), it is suggested that many types of game analysis while the simplest one is comparative analysis, which compares two games based on similar key aspects. The key aspects for comparison may be a game studio, game genre, technology context or social/historical context. This leads to an overview of the game understanding and valid resource for questions design in game comparison questionnaire.

In terms of the usability evaluation of the application, much research has been conducted, e.g. the evaluation of mobile systems in the field (Kjeldskov et al. 2004), the usability of consenting system among iPad, touch screen and paper-based systems (Madathil et al. 2011), the accessibility levels of popular academic websites based on user perception (Roy et al. 2014), etc. Therefore, these similar researches suggested common methods for the feasibility evaluation, from objective observation of researchers via error rate to subjective users' responses via questionnaires. Some of the most common/ typical questionnaires within this type are the workload estimation NASA-TLX one (Hart and Staveland 1988), the Computer Usability System Questionnaire (CSUQ) (Lewis 1992), and the After-Scenario Questionnaire (ASQ) (Lewis 1991). The NASA-TLX takes is based on six basic scales of demand while the CSUQ is task centred with user satisfaction at its core rather than workload. ASQ, which is the detailed version of CSUQ, measures the fulfilment of each specific scenario based on three standard questions.

According to the immersion level of the game, some previous studies suggested other questionnaires, e.g. the Immersive Experience Questionnaire (Jennett et al. 2008), the Simulator Sickness Questionnaire (Kennedy et al. 1993) or the Presence Questionnaire (Usoh et al. 2000). However, because of high quality relieving sickness of Oculus Rift DK2 and avoiding the complexity of this testing, all three questionnaires measuring the immersion are eliminated from the final testing questionnaires.

Following the literature review, this project, which aims to promote the pet game genre using emerging technology, conducts a comparison between an experimental group who plays the prototype game using the Oculus Rift plus the Leap Motion and then an independent group playing the same game genre though this time with an established title, Kinectimals. Each group is measured both on objective and subjective data via independent observation, logging files and feedback questionnaires. The questionnaires conduct a difference comparison of workload and satisfaction by NASA-TLX and CSUQ (respectively). ASQ adds more details in some scenarios, supporting the verification of some hypotheses related to specific common tasks. Because this research focuses on the usability of the game rather than immersion and cybersickness investigation, questionnaires related to the VR immersion were eliminated from the experiment, aiming to avoid an overload of questions. Instead, only one question of the extended CSUQ mentions about this.

4.2. Ratification of testing approach used

4.2.1 Objectives and Hypotheses

In terms of the research interest of this work, i.e. advancing emerging technologies, and in particular the virtual reality game context, it is reasonable to develop and evaluate a game prototype. As a result of this, a quantitative method is utilized to investigate the research question, "What is the usability of the prototype virtual reality pet game via the Oculus Rift and Leap Motion technologies like?". To answer this, the method has to observe the effectiveness and satisfaction of the prototype by comparing it to another pet game from the commercial arena. The first testing objective is obviously to measure the difference of the two games in the case of pet interaction and also menu interaction, via objective observations and subjective feedback questionnaires. Therefore, the common features between two games have been investigated; this consists of menu interaction, user workload and satisfaction, and results in the following hypotheses.

H1: There is no difference between the two groups in terms of menu interaction reliability.

H2: Overall, there is no difference between two groups in terms of player workload, on a six sub-scale including mental, physic, temporal, performance, effort and frustration workloads

H3: Overall, there is no difference between two groups in terms of player satisfaction on the system usefulness, information quality and interface quality

Secondly, the prototype's elements are explored via the improved performance of repeated tasks, referring to three contests including tricks training, ball throwing and, finally, car driving via score and success rate. Other game features including caring, feeding, cleaning, navigation, a hidden camera, pet appearance etc., which are all evaluated by satisfaction rating. Moreover, 10 hand gestures are examined using the success rate, player' satisfaction as well as the correlation between objective and subjective reporting. The second objective is divided into two following hypotheses.

H4: There is no improved performance of three contests including tricks training, ball throwing, car controlling via score and success rate.

H5: There are no correlations between success rate (objectively measure) and satisfaction (subjectively measure) in terms of 10 hand gestures.

4.2.2 Statistical analysis methods

Statistical tests within this experiment were non-parametric tests due to small sample size and failure of the normal distribution, including the Mann-Whitney test, Friedman test and the correlation Spearman coefficient.

To verify the first objective with three hypotheses, Mann-Whitney test is observed to compare mean of two different games, which stand for two independent groups playing two games separately. It is a common non-parametric test to compare two means of continuous variables including the score of NASA-TLX, CSUQ and the error rate of menu interaction.

Friedman test, on the other hand, is used to figure out the improvement in one sample of the repeated tasks. It is selected to investigate on the hypothesis 4, which is the player performance of three main contests in the prototype.

Spearman correlation is also non-parametric test regarding the monotonic relationship between two continuous variables. Within this case, it is the relation between success rate and satisfaction score in terms of hand gestures, aiming to verify the consistence of different ways of measures.

All statistical tests use a magic number which is 0.05 at significance level. If the probability is less than this level, meaning to reject the null hypothesis, in another word, retain the alternative hypothesis.

4.2.3. Why Kinectimals?

Among many pet games during several decades there are some highlights, for example, a popular handheld digital pet named Tamagotchi 1996 (Wikipedia 2016), Nintendogs on the Nintendo DS (Nintendo 2005), the EyePet of Sony PS Move (Sony 2010a), Kinectimals (Microsoft 2010b) and My Talking Tom 2013 (Outfit7 2013), this time on a mobile platform. In particular, Kinectimals is an artificial pet game based on the 2010 technology of Kinect - body motion gesture - whereas the prototype presented here is played using similar technology, utilising the aforementioned hand motion tracker called Leap Motion. The first reason is that both games are of the same game genre as well as using motion controlling. Secondly, because there are no pet games in terms of Virtual Reality at the moment, it is hard to compare two different game genre, which makes Kinectimals a validated option for comparison research. To qualify Kinectimals, this research conducts a formal analysis (see Appendix I-1).

4.3. Experiment design

4.3.1. Pilot test

After the game prototype completion, a pilot test was performed with two experts who were invited because of their development experience and one student who had no experience on software development. It was useful to estimate the average time for a real experiment as well as figure out unexpected issues or bugs during the prototype development.

4.3.2. Participants

After the pilot test, an experiment with two independent groups of 10 participants, who were randomly picked took place, with each group playing each different pet game consisting of Kinectimals and the prototype. Participants were invited via email and were Bournemouth University students including both undergraduate and post-graduate levels, attending to play the game and fill a pre-test as well as a post-test questionnaire for about 50-60 minutes in total. As a result of this, 20 participants (male 7, female 13) for two groups aged 18-36 (M=25.85, SD=4.49) were recruited successfully.

4.3.3. Apparatus

The prototype game run directly using Unity 3D (version 5.1.1f1) on a laptop, namely a Toshiba Satellite L50-C-13W with Intel® Core™ i7-5500U Processor, 8GB DDR3L RAM, NVIDIA® GeForce® 930M with NVIDIA® Optimus™ Technology; using the Oculus Rift DK2 with SDK version 0.6 connected with a Leap Motion SDK version 2.3. Participants were given headphones to hear the game sound effects. On the other hand, Kinectimals was carried out in a wide space of 2.5 meters for each size, displayed on a monitor screen of 23 inches, connected with an Xbox 360 controller and the Kinect for the Xbox 360. Moreover, an observation form measured data objectively (see Appendix I-7, I-8) and an online version of the questionnaire measured subject opinions designed using Google Forms for both groups, aiming for a convenient import of data to SPSS (see Appendix I-2, I-3, I-4, I-5, I-6).

4.3.4. Procedure

Both of the groups carried out the same testing procedure with a pre-test acquiring the gaming and technology experience as well as basic information including gender and age. In general, this questionnaire took a maximum of 5 minutes to complete before playing the game. Regarding the prototype, playing game duration was recorded around 30-41 minutes (M=35.6170, SD=3.3333), following a fixed list of quests (see Appendix II-1); whereas Kinectimals players spent an average of 26-39 minutes (M=33.7100, SD=3.7115) in minutes to accomplish the first three levels (minus the waiting for the introduction video). Before playing the game, subjects were given a verbal explanation about the devices' role and how to play with them, for example, the Oculus Rift simulating VR vision whereas Leap Motion tracking hands movement or Kinectimals playing with the whole body motion which needed standing back from the Kinect camera. In the prototype, players sat on a chair, wore the Oculus Rift connected with the Leap Motion, played the game via a laptop with all technical devices set up as aforementioned while for the Kinectimals testing, this was conducted in a larger space which satisfied the Kinect's requirement, and involved standing to play the game. Afterwards, a post-test questionnaire followed, which proposed to be filled within 10 minutes, divided into 4 sections consisting of NASA-TLX workload assessment, adjusted CSUQ, ASQ and open-end feedback questions. On the other hand, during the game playing process, the researcher played the role of an independent recorder of the objective data, including the number of failures/successes doing tasks and time durations for each task.

4.3.5. Questionnaires description

The gaming experience questionnaire collected information as follows.

- Age
- Gender
- How much time was spent playing game
- Game genre experience, particular in virtual pet games
- Virtual Reality experience via devices, application name.
- Motion controller experience via devices, application name.
- Oculus Rift and Leap Motion combination experience.

The NASA-TLX questionnaire (see Appendix I-2) utilises standard six demands including mental, physical, temporal, performance, effort and frustration via 10 rating points.

CSUQ questionnaire (see Appendix I-3) observes the usability of the game with 19 original questions consisting of system usefulness (1-8), information quality (9-15), interface quality (16-18) and one overall question. Moreover, this research aims to explore players' opinion about some specific game features, including the reliability of the motion controller, menu interaction, pet interaction, sound effects, navigation in 3D space, fun and desire to purchase of commercial potential. For the prototype questionnaire, one question is added to gain data related to 3D stereoscopic vision because of the virtual reality experience. In total, 25 questions and 26 questions are conducted for the Kinectimals group and the prototype group, respectively.

ASQ section is varied between two games due to different scenarios, however, a number of similar tasks are also studied. Common scenarios are pet care, feeding, cleaning, ball playing and its contest, car controlling and its contest, tricks training and its contest, pet outfit whereas the disparity activities are related to different gestures and some additional scenarios. ASQ for Kinectimals includes 21 questions, apart from aforementioned common questions, additional questions are spin, jump, star jump, sit, play dead, clap hand, beg, standing pose, playing disc, kicking a soccer ball and its contest. However, some questions cannot be verified such as playing disc, pet outfit, tricks training contest because of running out of playing time for the first three rounds. As a result, only 18 scenarios in Kinectimals are examined. On the other hand, the prototype game requires some estimations on movement, rotation tutorial, the camera following the pet feature, stop hand, swiping left/right, swiping up/down, fist hand, face-up stationary hand, rotate hand, clap hand, throw/grab hand and thumb up hand. To sum up, the prototype game includes 22 questions with only 10 common tasks.

The last section covers open-ended question and conducts 4 questions to consider the most interesting task, the most difficult task, the hand/leg fatigue issue as well as offering an improved suggestion. The detail of all questionnaires is described in the Appendix I.

4.3.6. Log data and observation data description

The objective data is divided into two parts consisting of time and failure measures. Time is recorded automatically via log file of the prototype while in the Kinectimals observation by a watcher is used. The failure or success times for each specific task are measured following an observation table (see Appendix I-6, I-7).

Chapter 4 Game prototype

1. Game introduction

The game prototype is a kind of life simulation game but it is put into a virtual reality world to enhance role-playing. To clarify, players live in a modest house and raise their pet from a puppy. Game flow will give the player instructions on how to interact with their pet and raise them by feeding, playing and training them. Instructions are not only a tutorial but also quests which require the player to complete. By completing these quests, the players will enhance their experience which helps to build a relationship with their pet. This PC game connects to Oculus Rift to simulate a VR environment as well as enhance natural interaction with the Leap Motion.

2. Game markets

Following the artificial pet game genre, Tamagotchi (Wikipedia 2016) is a classic handheld game which was released in Japan in 1996 and after more than ten years, the possibility of game technology allows the building of other raising virtual pet games such as Eye Pet (Sony 2010a) on PS3 using Augmented Reality in 2009 and Kinectimals (Microsoft 2010b) using Xbox Kinect in 2011. These games demonstrate an interesting gameplay with the motion controller, and gained high feedback from players as well as professional critics. As seen from other platforms, virtual pet raising games had the potential to enhance new technology, bringing a promising future of pet game development using Virtual Reality.

The greatest advantage of the aforementioned commercial games is not only a new kind of player control but also a wide range of features which interact with a pet. To explore prototype's game features, an analysis was conducted from well-known pet games consisting of Kinectimals (Microsoft 2010b), Kinectimals Unleashed (Studios 2014), Eye Pet (Sony 2010a), My Talking Tom (Outfit7 2013), Nintendogs (Nintendo 2005) . Because of limited resources playing the game, some games were studied via YouTube reviews.

The below table compares five common digital cross-platform pet games and the planned game design for the prototype game based on game features, published year, etc. This analysis supports ideas and qualifies for the game design of prototype. From the table, common elements of this game genre are fondle, feed, clean, change outfit, play with a pet, which evolve in the game prototype. Furthermore, prototype proposes some other features including pet commands, shop and growing up.

Table 4-1 Comparison of digital pet games

Observation		**Play**	**Play**	**YouTube Review (PlayStation)**	**Play**	**YouTube Review (Milelow1)**
Publisher		Microsoft	Microsoft	Sony	Outfit7	Nintendo
Year		2010	2014	2009	2013-now	2005-2011
	PC, Oculus, Leap	Xbox 360, Kinect	Mobile (iOS only)	PS3 , PS Move	Mobile	Nintendo DS
	Prototype	***Kinectimals***	***Kinectimals Unleashed***	***Eye Pet***	***My Talking Tom***	***Nintendogs***
Controller	Hand, VR	Body, Voice	Touch	PS Move, AR	Touch	Pointer, Touch, Voice
Fondle	Yes	Yes	Yes	Yes	Yes	Yes
Pet command	Sit, Lie, Play dead, Jump	Sit, Lie, Play dead, Jump, Stand, Beg, Spin, etc.	Sit, Jump, Play dead, Spin, Sitting Jump, Sitting Spin, Shuffle, Ballerina, etc.	No	No	No
Hunger	Yes	Yes	Yes	Yes	Yes	Yes
Hygiene	Yes	Yes	Yes	Yes	Yes	Yes
Toilet	No	No	No	No	Yes	No
Thirsty	No	No	Yes	No	No	Yes
Sleep	Yes	No	Yes	No	Yes	No
Walking with pet	No	No	No	No	No	Yes
Play with pet	Throw-catch ball, Drive car	Throw-catch ball/disc, Play volleyball, Drive car, Find hidden things	Throw-catch disc Throw-catch ball Play volleyball	Draw a toy to play with, Shooting bubble gun, Trampoline, Scan X-ray	Mini-game	Throw-catch disc, Race, Walk dog
Mini-game	Yes	Yes	Yes	No	Yes	Yes
Map	No	Yes	Yes	No	No	Yes
Outfit	Yes	Yes	Yes	Yes	Yes	Yes
A Narrator	No	Yes	No	Yes	No	No
Grow up	Yes	No	No	No	Yes	No
Shop	Yes	Yes	Yes	No	Yes	Yes
Communication with other dogs	No	No	No	No	No	Yes

On the other hand, depending on the different platforms between mobile and game console/PC, players' behaviour changes yield to different approaches on game design. Mobile games have a limit on controller ability but are portable, whereas console games take advantage of technology targeting long-term playing duration. The below table illustrates preliminary variations leading to mobile games' focus on pet emotional states (hungry / sleepiness / hygiene) to keep the user engaged and care for a pet frequently while PC pet games play with a variety of complex tasks which are advanced by technology performance. This result can be seen clearly in the above table about game elements' comparison and drives prototype's task design.

Table 4-2 Comparison of Mobile and PC gamers' behaviours

Mobile	Console/PC
short term (5 mins -> 20 mins)	long term (target > 20 mins game play)
low-cost machine	high-cost
low resolution/performance	high resolution/performance
portable, play many times many places on different context	at home, stationary or in small movement space

3. Game design

3.1. Game flow

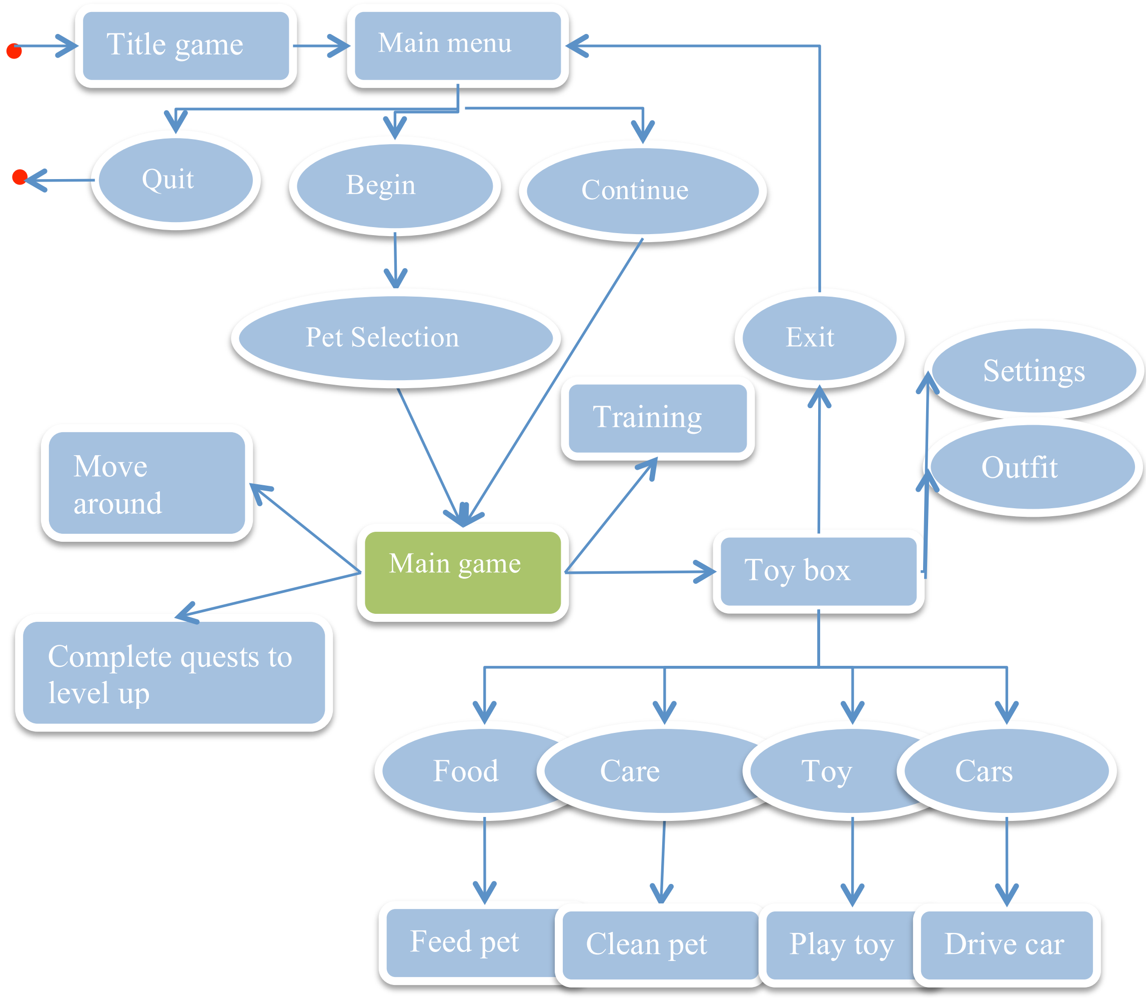


Figure 4-1 Game prototype Flow

The above chart illustrates the game flow. Coming up after the title screen is a menu with three options consisting of continuing playing with a previous pet, choosing a new pet or quitting the game. If it is the first time playing the game, there is only one option for the player to choose, which is raising a dog from a puppy. The new game option shows a variety of pets when selecting one pet leading to the main gameplay with level zero. During gameplay, if the players would like to exit, they can open an in-game menu and choose the exit option which leads to the main menu. The on-screen menu involves pet emotional states (e.g. energy, hunger, joy, hygiene) and two buttons, including Quest menu and Toy box. The Quest button opens current mission, experience level and current gold to drive players during game play. Toy box brings more options to a variety of activities; for example, the addition of items like pet outfit (e.g. hats, collars) to decorate their dog or a settings menu to customize hand skin.

Figure 4-2 Pet selection Scene

3.1.1. Navigation in 3D environment

Enhancing virtual reality perception by movement, it allows players to move around their house environment including the garden, living room, bedroom, bathroom and kitchen with only 2 DOF, consisting of moving forward and yaw, despite the fully 6 DOF of head movement. The moving mode is only available without opening menu or in pet training mode. This will be described in the control section.

3.1.2. Cleaning

To bathe their pet, players need to go to the bathroom and then call over their dog by clapping hands. Thus, players open the toy box to select a cared item (e.g. soap, brush) or buy it if it is not valid. The screen then automatically fades away in order to move the main character to stand in front of the shower with a cared item on hand. Players clean the whole dog body to create bubbles and use a shower to clean it up; the dog will change to bathe animation and there is a hot water effect from the floor. Continuing to bathe the dog until fulfilling the hygiene bar, the dog will get out of the shower and the game returns to the state before bathing.

Figure 4-3 Pet cleaning Scene

3.1.3. Feeding

To fulfil the hunger state, players have to feed their pet by taking food in their toy box and pour into a dog bowl in the kitchen. Firstly, players go to the kitchen to unlock the food menu and select one kind of food in the list. After food selection, it automatically pours into the bowl so that dog can come to eat.

Figure 4-4 Pet feeding Scene

3.1.4. Tricks training

The training program is an activity which trains the dog following hand commands such as sit, lie down, jump, play dead. After that, the game suggests a three-round contest to practice those tricks when the dog is pretended to be taught.

Figure 4-5 Tricks training Scene

3.1.5. Ball Playing

The Ball playing scenario occurs in the garden after selecting a toy (e.g. ball, bone toy) to play with. Players throw a toy sticking on their hand so that dog chases, catches and brings back. Therefore, players can grab a hand to collect. To make the game more interesting, a mini-game is suggested to play with the throwing ball gesture, including three rounds, targeting to hit down all the skittles from a distance.

Figure 4-6 Ball Throwing Scene

3.1.6. Car Controller

Driving a car is an idea from the Kinectimals game, allowing players to control an RC car in the garden via a virtual steering wheel. Subsequent goals to be accomplished are controlling the car to hit down standing skittles with help from the pet.

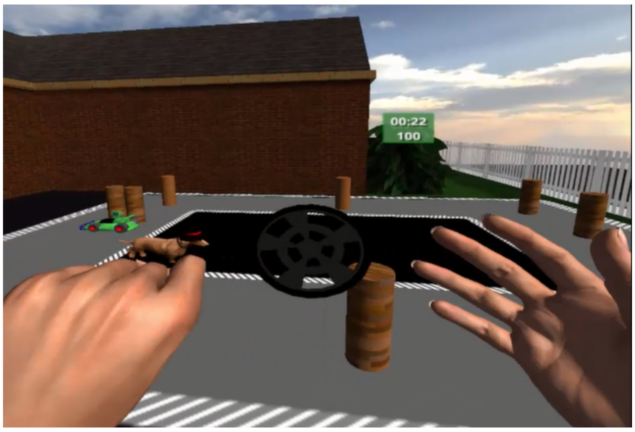


Figure 4-7 Car Controlling Scene

3.2. Levels and Quests

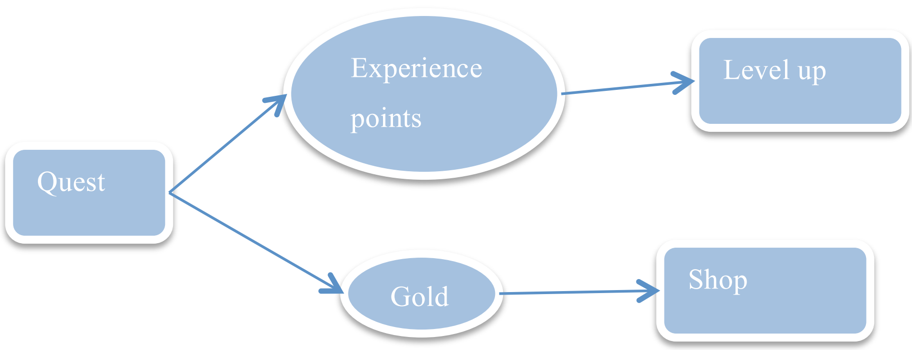


Figure 4-8 Quests Reward

Figure 4-8 summarises the game elements and their relationship. There are two game elements consisting of gold and experience which are rewarded after mission accomplishments in order to purchase items (e.g. food, care items, collars, RC cars) and level up. The dog grows up from a puppy following the level of experience that players achieve via quests. At the game testing design stage, there are 15 missions across 3 levels including contests and tutorials as described in the below table. After the completion of the three levels, players are free to play around with all the unblocked features. Table 4-3 gives the detail of each level information. Detailed events for each quest will be illustrated in the appendix.

Table 4-3 Rewards over quests

No.	Reward Experience	Reward Gold	Quest
1	10	20	New Dog
2	10	20	Fondle
3	30	20	Menu tutorial
4	30	50	Tricks
5	20	50	Tricks challenge
			Grow up to level 1
6	10	20	Hidden camera
7	10	20	Movement tutorial
8	10	20	Rotation tutorial
9	40	40	Feed
10	40	40	Clean
11	40	70	Play ball
12	50	70	Play ball challenge
			Grow up to level 2
13	20	50	Outfit
14	50	50	Car driving
15	50	50	Car driving challenge
			Grow up to level 3

Shopping using gold includes food, cared items, toys, cars, collars for a pet. Food and cared items can be purchased many times, for which a number indicates its quantity while other items can only be purchased once. The below table shows a list of items in the shop with its price.

Table 4-4 Shop items data

Category	Item	Price (gold)
Toy	Ball	50
Toy	Bone	100
Food	Coin Bites	10
Food	Bone Bites	40
Outfit	Top Hat	100
Outfit	Magic Hat	300
Care items	Soap	20
Care items	Brush	50
RC Car	F1 Model	150
RC Car	Truck	300

3.3. Head-up display (HUD)

The Menu or UI in the main game has a wide range of information, including quest dialog, in game menu dialog and main UI display on screen while playing. The HUD distance from the human eye is about 40 cm, within the range of hand interaction.

3.3.1. Main UI

The main UI is shown on the screen to keep updates of pet status, including hunger, energy (sleep), hygiene and joy, each represented by an icon which can be fulfilled. Moreover, players can see the overall mood of their pet in an icon on the left side of the pet status bar.

Figure 4-9 Main UI Scene

3.3.2. Menu

As aforementioned from the VR menu design in the literature review, the menu is placed at a fixed position in the middle of the screen and the background is a blur to keep human eye focus. The Quest menu opens from the left side while the Toy box menu is opposite, on the right side of the screen. To navigate between menu items, players perform swiping hand gestures while touching and hold items to select. Each menu state has a back button which is placed on the top right corner of the menu UI.

Figure 4-10 Toy box Scene

Figure 4-11 Quest menu Scene

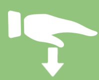
3.4. Control

There are 2 kinds of controllers, depending on specific actions, using head rotation and 3D hand gesture.

3.4.1. Hand gestures

The below table describes all available hand gestures in this game while the chart illustrates the context of gesture interaction.

Table 4-5 Hand gestures game description

No.	Gesture	Description	Image	Command
1	Thumb up hand	Thumb up hand and stay still for one second		Finish ball playing or car controlling mode
3	Clap hand	Clap 2 hands		Call over
4	Swipe left/right			Navigate menu
5	Swipe up	Face-up hand move up slowly		Jump command
6	Swipe down	Face-down hand move down slowly		Lie down command
7	Face-up hand	Face-up hand and stay still for one second		Sit command
8	Rotate fist	Close hand to be a fist		Play dead command
9	Stop hand	Open full straight hand with forward direction for one second		-In pet training mode, dog comes closer to be fondled -In free mode, open/close a hidden camera
10	Rotate 2 hands	Open full hand and rotate for 2 seconds		Free to go after training
11	Throw	Moving hand forward		Throw a toy
12	Grab	Grab hand		Collect/Hold a toy

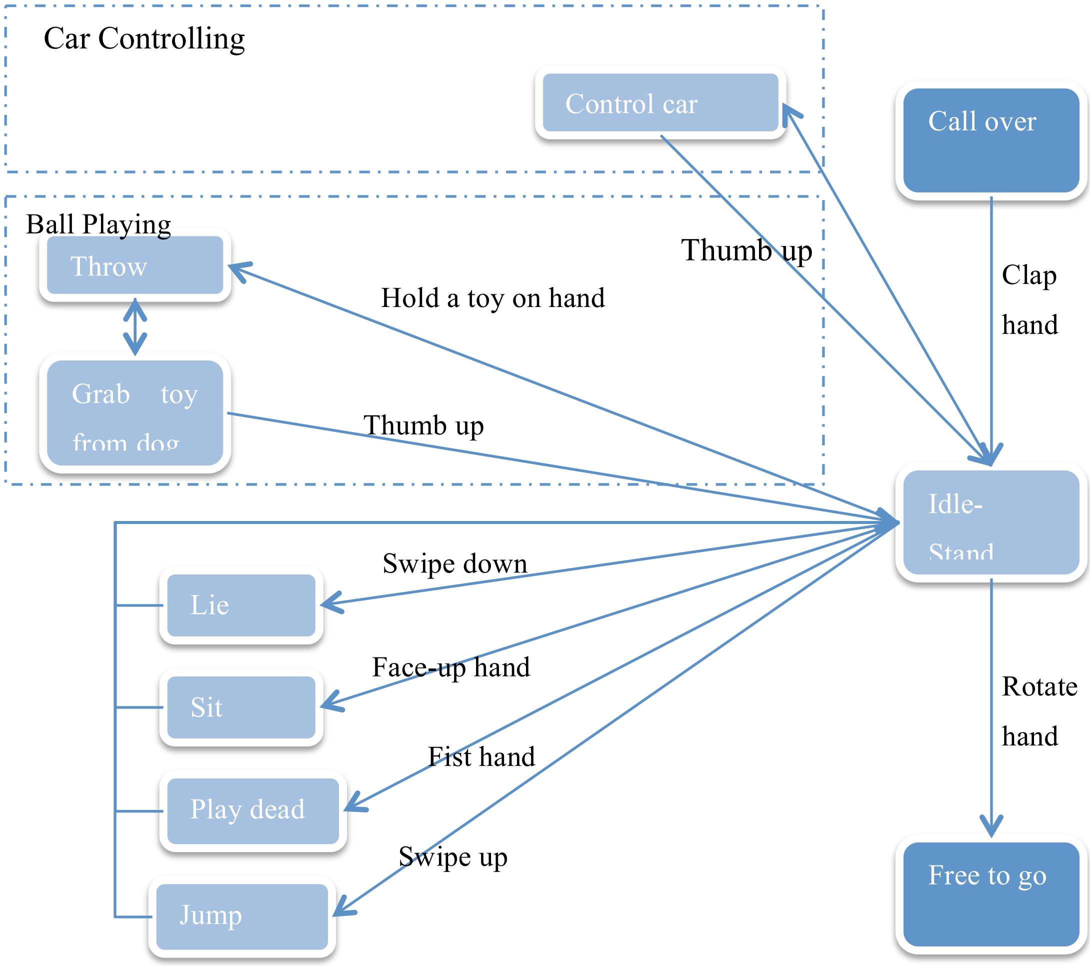


Figure 4-12 Hand gestures mapping

3.4.2. Head Movement

Movement control is available except in the case of opening menus or pet training. The move indicator is fulfilled when the player looks straight ahead and stays still for more than two seconds. When it is fulfilled, the human character will move forward until the player's head looks away in a different direction. The human character will move based on their looking direction until the player's eye changes direction.

Figure 4-13 Movement Scene

Figure 4-14 Rotation Scene

Another feature related to movement is rotation mode which allows turning head direction without physical changes. Players can enable rotation arrows using a fist hand and disable them by continuing moving ahead.

4. Implementation

4.1. Game assets

In game development, dachshund models and animations were downloaded from (4toonStudio 2016) with some customization. Besides, there are some 3D models resources, e.g. (TurboSquid 2016); (sketchup 2016); (UnityAssetStore 2016) and 2D icons, e.g. (Iconfinder 2016); (@theflaticon 2016) and sound effects, e.g (FreeBackgroundMusic 2016); (FreeSound 2016). The Appendix II-2 will be referred to the individual assets using in game.

4.2. Performance

Performance is a key feature of virtual reality games at the moment because of its hardware power limitation. The game engine used in this demo is Unity, which supports a number of techniques to optimize the 3D game. This section will go through available techniques which can be applied to a specific case in this game as well as solve the bottleneck of CPU and GPU for the limitation requirement of Oculus Rift and Leap Motion.

4.2.1. Physics

Unity's built-in physics engine is affected by collision, gravity and forces which simulate real physics. Rigid body with gravity is a component attached to a game object to simulate physics while the rigid body with kinematic is used for collision detection without physics simulation. Moreover, Unity uses collider to check the collision between game objects. There are 2 kinds of collider - static and dynamic. Static collider is a collider without a rigid body, should not be disabled or transformed during game play to avoid rebuild collision tree AABB. It is used for static objects in scene e.g. house, furniture, etc. Dynamic collider includes the human's hand, dog, toys (ball, bone) which are movement parts and need to check both physics and kinematic.

To reduce the cost of performance, this game suggests the combination of many primitive colliders i.e. box, sphere, capsule instead of a mesh colliders, even for the pet and the human's hand.

Character Controller is a built-in first player perspective of Unity. It uses non-physics and optimization for moving the character, which is proposed to be used in this game.

4.2.2. Lighting

Light and shadow impact on GPU which is strictly required for VR. The Unity game engine suggests techniques for lighting optimization. Baked global illumination (Baked GI) is suitable for the static environment and objects. For dynamic components, it must be rendered lights and shadow using real-time light. Baked GI is also known as Baked Light maps, which precomputes indirect light information and stores it into the light map. As a result, it reduces the burden of real-time light render and still keeps the quality of light and shadow for 3D objects. However, a limitation of Baked GI is that it eliminates bounce light of static objects onto dynamic objects, which will be resolved by Light probes.

4.2.3. Vertices and Polygons

A number of vertices of 3D models affect both CPU and GPU for further processing. Based on a simple test scene in Unity at a powerful PC, 100k vertices is a proposal of vertices limitation in one scene to achieve 75FPS (Oculus Rift requirement). Hardware test computer is Xeon ® 12 CPU 3.5GHz, NVIDIA Quadro K4000, 32GB RAM.

100k vertices are divided into 50 percent for the environment, i.e. house and furniture; 25 percent for characters, i.e. pet model, hand model; the remaining 25 percent is used for some dynamic objects e.g. toys, food.

Table 4-6 Distribution vertices in virtual environment

Static Objects		Vertices
Living room		
1	Sofa and mattress	2000
2	Shelf	1500
3	Dinner table	3500
Kitchen		
1	Cabinets	15000
2	Fridge	1000
3	Food bowl	2500
Bathroom		
1	Shower	2500
2	Mirror and Basin	1300
3	Toilet	5000
Bedroom		
1	Bed	2300
2	Drawer	1300
Garden		
1	Tree	5000
2	Dog house	200
43100		

The table above describes a division of vertices on each mesh used in the main game. The number of vertices is calculated using Unity importer based on FBX models. Notice that these numbers may change after applying lights.

As described above in the section lighting, lights increase the number of rendering vertices because it needs to render for shadow and light. This game during daytime uses one directional light as the Sun and one point light for ambient environment light. Using real-time light leads the vertices in the scene from 43k to around 130k for static objects. After baking light, it reduces approximately to 100k vertices.

This leads to another technique in Unity to reduce more vertices to achieve the target 50k for the environment (static objects). This prototype suggests Occlusion culling, which is a feature disabling rendering objects not seen in camera because they are occluded by other objects, e.g. table behind the wall does not need to be rendered when looking from the garden. It helps to decrease dramatically the numbers of vertices to 45k (the most expensive view in the scene).

4.3. Pathfinding

This is used to direct the pet moving around the house and avoid obstacles. In Unity, the game plane will be divided into a grid contains 0.5 metre size squares. Furniture is marked by a static layer mask which is built as an unwalkable region in the grid. Based on this grid, when a pet needs to move from one point to another one, both by the player's command or self-management, it will search on grid map using A* algorithm shortest path finding. Input is the current pet position and target position while the output is a list of nodes which directs a walkable path.

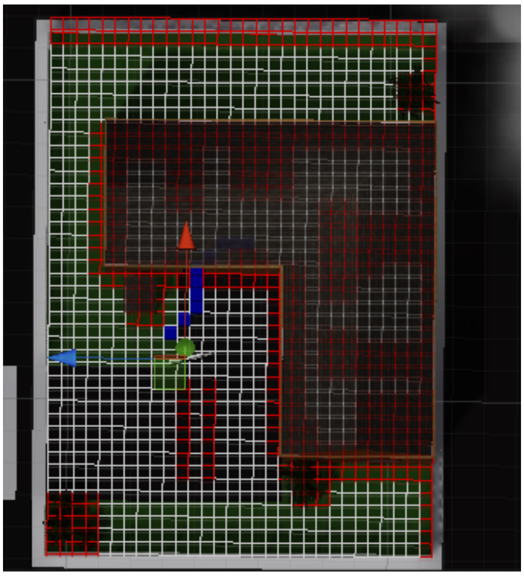


Figure 4-15 Grid map in Unity Scene

Chapter 5 Experiment Result

1. Presentation of experiment results

Data was analysed following demographics, comparison between two games and prototype's elements evaluation, using SPSS 23 (IBM Corporation, Somers, New York, USA). A summary table within the scope of prototype stated which the statistical test was carried out based on a number of data categories, put in an appendix.

1.1. Demographics

Data from 20 participants across two groups shows an estimation of playing game hours per week (M=10.15, SD=12.33) which observes a half of them plays the game under 3 hours a week while the highest number of hours is 45. According to the game genre, 30% of participants were recorded playing MMOG, 35% playing RPG, a half used to play the simulation games and 30% also playing other game genres, for example puzzle, strategy or board games. Additionally, 60% of participants used to play digital pet games, with a half of them playing My Talking Tom and a quarter of them playing Tamagotchi.

In terms of participants' virtual reality experience, 60% of players stated that they had tried VR devices while nearly a half of the VR experience people used Google Cardboard and two-thirds of them reported to play with Oculus Rift. Most of them experienced VR through some demo version on Oculus Rift store or VR applications on Google Play store by Google Cardboard. Only one person recorded using HTC Vive demo and another person with Samsung Gear VR via the exhibition.

Within 20 participants, 9 of them told about motion controller experience, nearly a half of them used to have Leap Motion acquaintance. Moreover, Kinect and Wii are more popular than the others with two-thirds of motion device experience users, whereas only 2 people reported using PS Move. In the scope of motion applications, Grand Slam Tennis using the Wii device is the most common, whereas the others told about other Kinect applications like Fable: The Journey, Rabbids: Alive & Kicking, Dance Central, Kinect Sports, Bowling Xbox, etc. Leap Motion has less frequently used applications with some demo version of Leap store, however, participants who use PS Move failed to remember the name of the applications they played.

Leap Motion and Oculus Rift combinations are truly strange for almost all people while only one person used to play with a demo version.

Gaming time per week was collected for the purpose of finding the correlation of menu interaction error rate, workload score as well as satisfaction. However, Spearman's correlation statistical test showed no monotonic relationship, (r_s=-0.002, n=20, p=0.995), (r_s=-0.024, n=20, p=0.920), (r_s=0.067, n=20, p=0.778), respectively. Game genre classification questions aimed to verify the length of gaming as the previous question and remind subjects to the next question about the virtual pet game genre. Likewise, questions related to named applications using motion controllers or VR or Pet games were carried out to support the main questions consisting of pet game experience, motion controller experience and VR experience, then data was divided into two groups. The Mann-Whitney test measured between a pet game and a non-pet game group showed a significant difference, (U=21.000, Z=-2.083, $p=0.037<0.05$) on menu error rate whereas it failed with workload and satisfaction. The same method approached for motion experience and VR experience with 5% level of significance revealing no difference. Although the total sample size was only 20 and the recruitment was randomly picked up, leading to the inequality of sample size between two groups, the statistical test was applied. More detail is presented in appendix III.

1.2. Comparison between two groups

1.2.1. Menu interaction

As aforementioned, the data collection for comparison between two games' purposes aims to investigate three hypotheses. The first hypothesis states that there is no difference between two groups in terms of menu interaction reliability. Menu interaction performance was evaluated based on two values, swipe left/right and select a menu item, which was possible to compare because of the similar design between the two games. Moreover, the average of these two values was calculated, called Menu Error Rate. In the case of the swipe left/right error rate (M=0.2748, SD=0.1277) and the menu item selection error rate (M=0.3323, SD=0.1337), a t-test was performed with a nonparametric Mann-Whitney test due to a small sample size, examining the variation between two groups. As a result, although in terms of each aspect, there was no statistically significant difference between two groups with (U=26.000, Z=-1.815, $p=0.072 > 0.05$) and (U=25.000, Z=-1.892, $p=0.060 > 0.05$) belonging to swipe and select rate respectively; whereas the average score of error rate (M=0.3035, SD=0847) indicated the opposite result, (U=15.000, Z=-2.646, $p=0.007<0.05$), implied to reject the null hypothesis.

The below bar chart shows in detail the difference between two groups in case of swipe, select and general error. Across the three cases, the prototype had been less reliable than Kinectimals while the swiping task was easier than selecting an item in both groups.

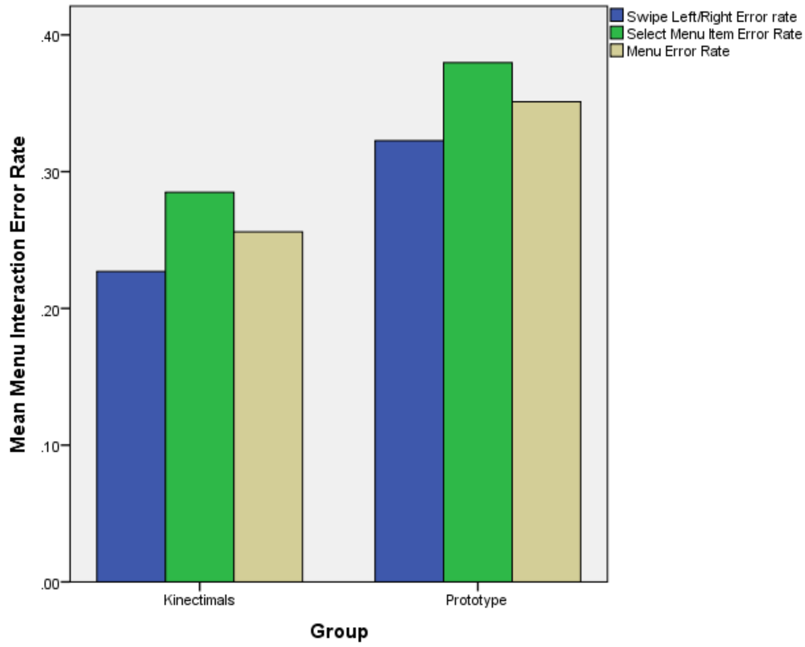


Figure 5-1 Comparison between two groups in Menu Interaction Error Rate

1.2.2. NASA-TLX

To investigate the experiment workload, the standard NASA-TLX was utilised to assess based on six scales including Mental, Physical, Temporal, Performance, Effort and Frustration. The average score of Kinectimals group was 57.67 while the prototype was rated 62.83, out of a maximum score of 100. A t-test nonparametric test, namely Mann-Whitney, revealed no statistically significant difference between two groups at 5%, ($U=32.500$, $Z=-1.328$, $p=0.195>0.05$), leading to retain the null hypothesis, which is no difference between two groups according to players' workload.

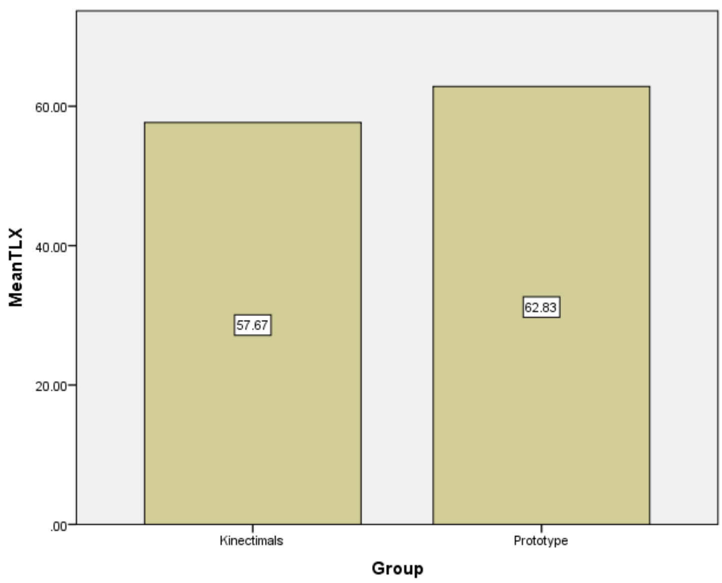


Figure 5-2 Comparison between two groups in mean workload score

A similar test was conducted to verify the hypothesis of a difference in each specific scale, in which data was seen not to differ significantly between Kinectimals and the prototype group either. Within the scope of each demand, the test resulted in mental demand (U=32.000, Z=-1.392, p=0.171>0.05), physical demand (U=28.500, Z=-1.667, p=0.098>0.05), temporal demand (U=45.500, Z=-0.344, p=0.752>0.05), performance (U=35.000, Z=-1.157, p=0.257>0.05), effort (U=45.000, Z=-0.386, p=0.726>0.05), frustration (U=35.000, Z=-1.154, p=0.266>0.05).

The below bar chart indicates the disparity between the six scales with each group as well as comparison between the two of them. Within the Kinectimals group, physical demand was the highest score, almost 80 per 100, while the largest score in prototype was effort, with approximately 70 out of 100. Moreover, both groups shared the lowest score via the frustration scale, around 40 for Kinectimals and 55 for prototype. Nevertheless, almost all scale scores in Kinectimals were lower than the prototype in their corresponding scales, except the physical demand and temporal scale. Although performance in Kinectimals was much better, the effort accomplishing that performance between the two groups was nearly the same.

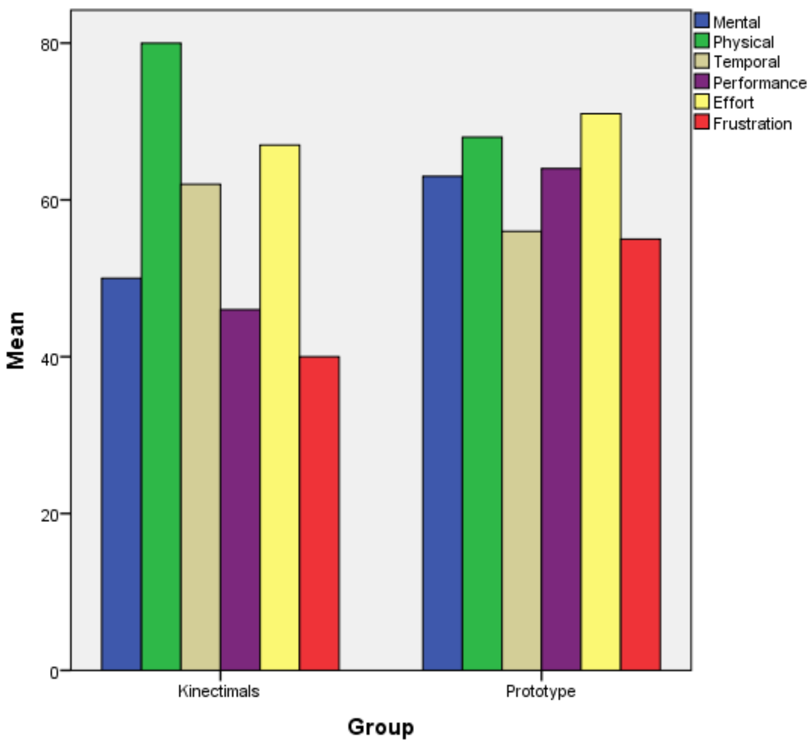


Figure 5-3 Comparison between the two groups in six scales of workload

1.2.3. CSUQ

Satisfaction evaluation via a standard 19 questions, was classified into 3 categories with 7 points of score scale including System Usefulness (M=2.656, SD=1.119), Information Quality (M=2.014, SD=0.773), Interface Quality (M=1.900, SD=0.950), additional pet game (M=2.150, SD=0.873), leading to the overall standard CSUQ (M=2.287, SD=0.813).

To analyse players' satisfaction via the Mann-Whitney nonparametric test, the system usefulness differed at 5% level of significance, (U=15.000, Z=-2.653, p=0.006<0.05), addition CSUQ (U=13.000, Z=-2.842, p=0.003<0.05) and the overall standard score (U=21.500, Z=-2.160, p=0.030<0.05). In contrast, the information quality and interface quality were observed via a similar test, resulting in retaining null hypotheses, with (U=37.000, Z=-0.988, p=0.340>0.05) and (U=32.000, Z=-1.396, p=0.172>0.05), respectively.

Additionally, the mean comparison chart indicated clearly that the players' satisfaction of prototype is lower than Kinectimals on the basis of every subscale as well as overall (the lower the score, the more satisfaction).

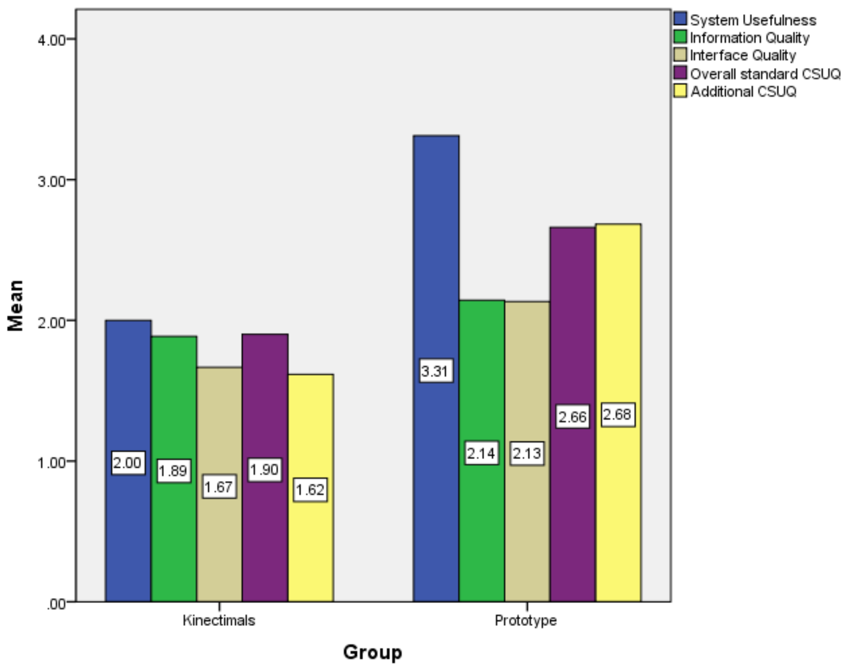


Figure 5-4 Comparison between the two groups in CSUQ

1.2.4. Additional CSUQ

Besides the aforementioned hypotheses, this experiment measured a variety of satisfaction information on some aspects of game context, belonging to an extended CSUQ questionnaire. Additional questions including 6 questions relating to game context, testing by Mann-Whitney nonparametric showed the difference in motion tracking reliability (U=7.000, Z=-3.332, p=0.001<0.05) and menu interaction design (U=25.000, Z=-2.030, p=0.044<0.05). The others retained the null hypotheses of no difference between two groups, pet interaction design (U=39.000, Z=-1.037, p=0.466>0.05), sound effects (U=36.000, Z=-1.137, p=0.363>0.05), navigation 3D environment (U=32.000, Z=-1.461, p=164>0.05) and valuable scale (U=41.000, Z=-0.378, p=0.747>0.05).

The bar chart adds more information about these disparities, with less satisfaction in prototype than Kinectimals. Within it, the fun factor of Kinectimals was high with the mean 1.78 out of 7, compared to 4.50 for prototype. The other aspects of Kinectimals were also lower scores with almost all below 2.20 while the corresponding prototype's questions achieved a higher score than 2.00, except the pet interaction design, which was approximately 1.80.

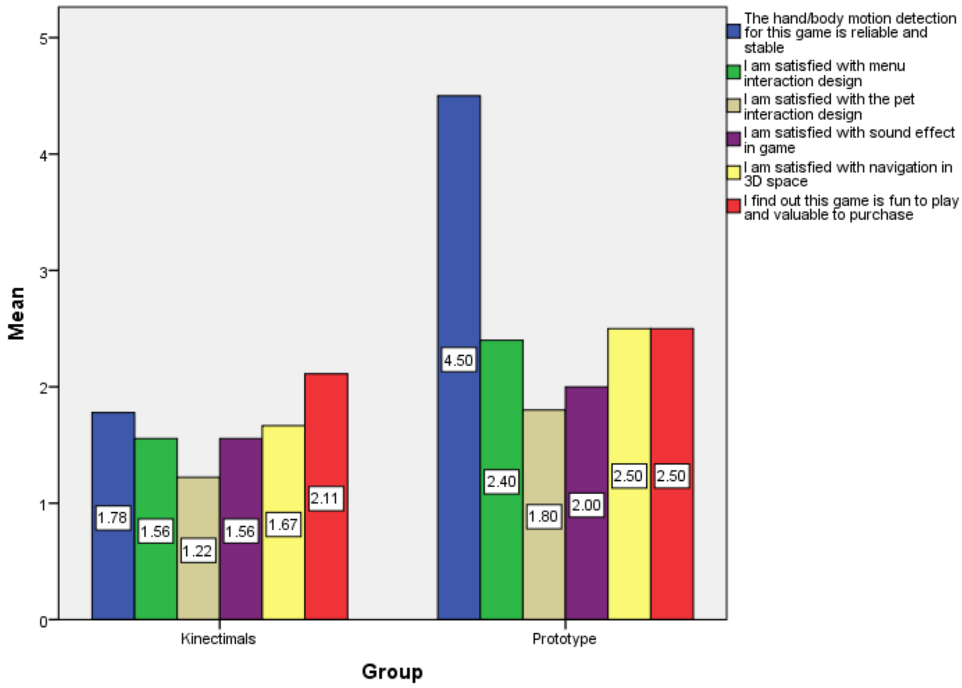


Figure 5-5 Comparison between the two groups in extended CSUQ

1.2.5. ASQ (8 common questions)

Each scenario contained three questions related to the ease of task, the amount of time and the support information, which their mean value was used for later data analysis. The common ASQ questions with similar scenarios, including stroking pet, feeding, cleaning, tricks training, ball playing and its contest, car controlling and its contest. The Mann-Whitney test examined the disparity of each question between Kinectimals and prototype group, revealing a statistically significant difference at 5% in the last two questions related to car controlling (U=9.500, Z=-3.079, $p=0.001<0.05$) and its contest (U=15.000, Z=-2.667, $p=0.005<0.08$). Kinectimals also significantly differed from prototype in overall score across 8 questions after running the same statistical test (U=15.000, Z=-2.648, $p=0.006$).

The bar charts presented that these scores from prototype were higher than Kinectimals, which indicated more satisfaction in Kinectimals' players. Within each group, car controlling and its contest task achieved the highest score of over 3.5 out of 7, indicating the most difficult activity and this was also consistent with feedback questions at the end of the questionnaire. While the throwing ball was the second unsatisfied activity in prototype games with approximately 2, the Kinectimals' second highest score of around 1.5 belongs to the tricks training. Additionally, the most enjoyment task in Kinectimals group was playing ball with above 1 score whereas in prototype was feeding a pet with nearly 2. Overall, across 8 common tasks, scores of Kinectimals accomplished less than prototype which implied the higher success of the Kinectimals game.

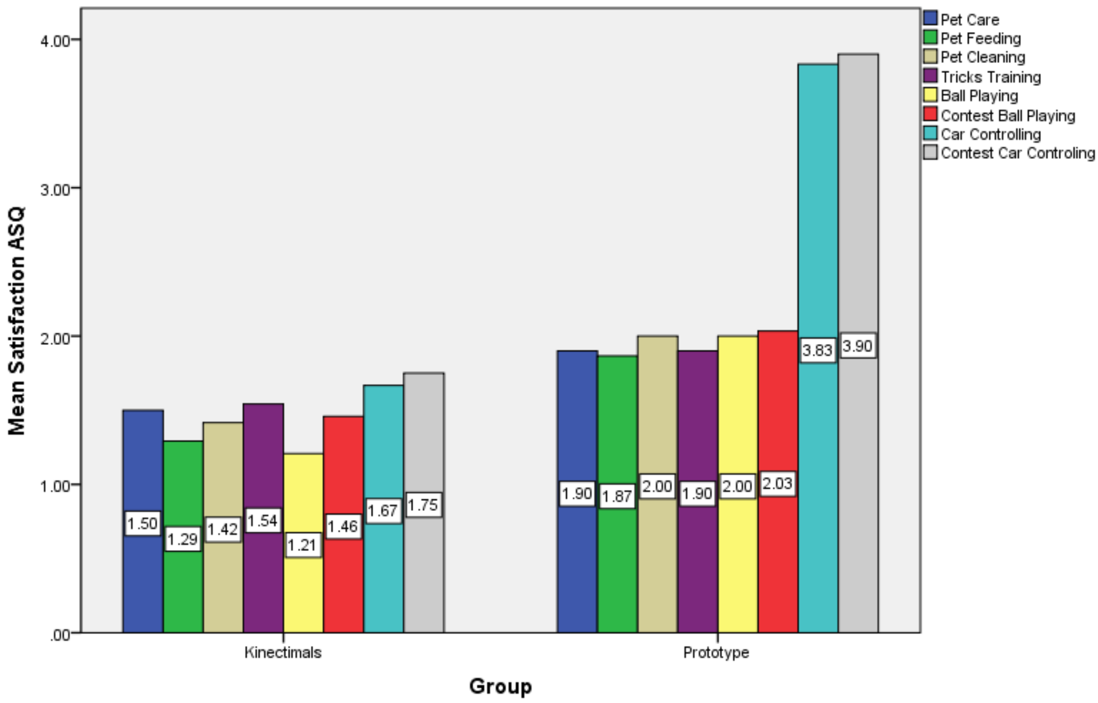


Figure 5-6 Comparison between the two groups in scenarios ASQ

1.3. Prototype

1.3.1. Hand gestures (success rate + ASQ (12-20))

The prototype game using a hand motion controller simulated 10 different hand gestures, including 5 stationary gestures (stop hand, thumb up, fist, face-up, grab) and 5 dynamic poses (rotate, clap, throw, swipe down, swipe up). Each hand gestures was recorded with the number of successful completions and failures.

The below bar charts show the mean number of times collected data cross hand poses. During one session, stop hand, thumb up, rotate hand, clap hand was required to do a constant time based on the game script; whereas the fist, face-up, swipe down, swipe up hand suggested randomly. The grab hand gesture was played in the throw-catch a toy feature while the throw hand gesture was recorded from both the throw-catch feature and the subsequent contest of playing with a toy.

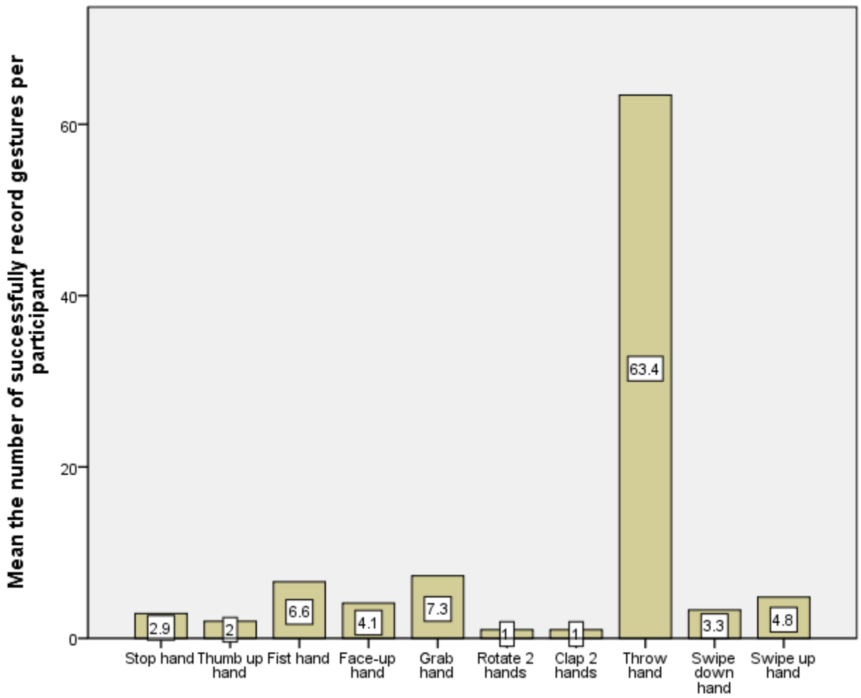


Figure 5-7 Mean recorded hand gestures

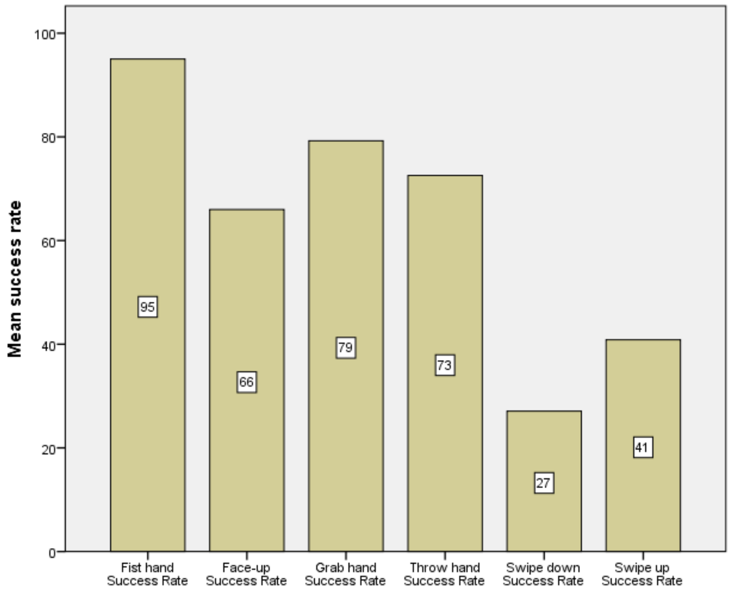


Figure 5-8 Hand gestures success rate

The success rate of each hand gesture was a single scale score for the reliability of hand gestures, which was presented in the above bar chart. However, since low recorded numbers of clap hand, rotate, stop and thumb up, these values were not sufficient in the comparison. Among 4 gestures prepared for the training tricks/commands, the fist was the most reliable gesture with 95% success rate, followed by an above 65% of the face-up hand, whereas swipe down and up hand displayed a higher effort to achieve with only approximately a quarter and 40% success rate, respectively. Throw and grab hand gesture data accomplished a better success ratio with above 70%.

As aforementioned, there were two categories of stationary and movement gesture, which is presented in the below chart. Stationary gestures were much more reliable and easier to accomplish than the others since the device limitation of tracking hand movement - 73.07% compared to 48.14%.

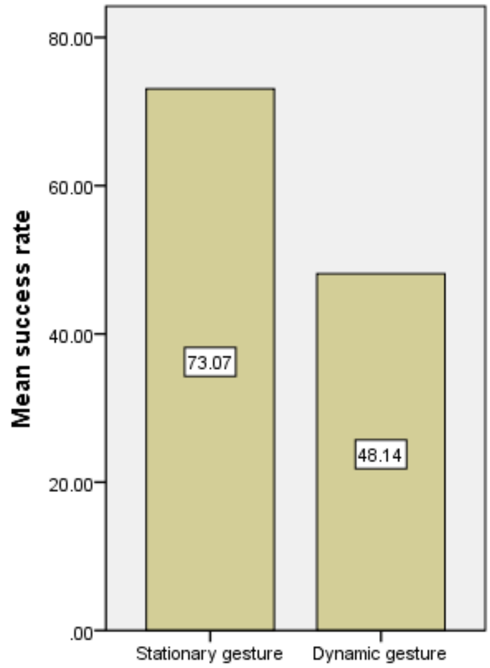


Figure 5-9 Comparison of stationary and dynamic hand gesture success rate

On the other hand, hand gesture satisfaction was observed via ASQ (question 12-20), which is revealed in the below bar chart. Among 9 different hand gestures, fist hand was the easiest gesture with a 1.10 score, followed by face-up hand which scored 1.33. Swiping left/right was the most difficult with the least satisfaction, scoring 2.83 out of 7 recorded from the players. The rest of hand gestures were approximately similar, around a score of 2 to 2.3, which was a highly acceptable score.

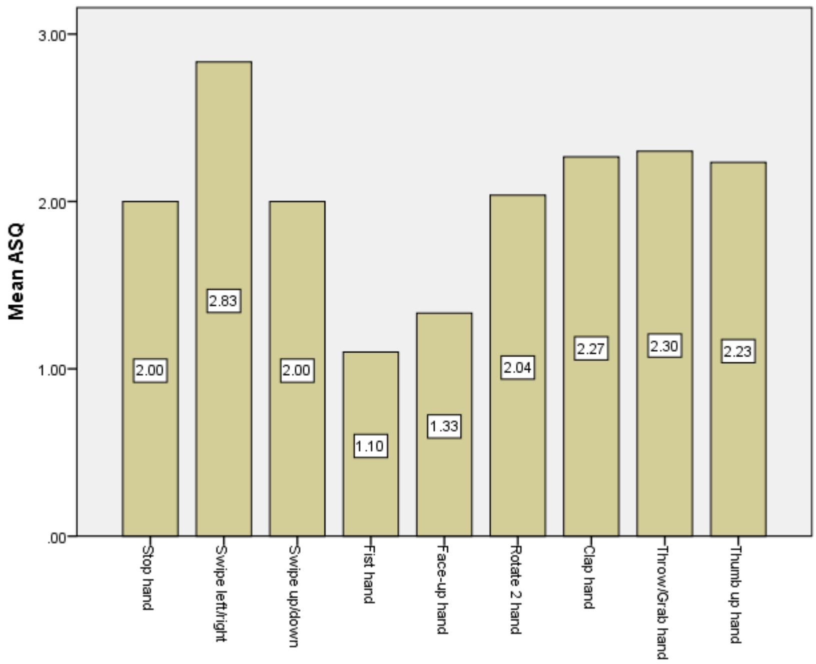


Figure 5-10 Satisfaction of hand gestures ASQ

On the other hand, the hypothesis of the none monotonic correlation between satisfaction and error rate was verified by the Spearman test for each hand gesture type, including swiping left/right (r_s=0.226, n=10, p=0.530>0.05), swiping up/down (r_s=0.188, n=10, p=0.603>0.05), fist hand (r_s=-0.214, n=10, p=0.552>0.05), face-up hand (r_s=0.131, n=10, p=0.718>0.05), throw-grab (r_s=0.441, n=10, p=0.202>0.05). All tests retained the null hypotheses leading to the conclusion of failure to detect the relationship between error rate and satisfaction. To be specific, the below chart presents that swipe left/right in menu interaction showed the highest dissatisfaction score of 2.83 whereas its error rate was acceptable with approximately 30%, still lower than face-up hand and swipe up/down, 34.02% and 66.02%. Throw/grab hand gesture resulted in the same outcome with inconsistent monotonic correlation. However, fist hand was the most reliable hand pose with almost 5% error.

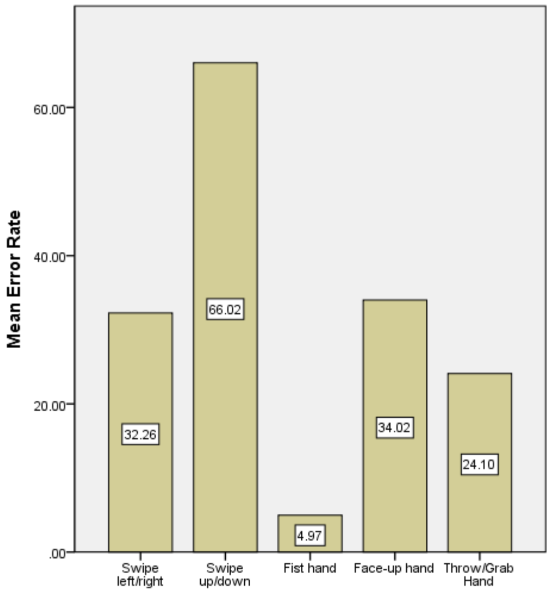


Figure 5-11 Hand gestures Error Rate

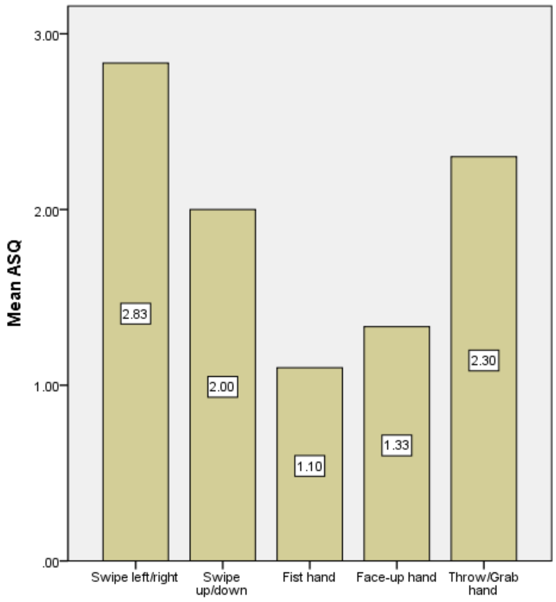


Figure 5-12 Hand gestures satisfaction

1.3.2. Ball playing

This game feature included 4 stages, training and a three-round contest aiming to hit down all skittles, with data collection involving the number of fallen skittles, score and time to achieve that goal. Because each section had a different time limit - 60 seconds for training and 30, 60, 90 seconds for the subsequent 3 rounds - the comparison was considered based on the number of skittles down per minute and score per minute. A small sample size with only 10 cases led to the choice of nonparametric statistical test.

The Friedman test was performed to figure out the improvement on the performance of 4 stages, representing 4 repeated groups of throwing the ball to the target. The result retains the null hypothesis ($\chi^2(3)$=7.408, p=0.056>0.05) with confidence intervals 0.95, which showed no significant difference among 4 trials. However, the bar chart displayed an increase of performance over trials from 5.31 skittles for the first time training to 16.40 skittles on the last round of the contest.

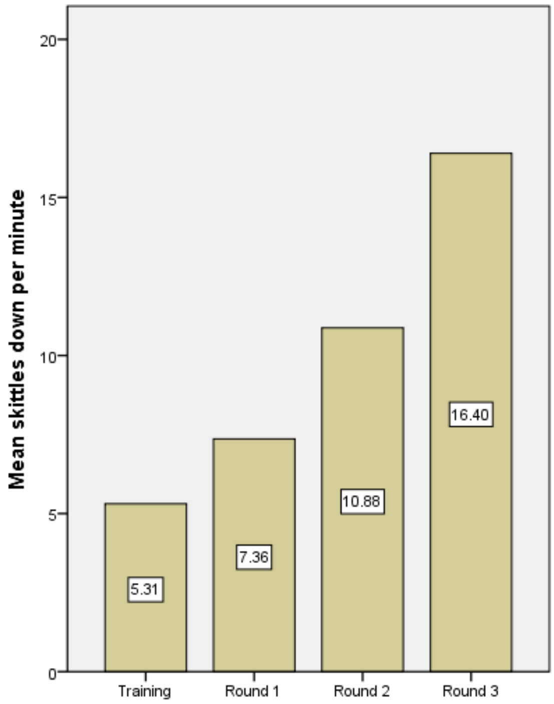


Figure 5-13 Comparison between ball playing stages in targets down per minute

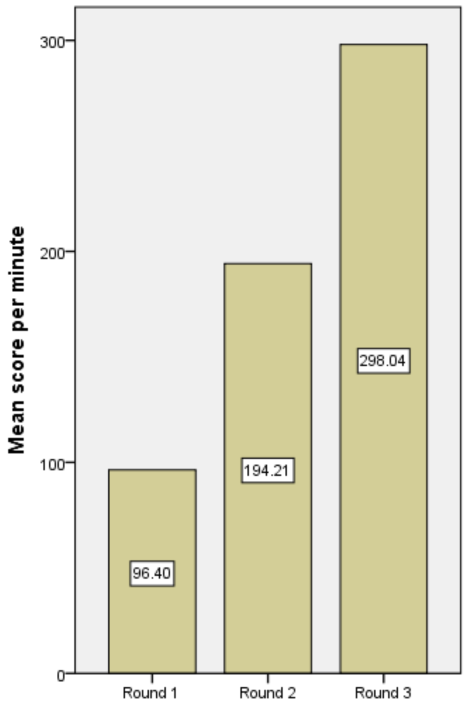


Figure 5-14 Comparison between ball playing rounds in score per minute

The score was calculated by the number of fallen skittles multiplied by 10 plus the bonus score when hitting in a row, and was collected only in the contest with 3 rounds. Again, the Friedman test revealed a significant difference among 3 groups ($\chi^2(2)$ = 6.513, p = 0.039<0.05). Based on this result, the post hoc Wilcoxon signed-rank test was performed to determine where the difference occurred with the difference being statistically significant at 5%. The comparison indicated that only the difference between round 1 and 3 was found, (Z = -2.429, p = 0.012 < 0.05). Nevertheless, the bar chart confirms an increase of observational score which is consistent with the increase of hitting skittles ratio, ranging from a score of 96.40 to 298.04 per minute.

1.3.3. Car controlling

Driving car was a skill which was improved via 4 stages, pre-contest training and a three-round contest, displayed as the number of fallen skittles hit by the car, score and time each round. Time spends 60 for the first stage and 30 seconds for each round in the contest. As each section had a different time limit, the comparison was also tested based on the number of skittles down per minute and score per minute.

The Friedman test was chosen to figure out the improvement on the performance over 4 stages corresponding to 4 repeated groups of controlling car. The outcome rejected the null hypothesis ($\chi^2(3)$ = 8.103, p = 0.039<0.05) which indicated the statistically significant difference among groups. To investigate which group differed, the Wilcoxon signed-rank test was performed at 5% level of significance. As a result, round 2 differed significantly from round 3 and 1, (Z = -2.554, p = 0.008<0.05) and (Z = -2.200, p = 0.014<0.05), respectively. In addition, the bar chart adds more information which the highest ratio of hitting target success rate is round 2, because the last round’s difficulty changed.

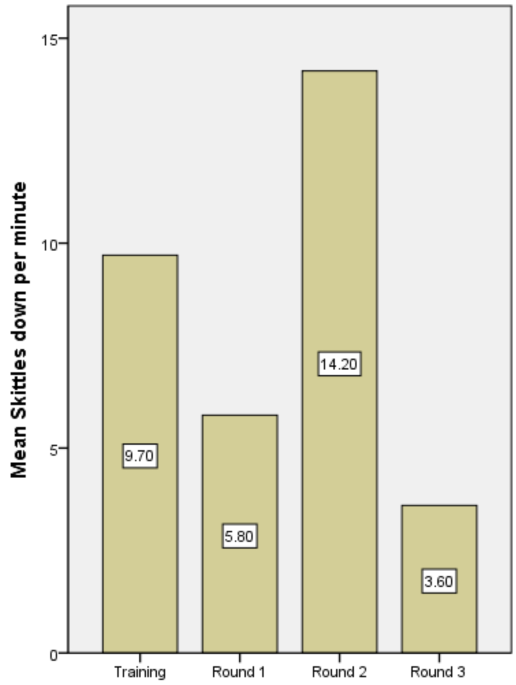


Figure 5-15 Comparison between car controlling stages in targets down per minute

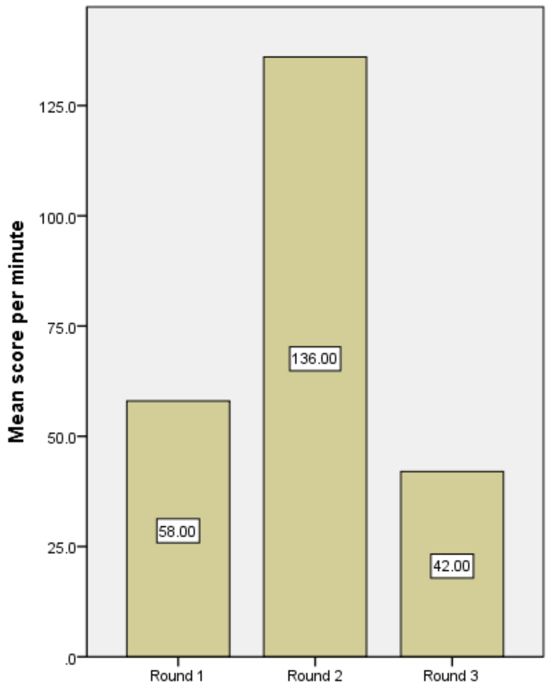


Figure 5-16 Comparison between car controlling three rounds in score per minute

The score was performed the same with previous task, and was examined only in the contest with 3 rounds. The comparison among the 3 rounds revealed by the Friedman test was that there was a significant difference ($\chi2(2) = 7.946$, $p = 0.017 < 0.05$) at 5% level of significance. To explore in detail, the post hoc test Wilcoxon signed-rank test was analysed in SPSS, which was consistent with the number of skittles each round. In particular, round 2 was the observational highest score of 136 and statistically significantly different from the other two rounds, round 1 ($Z = -2.142$, $p = 0.029 < 0.05$) and round 3 ($Z = -2.431$, $p = 0.012 < 0.05$).

1.3.4. Tricks Training

According to training tricks for dogs was observed by the number of successful tricks, score and time via the same concept with 4 trials including training section and three rounds, corresponding to the time limits of 60 seconds and 30, 60, 90 seconds, respectively. However, there was a difference in game design - the last round of the contest was divided into three 30-second stages, trying to track how much the players remember a list of displayed tricks and train following them. Data interpreted into the number of successful tricks per minute and score per minute.

To determine the statistically significant difference among 4 repeated groups of training the pet to do tricks, the Friedman test retained the null hypothesis ($\chi2(3) = 4.969$, $p = 0.175 > 0.05$), which indicated no statistically significant difference among groups.

The score in the tricks contest was again tested with the Friedman test at 95% confidence interval which failed to detect the distinction between 3 groups owing to the retaining of the null hypothesis ($\chi2(2) = 2.595$, $p = 0.304>0.05$).

1.3.5. CSUQ

The questionnaire designed for the prototype game has one more question than Kinectimals related to the stereoscopic vision on account of VR sight. Feedback from prototype's players was positive (M=2.500, SD=1.841) out of a maximum score of 7.

1.3.6. ASQ

Regarding the players' satisfaction for 10 features of the prototype game, consisting of ball throwing, car controlling and tricks training, movement, rotation tutorial, pet outfit and hidden camera, the comparison based on ASQ scale score of 7 points is presented in the below chart. The lower the score, the more satisfaction is in this feature.

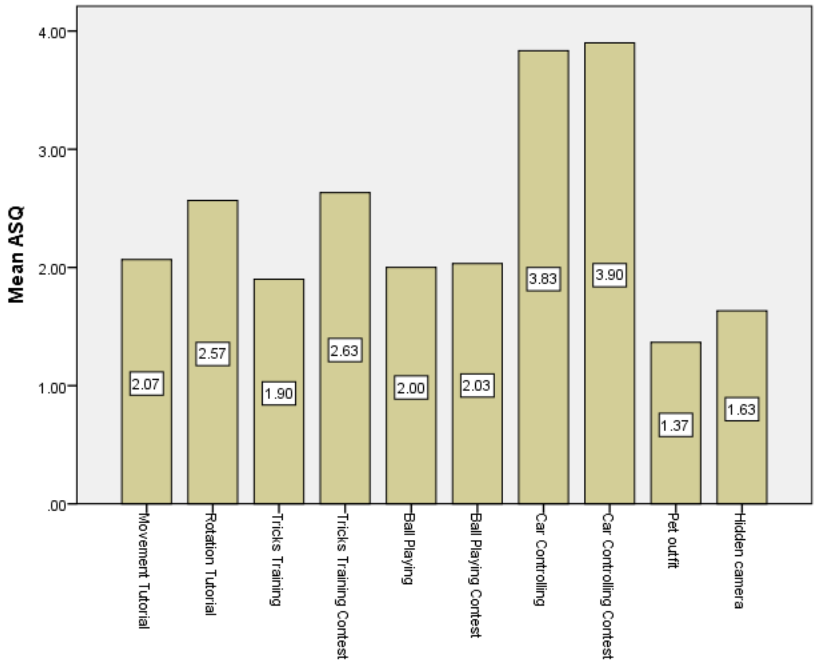


Figure 5-17 Satisfaction in scenarios ASQ prototype Game

Prototype game's highest scores were in car controlling and its mini-game, scoring nearly 4 out of 7, while the pet outfit and the hidden camera task were the favourite scenarios, rating a score of 1.37 and 1.63 respectively. The second group of dissatisfaction was the tricks training contest and rotation tasks with a score of approximately 2.60 while the movement, tricks training, ball playing and its contest achieved around score 2. As chart description, in spite of the high enjoyment of the tricks training stage, the contest right after that failed to satisfy the player which corresponded to the failure of the tricks observation score performance over trials. It implied that there was an issue in the design of this mini-game, leading to lower expectation.

1.4. Kinectimals

During the experiment of Kinectimals, a wide range of data was collected and interpreted. However, due to the time limits of this thesis, it will be analysed in the later study.

2. Discussion of the analysis

2.1. Objective

The purpose of this experiment was to estimate the effectiveness and value of the prototype game using emerging technologies, including Oculus Rift and Leap Motion. Aiming to promote this new game type, subsequent hypotheses were suggested to make it clearly and directed data collection for the experiment, followed by two objectives consisting of comparisons with another game and game features' evaluation.

2.2. Explain Demographics

The demographics data was collected with an aim to investigate on population VR gaming background. However, this failed to find the relationship between gaming experience and the advantages of goal accomplishment. The limitation may be explained because of a small sample size. However, this design was useful for the further experiment with a larger sample.

2.3. Explain comparison workload

Regarding workload assessment, both games showed a high demand on the mean of six scales compared to other studies using the NASA-TLX, particularly in physical demand. It was consistent with participants' opinions, who felt hand fatigue in prototype and leg fatigue in the soccer activity of Kinectimals. Kinectimals required more physical activities by using the whole body. However, the difference is not obvious owing to t-test failure. Additionally, the playing duration of Kinectimals achieved a higher score due to the long term of introduction video, which was reported by many participants. Additionally, some said that the pace of the prototype game was slow, leading to a further consideration on the time transition of quests as well as tutorials. As expected, prototype has some limitations on the tracking stabilization of Leap Motion, resulting in higher workload in mental and frustration levels. The failure of performance in prototype rather than Kinectimals may be explained by the incorrect response of visual hand animation from the Leap device, as well as bad game design. Some players admitted if they had more time to practice and gain familiarity with the devices, they may perform better. Similar effort level between two games was justified by the low performance of prototype and the high physical demand of Kinectimals.

2.4. Explain comparison satisfaction

The satisfaction was explored via two questionnaires, CSUQ in general and ASQ in particular. In the prototype, participants who appeared to experience the lag of hand movement due to the reliability of the device lowered the system usefulness and also contributed to the overall game satisfaction. It was consistent with the higher workload as well as the reliability of motion tracker question in extended CSUQ. The advantages of the VR research game was that information quality and interface quality level was acceptable compared to Kinectimals, which was developed by a professional team.

2.5. Menu

Even though almost all participants were satisfied with the size and clarity of text in the menu, its interaction effectiveness in a VR environment was addressed by low performance in success rate and an additional satisfaction question related to menu interaction design. Participants experienced the menu navigation by swiping left and right, which was difficult to perform and distinguish the direction of hand swiping gesture. Another issue was found via the independent observation that players could easily misunderstand the left/right arrows appearing on the menu which were touchable to navigate the menu, in spite of a clear tutorial. These findings resulted in the further improvement of the prototype in terms of menu.

2.6. Navigation

Navigation in the virtual environment against the physical world was estimated by one question in extended CSUQ as well as movement and rotation tutorial ASQ questions, which was satisfied. Participants reported positive feedbacks in the environment simulation and hardly experienced any nausea or dizziness with movement in VR, notwithstanding the hardware shortcomings when playing the high requirement Oculus Rift on a laptop. They were impressed in stereoscopic vision simulated by VR glass which was rated by one more question of CSUQ leading to a successful development in VR, especially the improvement of high resolution and wider FOV. However, future research should investigate more detail in VR players via the simulator sickness questionnaire SSQ (Kennedy et al. 1993) and presence questionnaire SUS in a virtual environment (Usoh et al. 2000), for example.

2.7. Pet interaction

In terms of pet interaction, an additional question CSUQ revealed an advantage satisfaction on account of a wide range of activities from daily pet care to tricks, ball and car to play with. This evidence was exploited by ASQ on each scenario, receiving confident confirmation, in particular, cleaning activity, throwing the ball and patting the dog. Compared to Kinectimals, pet interaction in prototype was limited on the variety as well as the satisfaction level. However, based on the drawbacks of development about time and resources, these feedbacks made a promising game in the commercial. The worst scenario in prototype was the car controlling feature, for which most of the participants complained about its difficulty and received a significantly low score of satisfaction. This feature needed to be adjusted to fit the hand movement gesture as well as making it relevant to the dog, for example, the dog sitting on the car.

To examine on improving performance possibility through training, three main features including ball playing, car controlling and tricks training, were designed in repeated stages to measure score and success ratio to accomplish goals. These findings revealed the success of throwing ball design, but the failure of tricks training. It can be argued that this activity required more of a variety of hand gestures than others, leading to the dependence on the reliability of the motion tracker and was the first task when participants were not familiar with the hand controller. Based on this evidence, future research would reorganise this tricks task after other quests, as well as give more training sections. Moreover, it was consistent with participants' opinions, that the performance measured on the car controlling task was lower than expected, while a few players accomplished the goal. Another issue was found that the design of 4 stages of this activity was not sufficient to help players get used to it. Score and success ratio did not steadily increase like throwing the ball, indicating the training stage was too short and easy before moving forward to the contest. In the contest, the last round was much too difficult which drowned the whole contest's effort. The contest satisfaction was affected by the game reward design, particularly gold/silver/bronze medal. This research missed the careful consideration of the balance of level reward, contributing to the low enjoyment in general.

Furthermore, additional game scenarios including pet outfit and hidden camera were bonus marks contributing to the diversity of pet interaction activities and also satisfied most participants.

2.8. Hand gesture

In the case of hand gesture investigation, the prototype tried to introduce as many as possible varieties of gesture. which focused on the complexity of hand gestures using the fingers tracking such as thumb up, rotation, grab hand, etc. which cannot be recognised with Kinect. Some gestures including stop hand, thumb up, rotate hand, clap hand, identified some issues via the observation and satisfaction questionnaire even though the data collection was not qualified to run the statistical tests. Stop hand and rotate hand was sensitive to be detected and received firm criticisms, whereas thumb up and clap hand experienced more difficulty. Leap Motion struggled to recognise the thumb up hand immediately. Instead, players had to slowly make a thumb up from a fully opened hand. The clap hand problem was the speed of moving two hands to make a clapping gesture.

In contrast, some gestures were mostly reliable, like making a fist, which was the easiest recognition thanks to full support from Leap Motion API. Both throwing, based on the hand's velocity vector and grab gesture, depending on the position of five individual fingers, were successfully detected from independent observational data as well as satisfaction scores. Although face-up stationary hand achieved a low success rate, the reactions from participants were encouraged, leading to the promising gesture. Nevertheless, swiping gestures received the most negative comments from players and were consistent with objectively recorded data. It can be argued that hand palm direction and a threshold of movement speed need to be considered again.

Chapter 6 Conclusion

1. An overview of the findings

Research experiment results illustrate positive points without cyber sickness during more than half an hour of VR experience, even in navigation mode which potentially causes the occurrence of nausea. Even though the experiment is lack of the immersion investigation, some positive scores of satisfaction were reflected the high acceptance of stereoscopic vision which is the heart of VR. The interface and information quality of the prototype showed benefits in UI game design as well as in tutorial mode. Also, fixed menu design, clarity of text and sufficient distance between UI elements and the human eye within hand reach are enhanced. Another confident feature is the variety of pet interactions, while the most preferred tasks are pet cleaning, patting, throw-catch, hidden camera exploration and pet outfit. The ball throwing mini-game is evaluated with appropriate design in goal achievement through three rounds as well as training time. Regarding hand gestures; fist, face-up hand stationary and throw-grab gestures are the most reliable ones which show potential for other developments in Leap Motion gestures.

In contrast, there are shortcomings in the game features coming from the lack of robustness hand tracking. High workload demand and failure of system usefulness estimation are the evidence for this argument. Hand gesture measures including thumb up, clap and swiping hand were rated low due to this limitation. In terms of game design, some issues were presented such as hand fatigue comments, slow game pace, too many tutorials and heavy reliance on missions. The tricks training contest requires increased practice time whereas the car controller has to be redesigned with other control methods.

2. Conclusion

Even though there is a variety of games/applications using the Oculus Rift DK2 or the Leap Motion separately, the combination both technologies is quite limited, which makes this research worth to carry on. The current implementation is only a prototype to investigate on the capability of a potential game using those emerging technologies, however, its contribution is to make VR more accessible to ordinary people via the game as well as how to apply the immersion into a specific game genre. To be specific, the immersion in the prototype was proved by the high score of stereoscopic vision in particular and the game playing satisfaction in general. The immersion breaks down into virtual surroundings, interaction and navigation design. For example, a personalized human hand avatar and the main character's emotional states (e.g hungry, cleaning, joy, etc.), are within the virtual environment considering. Fixed screen menu, natural hand gestures were applied to increase the ease of interaction with artificial elements. Regarding navigation, walking in place, degree of freedom reduction in movement, and the constant speed were inherited from other studies results to apply into game, thus, contribute to make the game success. Simulation sickness relieving from this game is the evidence of other studies benefits. There are avoiding non-forward movement, accelerometer replacement by a constant speed, blinking camera to teleport, reducing the yaw of camera and using the static visual reference. The prototype applied the first three tricks whereas the other two were need to scarified to increase the immersion and game satisfaction.

The game content, on the other hand, is rich by a broad range of exciting activities and the implementation is quite simple with supporting from Unity. This success motivates not only a wide developer community to increase the number of VR game contents in the near future but also another application possibilities, e.g. pilot training, surgery simulation, therapy, etc. Future work might focus to overcome the aforementioned issues as well as consider to add more features which will be discussed next.

3. Further research

The result of preliminary experiment enables the feasibility of a pioneer VR digital pet game, comparing to Kinectimals. Although the experiment results showed a high acceptance of player workload, interface and information quality, there are some identified issues which need to overcome in the further research. Firstly, immersion and simulation sickness aspects are required much more data to collect qualified evidence for relieving sickness and "being there" feeling. The next experiment may conduct a simulator sickness questionnaire and also presence form which was mentioned in the testing literature review. It contributes to investigate on the virtual reality aspect of game, particular in immersion scale. Secondly, due to the time limitation of this project, only a small group of participants were chosen to play game. Further experiment should conduct data based on a larger sample size, verifying this game with statistical significance.

According to testing results with the poor robustness regardless of technology, game improvements suggest updating the Leap Motion SDK with the Orion version, optimized for VR, in order to increase the reliability of hand tracking. Moreover, in terms of game design, the prototype needs the players to remember too many gestures and since a human can normally not remember more than about 7 of them due to the limited capacity of the working memory, this can also be an issue. The next game should alternate some gesture controls with other natural interactions such as voice commands. In case of pet activities, more detailed pet animations and responses (i.e. facial expressions following mood) would be ideal for the advancement of the deeper human-pet relationship.

Regarding the literature review, a virtual human body with foot step simulation is vital to consider in a contemporary VR game. Moreover, in terms of the latest technology, eye tracking

HMD (e.g. FOVE (Fove-inc 2016)) may be validated in order to improve the VR game controls such as navigation, path prediction or pet responses following human expression. Likewise, haptic feedback controlling (e.g. GloveOne (GloveOne 2016)) is the next promising option in terms of future VR games.

Appendix I - Experiment

1. Analysis Kinectimals based MIT guidelines

Table A - 1 Kinectimals game analysis

	Kinectimals
Goal and rule	-6 levels -Each level completion lead to a contest to explore a part of island -Set of available activities to gain experience to increase level -Activities include numerous kinds of pet interaction, missions/quests/mini game
Gameplay description	Activities: -Train pet some tricks (jump, spin, sit, lie, play dead, beg, stand) -Touch and fondle pet -Take care of feeding, cleaning, changing clothes -Play (throw catch ball, play volleyball, drive a car, explore hidden items on the island, run over obstacles)
Space	-Island map -Player can be in different parts of the island (background) based on game context, however, still stationary (cannot move freely around the island) -Kinect track body motion lead to the possibility of player's movement in a small physical space (impact how to control game)
Control/ Interact	-Body and hand motion tracking -Voice command to train pet, naming pet
Game world rules	-Fiction world with a concept of island exploration via pet -Still based on some physics in the real world, gravity mode

2. Questionnaire – NASA-TLX

Table A - 2 NASA-TLX questions

		Very Low	1	2	3	4	5	6	7	8	9	10	Very High
Mental Demand	How mentally demanding was the game ?	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?											
Physical Demand	How physically demanding was the game ?	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?											
Temporal Demand	How hurried or rushed was the pace of the game ?	How much time pressure did you feel due to the rate of pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?											
Performance	How successful were you in accomplishing what you were asked to do ?	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?											

Effort	have to work to accomplish your level of performance ?	How hard did you have to work (mentally and physically) to accomplish your level of performance?											
Frustration	discouraged irritated, stressed and annoyed were you?	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?											

3. Questionnaire – CSUQ

Table A - 3 Computer Satisfaction Usability Questionnaire

	Strongly AGREE	1	2	3	4	5	6	7	Strongly DISAGREE
1	Overall, I am satisfied with how easy it is to use this system								
2	It was simple to use this system								
3	I can effectively complete my work using this system								
4	I am able to complete my work quickly using this system								
5	I am able to efficiently complete my work using this system								
6	I feel comfortable using this system								
7	It was easy to learn to use this system								
8	I believe I became productive quickly using this system								
9	The system gives error messages that clearly tell me how to fix problems								
10	Whenever I make a mistake using the system, I recover easily and quickly								
11	The information (such as online help, on-screen messages, and another documentation) provided with this system is clear								
12	It is easy to find the information I needed								
13	The information provided for the system is easy to understand								
14	The information is effective in helping me complete the tasks and scenarios								
15	The organization of information on the system screens is clear								
16	The interface of this system is pleasant								
17	I like using the interface of this system								
18	This system has all the functions and capabilities I expect it to have								

19	Overall, I am satisfied with this system								[redacted]
20	The hand/body motion detection for this game is reliability and stable								[redacted]
21	I am satisfied with menu interaction design								[redacted]
22	I am satisfied with the pet interaction design								[redacted]
23	I am satisfied with sound effect in game								[redacted]
24	I am satisfied with navigation in 3D space								[redacted]
25	I am satisfied with 3D vision (stereoscopic) and FOV								[redacted]
26	I find out this game is fun to play and valuable to purchase								[redacted]

4. Questionnaire – ASQ Kinectimals

Table A - 4 After-Scenario Questionnaire Kinectimals

ASQ1	Scenario 1: Stroke/Fondle/Care pet
ASQ2	Scenario 2: Pet feeding
ASQ3	Scenario 3: Pet cleaning
ASQ4	Scenario 4: Training tricks (jump, sit, lie, play dead)
ASQ5	Scenario 5: Contest/Mini-game for Training tricks
ASQ6	Scenario 6: Playing ball (Throw-catch)
ASQ7	Scenario 7: Contest/Mini-game for Playing a ball
ASQ8	Scenario 8: Controlling car
ASQ9	Scenario 9: Contest/Mini-game for Driving car
ASQ10	Scenario 10: Collars/Outfit appearance for pet
ASQ11	Scenario 11: Spin command - Spin body
ASQ12	Scenario 12: Jump command - Jump body
ASQ13	Scenario 13: A star jump command -a star Jump body
ASQ14	Scenario 14: Sit command - Sit body
ASQ15	Scenario 15: Play dead command - Lie body
ASQ16	Scenario 16: Play disc with pet
ASQ17	Scenario 17: Play soccer ball with pet
ASQ18	Scenario 18: Contest/Minigame Kick a ball
ASQ19	Scenario 19: Clap command - Clap hand

ASQ20	Scenario 20: Beg command - Lean your knee
ASQ21	Scenario 21: Stand - Spread 2 hands gesture

Three questions for each scenario

1	Overall, I am satisfied with the **ease of completing** this task.
2	Overall, I am satisfied with the **amount of time** it took to complete this task.
3	Overall, I am satisfied with the **support information** (on-line help, messages, documentation) when completing this task

5. Questionnaire – ASQ Prototype

Table A - 5 After-Scenario Questionnaire Prototype Game

ASQ1	Scenario 1: Stroke/Fondle/Care pet
ASQ2	Scenario 2: Pet feeding
ASQ3	Scenario 3: Pet cleaning
ASQ4	Scenario 4: Movement tutorial in Virtual Reality space
ASQ5	Scenario 5: Rotation tutorial in Virtual Reality space
ASQ6	Scenario 6: Training tricks (jump, sit, lie, play dead)
ASQ7	Scenario 7: Contest/Minigame for Training tricks
ASQ8	Scenario 8: Playing ball (Throw-catch)
ASQ9	Scenario 9: Contest/Minigame for Playing a ball
ASQ10	Scenario 10: Controlling car
ASQ11	Scenario 11: Contest/Minigame for Driving car
ASQ12	Scenario 12: Stroke pet/Camera opening - Open full hand gesture
ASQ13	Scenario 13: Navigation menu - Swipe right/left-hand gesture
ASQ14	Scenario 14: Jump/Lie dog command - Swipe up/down hand gesture
ASQ15	Scenario 15: Play dead - Fist hand gesture
ASQ16	Scenario 16 : Sit - Face up stationary hand gesture
ASQ17	Scenario 17: Free pet - Rotate hand gesture
ASQ18	Scenario 18: Call over pet - Clap hand gesture
ASQ19	Scenario 19: Throw/Grab an object Hand gesture
ASQ20	Scenario 20: Give positive feedback - Thumb up hand gesture
ASQ21	Scenario 21: Collars/Outfit appearance for pet
ASQ22	Scenario 22: Camera following pet

Three questions for each scenario

1	Overall, I am satisfied with the **ease of completing** this task.
2	Overall, I am satisfied with the **amount of time** it took to complete this task.
3	Overall, I am satisfied with the **support information** (on-line help, messages, documentation) when completing this task

6. Questionnaire – Final Question

1 What is the most interesting scenario/task in the game? Why?

2 What is the most difficult scenario/task in the game? Why?

3 Do you feel nausea or hand fatigue ? If yes, any recommendation to solve this?

4 Do you have any suggestions for this game to make it much more fun and valuable?

7. Observation – Kinectimals

Table A - 6 Observation form of Kinectimals

	Task		Time
1	Introduction video		
2	Pet selection	Swipe left	
3		Swipe right	
4		Select	
5		Confirm	
6	Naming pet by voice		
7	Scan a picture of player		
8	Start game: introduce map		
9	Train with tricks	Jump	
10		Spin	
11		Star jump	
12		Beg	
13		Sit	
14		Play dead	
15		Lie	
16		Clap hand	
17		Stand	
18	Play with ball	Throw	
19		Hit skittles	
20		Hit target	
21	Contest 1: Play ball	Round 1	
22		Round 2	
23		Round 3	
24	Feed pet	Throw	
25	Brush pet		

	Task		Time
31	Play with soccer ball (optional)	Throw	
32		Hit 3 times in a row	
33	Contest 3: Kickball (optional)	Round 1	
34		Round 2	
35		Round 3	
36	Playing disc (optional)	Throw	
37		Hit all target	
38	Discovery hidden items (optional)	Find hidden item	
39		Dig	
40	Contest 4: Trick practice (optional)	Round 1	
41		Round 2	
42		Round 3	

26	Control a car	Drive forward for 5 seconds	
27		Hit all skittles / lanterns	
28		Jump car	
29	Contest 2: Race car	Jump car	
30		Stop	

Table A - 7 Observation form Kinectimals 2

	Task		Fail	Success
1	Pet selection	Swipe left		
2		Swipe right		
3		Select		
4		Confirm		
5	Naming pet by voice			
6	Scan a picture of player			
7	Train with tricks	Jump		
8		Spin		
9		Star jump		
10		Beg		
11		Sit		
12		Play dead		
13		Lie		
14		Clap hand		
15		Stand		
17	Play with ball	Throw		
18		Hit skittles		
19		Hit target		
20		Hit Frog		
21	Contest 1: Play ball	Round 1, Score		
22		Round 2, Score		

	Task		Fail	Success
31	Play with soccer ball (optional)	Throw		
32		Hit 3 times in a row		
33	Contest 3: Kickball (optional)	Round 1, Score		
34		Round 2, Score		
35		Round 3, Score		
36	Playing disc (optional)	Throw		
37		Hit all target		
38	Discovery hidden items (optional)	Find hidden item		
39		Dig		
40	Contest 4: Trick practice (optional)	Round 1, Score		
41		Round 2, Score		
42		Round 3, Score		

23		Round 3, Score		
24	Feed pet	Throw		
25	Control a car	Drive forward for 5 seconds		
26		Hit all skittles / latterns		
27		Jump car		
28	Contest 2: Race car	Jump car		
29		Stop		
30		Score		

8. Observation – Prototype

Table A - 8 Observation form Prototype game

Task				Fail
Menu		1	Swipe left /right menu	
Menu		2	Select menu item	
Menu		3	Select screen button	
Commands		4	Clap	
Commands		5	Stop Hand	
Commands		6	Swipe down	
Commands		7	Swipe up	
Commands		8	Fist	
Commands		9	Faceup hand	
Commands		10	Rotate hand	
Commands		11	Throw	
Commands		12	Grab	
Commands		13	Thumb up	
Tricks commands	Training	14	Sit	
Tricks commands	Training	15	Lie	
Tricks commands	Training	16	Jump	
Tricks commands	Training	17	Play dead	
Tricks commands	Challenge Round 1	18	Sit	
Tricks commands	Challenge Round 1	19	Lie	
Tricks commands	Challenge Round 1	20	Jump	
Tricks commands	Challenge Round 1	21	Play dead	
Tricks commands	Challenge Round 2	22	Sit	
Tricks commands	Challenge Round 2	23	Lie	

Task				Fail
Move		30	Move forward	
Rotate		31	Rotate fist	
Play ball	Training	32	Throw	
Play ball	Challenge Round 1	33	Throw	
Play ball	Challenge Round 2	36	Throw	
Play ball	Challenge Round 3	39	Throw	

		24	Jump	
		25	Play dead	
	Challenge Round 3	26	Sit	
		27	Lie	
		28	Jump	
		29	Play dead	

9. Log file – Prototype

Table A - 9 Log file data for Prototype game

StartTime	SitRequireR1	ThrowBallTraining
EndTime	LieRequireR1	MissTargetBallTraining
	JumpRequireR1	SkittlesDownBallTraining
SwipeLeftRight1	PlaydeadRequireR1	SkittlesTotalBallTraining
SwipeLeftRight2	SitSuccessR1	TimePlayBallTraining
SwipeLeftRight3	LieSuccessR1	
SwipeLeftRight4	JumpSuccessR1	ThrowBallR1
SwipeLeftRight5	PlaydeadSuccessR1	MissTargetBallR1
SwipeLeftRight6	TimePlayTricksR1	SkittlesDownBallR1
SwipeLeftRight7	ScoreTricksR1	SkittlesTotalBallR1
SelectMenuItem1		TimePlayBallR1
SelectMenuItem2	SitRequireR2	ScoreBallR1
SelectMenuItem3	LieRequireR2	
SelectMenuItem4	JumpRequireR2	ThrowBallR2
SelectMenuItem5	PlaydeadRequireR2	MissTargetBallR2
SelectMenuItem6	SitSuccessR2	SkittlesDownBallR2
SelectMenuItem7	LieSuccessR2	SkittlesTotalBallR2
SelectScreenButton	JumpSuccessR2	TimePlayBallR2
	PlaydeadSuccessR2	ScoreBallR2
StopHand	TimePlayTricksR2	
Rotate2Hand	ScoreTricksR2	ThrowBallR3
Clap2Hand		MissTargetBallR3
ThrowHand	SitRequireR3	SkittlesDownBallR3
GrabHand	LieRequireR3	SkittlesTotalBallR3
Thumbup	JumpRequireR3	TimePlayBallR3
Swipedown	PlaydeadRequireR3	ScoreBallR3
SwipeUp	SitSuccessR3	
FistHand	LieSuccessR3	SkittlesDownCarTraining
FaceupHand	JumpSuccessR3	SkittlesTotalCarTraining
	PlaydeadSuccessR3	TimePlayCarTraining
SitRequireTraining	TimePlayTricksR31	
LieRequireTraining	TimePlayTricksR32	SkittlesDownCarR1
JumpRequireTraining	TimePlayTricksR33	SkittlesTotalCarR1
PlaydeadRequireTraining	ScoreTricksR3	TimePlayCarR1

SitSuccessTraining		ScoreCarR1
LieSuccessTraining	MoveForward	
JumpSuccessTraining	RotateFistHand	SkittlesDownCarR2
PlaydeadSuccessTraining		SkittlesTotalCarR2
TimePlayTricksTraining		TimePlayCarR2
		ScoreCarR2

Appendix II – Game Prototype

1. Quests description

Table A - 10 List of quests description in Prototype

Task	Stage	Detail	Register Event
New Dog	1	Present two hands for detection	Detect both hands
	2	Learn to swipe hand left	Swipe left event
	3	Learn to swipe hand right	Swipe right event
	4	Instruction text for navigation	Timeout
	5	Select menu	Menu Selection
	6	Choose your favourite dog	Dog Selection
Fondle	1	Open hand to toggle fondle mode	Open hand event
	2	Fondle his head Fondle his back Fondle his abdominal	Reach target or run out of 60 seconds
Menu	1	Instruction icon dog emotion	Timeout
	2	Instruction keeps dog healthy	Timeout
	3	Instruction button open quest menu	Timeout
	4	Select quest button	Button selection event
	5	Instruction gold UI	Timeout
	6	Instruction level progression	Timeout
	7	Instruction purpose of quest menu	Timeout
	8	Prompt to engage more gold as well as experience	Timeout
	9	Instruction how to close quest menu	Close Quest menu event
	10	Instruction button open toy box	Timeout
	11	Select toy box button	Button selection event
	12	Select Settings	Menu Selection
	13	Hand customizes and close toy box	Close Toy box event
Training skill	1	Learn to use swipe down hand	Swipe down hand
	2	Wait for dog response	Dog Lie down
	3	Learn to use swipe up hand	Swipe up hand
	4	Wait for dog response	Dog Jump
	5	Learn to use fist hand	Fist hand
	6	Wait for dog response	Dog Play dead
	7	Learn to use face-up hand	Faceup hand
	8	Wait for dog response	Dog Sit

	9	Suggestion randomly picks from 4 skills (over 10 seconds, give a clue; over 20 seconds, try with other skill suggestion)	Complete 5 times or run out of 60 seconds
Training skill Challenge	1	Get Ready!	Timeout
	2	Round 1: Suggestion randomly skill (no clue, over 20 seconds, try with other skill suggestion)	Timeout
	3	Get Ready!	Timeout
	4	Round 2: Suggestion randomly skill (no clue, over 20 seconds, try with other skill suggestion)	Timeout
	5	Get Ready!	Timeout
	6	Round 3: Remember skill to do, 3 times in a row (no clue, no alternative choice)	Timeout
	7	Master command dog tricked	Timeout
Grow up		Complete level 1	
Camera Control	1	Learn to free pet to wander around house	Rotate hand
	2	Get back to normal view of human	Timeout
	3	Learn to open camera following dog	Open hand
	4	Observe dog far from camera	Timeout
	5	Learn to close camera	Open hand
Movement	1	Instruction arrow eye-gazing direction	Timeout
	2	UP arrow	Timeout
	3	DOWN arrow	Timeout
	4	Learn to stay middle to move forward	Timeout
	5	Learn to stop movement	Timeout
	6	Try to go and stop 3 times	Done 3 times
Rotation	1	Instruction the reason of rotation in game	Timeout
	2	Present hand to be detected	Present hand
	3	Make fist hand to display rotation arrow	Fist hand
	4	Stay looking forward and use LEFT arrow	Left arrow rotation
	5	Stay looking forward and use RIGHT arrow	Right arrow rotation
	6	Move forward to hide arrow	Move forward
Feed	1	Dog is hungry	Timeout
	2	Follow arrow moving to the kitchen	In the kitchen
	3	Look at the dog bowl	Look at bowl
	4	Explain 3D text show active object	Timeout

	5	Open toy box	Button selection
	6	Select Food menu	Menu Selection
	7	Instruction how much food in box	Timeout
	8	Instruction to buy food	Buy food
	9	Select which food to feed dog	Food Selection
	10	Wait for dog run over	Dog start to eat
	11	Dog hunger emotion shows up	Timeout
	12	Wait for finish lunch	Fulfilling eat status
Clean	1	Dog is dirty	Timeout
	2	Follow arrow moving to the bathroom	In the bathroom
	3	Look at the bath tube	Look at
	4	Present hand	Present hand
	5	Clap hand to call over dog	Clap hand
	6	Wait dog	Dog go to the bathroom
	7	Open toy box	Button Selection
	8	Select care items menu	Menu Selection
	9	Select care item	Menu Selection
	10	Learn to use soap to create bubbles	Clean whole dog body
	11	Learn to use shower spray	Spray dog until clean
	12	Hygience emotion explaination	Timeout
	13	Wait for fulfilling status	Fulfilling clean status
Play catch a ball	1	Instruction how to play catch	Timeout
	2	Open Toy box	Button Selection
	3	Select Toy menu	Menu Selection
	4	Select favorite toy	Menu Selection
	5	Instruction moving to garden	Timeout
	6	Learn to throw toy	Throw
	7	Wait dog catch and bring back	Dog catch
	8	Learn to grab hand to get back	Grab
	9	Practice this throw-catch skill again	Throw-catch
	10	Hit all skittles	All skittles down or Timeout
	11	Learn how to exit play catch mode	Thumb up hand
Play catch Challenge	1	Get Ready!	Timeout
	2	Round 1: Hit all skittles	Timeout
	3	Get Ready!	Timeout
	4	Round 2: Hit all skittles	Timeout
	5	Get Ready!	Timeout
	6	Round 3: Hit all skittles	Timeout
	7	Master command dog tricked	Timeout
Grow up		Complete level 2	

Change outfit	1	Instruction new outfit coming	Timeout
	2	Open Toy box	Button Selection
	3	Select Collar menu	Menu Selection
	4	Select your favorite collar	Menu Selection
Drive car	1	Open Toy box	Button Selection
	2	Select RC Car menu	Menu Selection
	3	Select favorite car	Menu Selection
	4	Instruction moving to garden	Timeout
	5	Control car forward	Car goes forward
	6	Control car backward	Car goes backward
	7	Control car turn left/right	Car rotate
	8	Run forward 5 seconds	Reach target or Timeout
	9	Hit all skittles	Reach target or Timeout
	10	Learn how to exit play catch mode	Thumb up hand
Drive car challenge	1	Get Ready!	Timeout
	2	Round 1: Hit all skittles	Timeout
	3	Get Ready!	Timeout
	4	Round 2: Hit all skittles	Timeout
	5	Get Ready!	Timeout
	6	Round 3: Hit all skittles	Timeout
	7	Master control RC Car with dog	Timeout
Free to play			

2. Game Assets

No.	Name	Reference
1	House frame	(FDC000 2014)
2	Dog house	(SketchUp 2014)
3	Dog ball	(Matty 2014)
4	Dog food	(Indie 2014)
5	Food bowl	(Raye_nbow 2014)
6	Dog models	(4toonStudio 2016)
7	Kitchen	(V. 2014)
8	Shower	(Edmondson 2014), (M 2015)
9	Toilet	(E 2014)
10	Bedroom	(E 2014)
11	Table	(jdbfishmanistee 2014)
12	Window	(Gutiérrez 2014), (kyle1456 2014),(Toxic 2014)
13	Tree	(MusicResponder 2014)
14	Skybox, Cloud	(Olson 2015), (ikke998 2010)
15	Soap	(Dakota 2014)
16	Brush	(T. 2014)
17	Water	(UnityTechnologies 2014)
18	Wheels	(Fibonacci 2014)
19	RC Cars	(B. 2014), (M. 2014)
20	Dog Hat	(sinjohnt 2014), (Guamokolatokint 2003)
21	Collars	(Girls 2014)

Appendix III – Experiment Result

1. Summary statistics test – Prototype

Table A - 11 Summary all statistics test using in Prototype game

		Trial Times	Playing games hours/week	Played Pet game	Experience with Oculus	Experience with Motion controller	Menu Success Rate	10 different body gesture	Successful tricks per times	Score per times	Successful fallen target per times	Score per times	Successful fallen target per times	Score per times	TLX	CSUQ	ASQ
Demographics	Playing games hours/week	1															
	Played Pet game	1															
	Experience with VR	1															
	Experience with Motion controller	1															
Menu	Menu Error Rate	7	C	M	M	M											
Gesture based	10 different body gesture	1															
Training tricks	Successful tricks per times	4							F								
	Score per times	3								F							
Play ball	Successful fallen target per times	4									F						
	Score per times	3										F					
Drive car	Successful fallen target per times	4											F				
	Score per times	3												F			
TLX	Mean 6 scales	1	C	M	M	M											
CSUQ	Mean 19 standard question	1	C	M	M	M											
ASQ	Relevant scenarios	1						C									

C	Spearman test (Correlation Bivariate)
F	Friedman test (analogy to repeated ANOVA)
M	Man-Whitney U test (analogy to independent T-test)
W	Wilcoxon Signed Rank test (analogy to pair T-test)

2. Statistics table result

2.1. Correlation playing game per week

Table A - 12 Correlation gaming time per week and menu error

			How much do you play games each week? (hours/week)	Menu Error Rate
Spearman's rho	How much do you play games each week? (hours/week)	Correlation Coefficient	1.000	-.002
		Sig. (2-tailed)	.	.995
		N	20	20
	Menu Error Rate	Correlation Coefficient	-.002	1.000
		Sig. (2-tailed)	.995	.
		N	20	20

Table A - 13 Correlation gaming time per week and workload score TLX

			How much do you play games each week? (hours/week)	Mean workload TLX
Spearman's rho	How much do you play games each week? (hours/week)	Correlation Coefficient	1.000	-.024
		Sig. (2-tailed)	.	.920
		N	20	20
	Mean workload TLX	Correlation Coefficient	-.024	1.000
		Sig. (2-tailed)	.920	.
		N	20	20

Table A - 14 Correlation gaming time per week and satisfaction score

			How much do you play games each week? (hours/week)	Overall standard CSUQ
Spearman's rho	How much do you play games each week? (hours/week)	Correlation Coefficient	1.000	.067
		Sig. (2-tailed)	.	.778
		N	20	20
	Overall standard CSUQ	Correlation Coefficient	.067	1.000
		Sig. (2-tailed)	.778	.
		N	20	20

2.2. Pet game experience vs Non-Pet game experience

Table A - 15 Mann-Whitney test between Pet game experience and Non-Pet game experience based on Menu error, workload, satisfaction score

Ranks

	Have you ever play a virtual pet raising game?	N	Mean Rank	Sum of Ranks
Menu Error Rate	0	8	7.13	57.00
	1	12	12.75	153.00
	Total	20		
Mean workload TLX	0	8	9.94	79.50
	1	12	10.88	130.50
	Total	20		
Overall standard CSUQ	0	8	10.44	83.50
	1	12	10.54	126.50
	Total	20		

Test Statistics[a]

	Menu Error Rate	Mean workload TLX	Overall standard CSUQ
Mann-Whitney U	21.000	43.500	47.500
Wilcoxon W	57.000	79.500	83.500
Z	-2.083	-.349	-.039
Asymp. Sig. (2-tailed)	.037	.727	.969
Exact Sig. [2*(1-tailed Sig.)]	.039[b]	.734[b]	.970[b]

a. Grouping Variable: Have you ever play a virtual pet raising game?

b. Not corrected for ties.

2.3. Motion controller experience vs Non-Motion controller experience

Table A - 16 Mann-Whitney test between Motion controller experience and Non-Motion controller experience based on Menu error, workload, satisfaction score

Ranks

	Have you ever experience motion controlling before?	N	Mean Rank	Sum of Ranks
Menu Error Rate	0	11	8.82	97.00
	1	9	12.56	113.00
	Total	20		
Mean workload TLX	0	11	11.45	126.00
	1	9	9.33	84.00
	Total	20		
Overall standard CSUQ	0	11	10.36	114.00
	1	9	10.67	96.00
	Total	20		

Test Statistics[a]

	Menu Error Rate	Mean workload TLX	Overall standard CSUQ

Mann-Whitney U	31.000	39.000	48.000
Wilcoxon W	97.000	84.000	114.000
Z	-1.406	-.801	-.114
Asymp. Sig. (2-tailed)	.160	.423	.909
Exact Sig. [2*(1-tailed Sig.)]	.175[b]	.456[b]	.941[b]

a. Grouping Variable: Have you ever experience motion controlling before?

b. Not corrected for ties.

2.4. Virtual Reality experience vs Non-VR experience

Table A - 17 Mann-Whitney test between VR experience and Non-VR experience based on Menu error, workload, satisfaction score

Ranks

	Have you ever experience Virtual Reality before?	N	Mean Rank	Sum of Ranks
Menu Error Rate	0	8	8.50	68.00
	1	12	11.83	142.00
	Total	20		
Mean workload TLX	0	8	7.63	61.00
	1	12	12.42	149.00
	Total	20		
Overall standard CSUQ	0	8	8.31	66.50
	1	12	11.96	143.50
	Total	20		

Test Statistics

	Menu Error Rate	Mean workload TLX	Overall standard CSUQ
Mann-Whitney U	32.000	25.000	30.500

Wilcoxon W	68.000	61.000	66.500
Z	-1.234	-1.782	-1.354
Asymp. Sig. (2-tailed)	.217	.075	.176
Exact Sig. [2*(1-tailed Sig.)]	.238[b]	.082[b]	.181[b]

a. Grouping Variable: Have you ever experience Virtual Reality before?

b. Not corrected for ties.

2.5. Compare Kinectimals and Prototype

2.5.1. Menu Interaction

Table A - 18 Mann-Whitney test between Kinectimals and Prototype based on swiping gesture, select menu item and mean of menu error rate

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Swipe Left/Right Error rate	20	.2748	.12774	.08	.49
Select Menu Item Error Rate	20	.3323	.13366	.11	.59
Menu Error Rate	20	.3035	.08469	.12	.43
Group	20	1.50	.513	1	2

Ranks

	Group	N	Mean Rank	Sum of Ranks
Swipe Left/Right Error rate	Kinectimals	10	8.10	81.00
	Prototype	10	12.90	129.00
	Total	20		
Select Menu Item Error Rate	Kinectimals	10	8.00	80.00
	Prototype	10	13.00	130.00
	Total	20		
Menu Error Rate	Kinectimals	10	7.00	70.00
	Prototype	10	14.00	140.00

	Total	20

Test Statistics[a]

	Swipe Left/Right Error rate	Select Menu Item Error Rate	Menu Error Rate
Mann-Whitney U	26.000	25.000	15.000
Wilcoxon W	81.000	80.000	70.000
Z	-1.815	-1.892	-2.646
Asymp. Sig. (2-tailed)	.070	.058	.008
Exact Sig. [2*(1-tailed Sig.)]	.075[b]	.063[b]	.007[b]
Exact Sig. (2-tailed)	.072	.060	.007
Exact Sig. (1-tailed)	.036	.030	.003
Point Probability	.003	.003	.001

a. Grouping Variable: Group

b. Not corrected for ties.

2.5.2. NASA-TLX

Table A - 19 Mann-Whitney test between Kinectimals and Prototype based on six subscales NASA-TLX

Test Statistics[a]

	Mental	Physical	Temporal	Performance	Effort	Frustration
Mann-Whitney U	32.000	28.500	45.500	35.000	45.000	35.000
Wilcoxon W	87.000	83.500	100.500	90.000	100.000	90.000
Z	-1.392	-1.667	-.344	-1.157	-.386	-1.154
Asymp. Sig. (2-tailed)	.164	.095	.731	.247	.699	.248
Exact Sig. [2*(1-tailed Sig.)]	.190[b]	.105[b]	.739[b]	.280[b]	.739[b]	.280[b]
Exact Sig. (2-tailed)	.171	.098	.752	.257	.726	.266
Exact Sig. (1-tailed)	.085	.049	.376	.128	.363	.133
Point Probability	.004	.005	.015	.006	.016	.011

a. Grouping Variable: Group

b. Not corrected for ties.

Table A - 20 Mann-Whitney test between Kinectimals and Prototype based on mean workload score

Test Statistics[a]

	Mean workload score
Mann-Whitney U	32.500
Wilcoxon W	87.500
Z	-1.328
Asymp. Sig. (2-tailed)	.184
Exact Sig. [2*(1-tailed Sig.)]	.190[b]
Exact Sig. (2-tailed)	.195
Exact Sig. (1-tailed)	.098
Point Probability	.007

a. Grouping Variable: Group

b. Not corrected for ties.

2.5.3. CSUQ

Table A - 21 Mann-Whitney test between Kinectimals and Prototype based on System Usefulness, Information Quality, Interface Quality, Overall standard and extended CSUQ

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
System Usefulness	20	2.6562	1.11941	1.13	5.50
Information Quality	20	2.0143	.77265	1.14	4.29
Interface Quality	20	1.9000	.94961	1.00	4.67
Overall standard CSUQ	20	2.2806	.81320	1.17	4.39
Additional CSUQ	20	2.1500	.87342	1.17	4.33
Group	20	1.50	.513	1	2

Ranks

	Group	N	Mean Rank	Sum of Ranks
System Usefulness	Kinectimals	10	7.00	70.00
	Prototype	10	14.00	140.00
	Total	20		
Information Quality	Kinectimals	10	9.20	92.00
	Prototype	10	11.80	118.00
	Total	20		
Interface Quality	Kinectimals	10	8.70	87.00
	Prototype	10	12.30	123.00
	Total	20		
Overall standard CSUQ	Kinectimals	10	7.65	76.50
	Prototype	10	13.35	133.50
	Total	20		
Additional CSUQ	Kinectimals	10	6.80	68.00
	Prototype	10	14.20	142.00
	Total	20		

Test Statistics[a]

	System Usefulness	Information Quality	Interface Quality	Overall standard CSUQ	Additional CSUQ
Mann-Whitney U	15.000	37.000	32.000	21.500	13.000
Wilcoxon W	70.000	92.000	87.000	76.500	68.000
Z	-2.653	-.988	-1.396	-2.160	-2.842
Asymp. Sig. (2-tailed)	.008	.323	.163	.031	.004
Exact Sig. [2*(1-tailed Sig.)]	.007[b]	.353[b]	.190[b]	.029[b]	.004[b]
Exact Sig. (2-tailed)	.006	.340	.172	.030	.003
Exact Sig. (1-tailed)	.003	.170	.086	.015	.002
Point Probability	.000	.009	.005	.002	.000

a. Grouping Variable: Group

b. Not corrected for ties.

Table A - 22 Mann-Whitney test between Kinectimals and Prototype based on each satisfaction question in extended CSUQ

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
The hand/body motion detection for this game is reliable and stable	20	3.25	1.713	1	7
I am satisfied with menu interaction design	20	1.95	1.276	1	6
I am satisfied with the pet interaction design	20	1.50	1.147	1	6
I am satisfied with sound effect in game	20	1.80	.768	1	3
I am satisfied with navigation in 3D space	20	2.05	1.432	1	6
I find out this game is fun to play and valuable to purchase	19	2.32	1.336	1	7
Group	20	1.50	.513	1	2

Ranks

	Group	N	Mean Rank	Sum of Ranks
The hand/body motion detection for this game is reliable and stable	Kinectimals	10	6.20	62.00
	Prototype	10	14.80	148.00
	Total	20		
I am satisfied with menu interaction design	Kinectimals	10	8.00	80.00
	Prototype	10	13.00	130.00
	Total	20		
I am satisfied with the pet interaction design	Kinectimals	10	9.40	94.00
	Prototype	10	11.60	116.00
	Total	20		
I am satisfied with sound effect in game	Kinectimals	10	9.10	91.00
	Prototype	10	11.90	119.00
	Total	20		

I am satisfied with navigation in 3D space	Kinectimals	10	8.70	87.00
	Prototype	10	12.30	123.00
	Total	20		
I find out this game is fun to play and valuable to purchase	Kinectimals	9	9.56	86.00
	Prototype	10	10.40	104.00
	Total	19		

Test Statistics[a]

	The hand/body motion detection for this game is reliable and stable	I am satisfied with menu interaction design	I am satisfied with the pet interaction design	I am satisfied with sound effect in game	I am satisfied with navigation in 3D space	I find out this game is fun to play and valuable to purchase
Mann-Whitney U	7.000	25.000	39.000	36.000	32.000	41.000
Wilcoxon W	62.000	80.000	94.000	91.000	87.000	86.000
Z	-3.332	-2.030	-1.037	-1.137	-1.461	-.378
Asymp. Sig. (2-tailed)	.001	.042	.300	.255	.144	.705
Exact Sig. [2*(1-tailed Sig.)]	.000[b]	.063[b]	.436[b]	.315[b]	.190[b]	.780[b]
Exact Sig. (2-tailed)	.001	.044	.466	.363	.164	.747
Exact Sig. (1-tailed)	.000	.022	.233	.182	.082	.372
Point Probability	.000	.004	.163	.085	.017	.051

a. Grouping Variable: Group

b. Not corrected for ties.

2.5.4. ASQ

Table A - 23 Mann-Whitney test between Kinectimals and Prototype based on 8 common questions of satisfaction

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Pet Care	20	1.7167	.75915	1.00	4.00
Pet Feeding	19	1.6667	.65734	1.00	3.00
Pet Cleaning	19	1.7018	.75273	1.00	3.33
Tricks Training	20	1.7167	.83963	1.00	4.00
Ball Playing	20	1.6000	1.09009	1.00	5.00
Contest Ball Playing	20	1.7000	1.14912	1.00	5.00
Car Controlling	20	2.8167	1.66658	1.00	7.00
Contest Car Controlling	20	2.9167	1.67847	1.00	7.00
Group	20	1.50	.513	1	2

Ranks

	Group	N	Mean Rank	Sum of Ranks
Pet Care	Kinectimals	10	9.15	91.50
	Prototype	10	11.85	118.50
	Total	20		
Pet Feeding	Kinectimals	9	8.00	72.00
	Prototype	10	11.80	118.00
	Total	19		
Pet Cleaning	Kinectimals	9	7.67	69.00
	Prototype	10	12.10	121.00
	Total	19		
Tricks Training	Kinectimals	10	9.90	99.00
	Prototype	10	11.10	111.00
	Total	20		
Ball Playing	Kinectimals	10	9.05	90.50

	Prototype	10	11.95	119.50
	Total	20		
Contest Ball Playing	Kinectimals	10	9.15	91.50
	Prototype	10	11.85	118.50
	Total	20		
Car Controlling	Kinectimals	10	6.45	64.50
	Prototype	10	14.55	145.50
	Total	20		
Contest Car Controling	Kinectimals	10	7.00	70.00
	Prototype	10	14.00	140.00
	Total	20		

Test Statistics[a]

	Pet Care	Pet Feeding	Pet Cleaning	Tricks Training	Ball Playing	Contest Ball Playing	Car Controlling	Contest Car Controlling
Mann-Whitney U	36.500	27.000	24.000	44.000	35.500	36.500	9.500	15.000
Wilcoxon W	91.500	72.000	69.000	99.000	90.500	91.500	64.500	70.000
Z	-1.042	-1.518	-1.779	-.464	-1.238	-1.096	-3.079	-2.667
Asymp. Sig. (2-tailed)	.297	.129	.075	.643	.216	.273	.002	.008
Exact Sig. [2*(1-tailed Sig.)]	.315[b]	.156[b]	.095[b]	.684[b]	.280[b]	.315[b]	.001[b]	.007[b]
Exact Sig. (2-tailed)	.306	.134	.081	.674	.233	.294	.001	.005
Exact Sig. (1-tailed)	.153	.065	.045	.337	.117	.147	.001	.003
Point Probability	.004	.004	.010	.023	.021	.014	.000	.000

a. Grouping Variable: Group

b. Not corrected for ties.

2.6. Prototype evaluation

2.6.1. Hand gesture

Table A - 24 Correlation between error rate and satisfaction score of swiping left/right gesture

			Swipe left/right Error Rate	Swipe left/right Satisfaction
Spearman's rho	Swipe left/right Error Rate	Correlation Coefficient	1.000	.226
		Sig. (2-tailed)	.	.530
		N	10	10
	Swipe left/right Satisfaction	Correlation Coefficient	.226	1.000
		Sig. (2-tailed)	.530	.
		N	10	10

Table A - 25 Correlation between error rate and satisfaction score of swiping up/down gesture

			Swipe up/down Error Rate	Swipe up/down Satisfaction
Spearman's rho	Swipe up/down Error Rate	Correlation Coefficient	1.000	.188
		Sig. (2-tailed)	.	.603
		N	10	10
	Swipe up/down Satisfaction	Correlation Coefficient	.188	1.000
		Sig. (2-tailed)	.603	.
		N	10	10

Table A - 26 Correlation between error rate and satisfaction score of Fish hand

			Fist hand Error Rate	Fist hand Satisfaction

Spearman's rho	Fist hand Error Rate	Correlation Coefficient	1.000	-.214
		Sig. (2-tailed)	.	.552
		N	10	10
	Fist hand Satisfaction	Correlation Coefficient	-.214	1.000
		Sig. (2-tailed)	.552	.
		N	10	10

Table A - 27 Correlation between error rate and satisfaction score of Face-up hand

			Face-up hand Error Rate	Face-up hand Satisfaction
Spearman's rho	Face-up hand Error Rate	Correlation Coefficient	1.000	.131
		Sig. (2-tailed)	.	.718
		N	10	10
	Face-up hand Satisfaction	Correlation Coefficient	.131	1.000
		Sig. (2-tailed)	.718	.
		N	10	10

Table A - 28 Correlation between error rate and satisfaction score of Throw/Grab hand

			Throw/Grab Hand Error Rate	Throw/Grab hand Satisfaction
Spearman's rho	Throw/Grab Hand Error Rate	Correlation Coefficient	1.000	.441
		Sig. (2-tailed)	.	.202
		N	10	10
	Throw/Grab hand Satisfaction	Correlation Coefficient	.441	1.000
		Sig. (2-tailed)	.202	.

N	10	10

2.6.2. Ball playing

Table A - 29 Friedman test for 4 stages of ball playing

Ranks

	Mean Rank
Skittles Down Per Times Contest 2 Training	1.85
Skittles Down Per Times Contest 2 R1	2.55
Skittles Down Per Times Contest 2 R2	2.25
Skittles Down Per Times Contest 2 R3	3.35

Test Statistics[a]

N	10
Chi-Square	7.408
df	3
Asymp. Sig.	.060
Exact Sig.	.056
Point Probability	.001

a. Friedman Test

Table A - 30 Friedman test for 3 rounds contest of ball playing

Ranks

	Mean Rank
Score per times Contest 2 R1	1.65

Score per times Contest 2 R2	1.70
Score per times Contest 2 R3	2.65

Test Statistics[a]

N	10
Chi-Square	6.513
df	2
Asymp. Sig.	.039
Exact Sig.	.039
Point Probability	.004

a. Friedman Test

2.6.3. Car controlling

Table A - 31 Friedman test for 4 stages of car controlling

Ranks

	Mean Rank
Skittles Down Per Times Contest 3 Training	2.35
Skittles Down Per Times Contest 3 R1	2.55
Skittles Down Per Times Contest 3 R2	3.35
Skittles Down Per Times Contest 3 R3	1.75

Test Statistics[a]

N	10
Chi-Square	8.103
df	3
Asymp. Sig.	.044
Exact Sig.	.039
Point Probability	.000

a. Friedman Test

Table A - 32 Friedman test for 3 rounds contest of car controlling

Ranks

	Mean Rank
Score per times Contest 3 R1	1.90
Score per times Contest 3 R2	2.65
Score per times Contest 3 R3	1.45

Test Statistics[a]

N	10
Chi-Square	7.946
df	2
Asymp. Sig.	.019
Exact Sig.	.017
Point Probability	.004

a. Friedman Test

2.6.4. Tricks training

Table A - 33 Friedman test for 4 stages of tricks training

Ranks

	Mean Rank
Success rate per times Contest 1 Round 0	3.00
Success rate per times Contest 1 Round 1	1.90
Success rate per times Contest 1 Round 2	2.25
Success rate per times Contest 1 Round 3	2.85

Test Statistics[a]

N	10
Chi-Square	4.969
df	3
Asymp. Sig.	.174
Exact Sig.	.175
Point Probability	.003

a. Friedman Test

Table A - 34 Friedman test for 3 rounds contest of tricks training

Ranks

	Mean Rank
Score per times Contest 1 Round 1	1.80
Score per times Contest 1 Round 2	2.40
Score per times Contest 1 Round 3	1.80

Test Statistics[a]

N	10
Chi-Square	2.595
df	2
Asymp. Sig.	.273
Exact Sig.	.304
Point Probability	.012

a. Friedman Test

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