

THE UNIVERSITY OF NOTTINGHAM

Hybrid Desktop

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I declare that this dissertation is all my own work, except as indicated in the text:

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Abstract

Hybrid Desktop is a new studying environment which aims to make good use of the advantages of both physical and electronic desktops by using the Mixed Reality technology. Students can use their smart phone and a simple VR headset to get involved in this new world where digital study materials are integrated with a physical desktop and physical interactions are supported. Students are able to view their electronic lecture notes, control the lecture notes by using a Leap Motion (a device which senses the hand and fingers information), annotate their documents, check their to-do list, etc.

This dissertation presents a literature review of existing Mixed Reality workspace applications and relevant research in Education, outlines the requirements and designs, and details the implementation of an Unity Project to build the Augmented Reality Scene, a C# program to recognize the gestures and convert Leap Motion positions to readable information, a socket program for transferring information between Leap Motion and iPhone, a web-based system for making electronic annotations and managing task lists, and a Python Web Crawler to get the latest weather information.

A study performed at the end, found that most students would like to study in such an environment in the future. They reflected that the Hybrid Desktop concept is promising, but also highlighted some current limitations. For example, the gesture controls should be more flexible, and a comfortable headset is needed, which can provide a broader and clearer view. Based on the feedbacks from university students, there is a discussion of some further improvements and potential implementations.

An overview of the features of the implemented system can be seen here:

https://youtu.be/Sr_5MuuKzYA

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Chapter 1

Introduction

Desktop metaphor developed by Xerox PARC led visionaries to predict the “paperless office”, but the problem is that people like paper too much. After that, Pierre David Wellner from University of Cambridge tried to provide a Computer Augmented Environment for paper by using video camera and electronic projector [1]. In his project, three main functionalities were achieved, Calculator, PaperPaint, and DoubleDigitalDesk. Calculator enables user to select some numbers which could be recognized by the camera, and the answer will be projected to the paper after the computer finished the calculation. PaperPaint allows user to move a copy of anything he writes on the paper. DoubleDigitalDesk is a remote digital desktop which enables user to cooperate or play games. At the end of his research, Pierre discussed some potential directions for continuing work on this Digital Desktop and Augmented Environment, like getting rid of the tablet which used to allow pointing at projected images, and implementing electronic annotation of paper documents. With the booming of Mixed Reality technology, advanced devices and software development kit, the current technology provides more opportunities for developing new digital desktop. And the advanced VR headset improves the user experience and provides more options for developer to introduce more common computer functions (like task manager and weather forecast) into the virtual world.

Hybrid desktop is a project aimed at improving the university students studying and working efficiency and providing them a brand-new way to study. Hybrid means a combination of physical and electronic desktop. Compared with electronic desktop, it is hard for physical desktop to get access to large amount of materials, and especially when the final is approaching, students need to carry heavy paper with them which will be a burden, and physical documents are easy to lose and the capacity is limited as well. As time goes by, students will have more and more notebooks, and it is also difficult for them to manage these materials. If they only work with electronic documents, it is not convenient for them to take notes on the graphs, and highlight some important points. When people are drawing something, keyboard and mouse are especially hard to control. However, physical desktop can fix this problem. It is easier to interact, because using a pen to write down notes and draw diagrams can provide a much simpler way for students to express their idea accurately.

In conclusion, hybrid desktop will take advantages of both physical and electronic desktop. Users are not only able to get access to their module’s PDF or PPT slides and view them in an electronic way, but also interact with their physical documents (books and notes). This project is going to provide a comprehensive environment for students to study.

Chapter 2

Motivation

Based on 2016 augmented and virtual reality survey report [10], within 10 years, AR and VR would produce revenue in the tens of billions of dollars. However, the majority of participants respond that the lack of compelling content and user experience was the most significant obstacle for AR/VR industry. And two-thirds of participants expect the AR market to surpass VR in revenue. Game, movies and television, live events and education are the top four sectors which respondents expect to see. But the biggest obstacle to mass adoption of VR technology is user experience and cost. These results indicate AR/VR market is full of potential, and these products should be more linked with people's daily life.

The ultimate goal of Pierre David Wellner's research on interacting with paper on digital Desktop is instead of making us work in the computer's world, let us make it work in our world. In conclusion, the motivation of this project is to enhance the students after-school learning experience by allowing them to interact with physical and electronic materials by using Mixed reality technology. Although there has already existed some application which fits the idea of working with Mixed reality, the price and weight of the device are such a burden for users. So, developing a hybrid desktop based on smart phone which is a device that almost everyone has is very worthwhile. It ensures that most students are able to get access to it and they do not need to buy any other devices, using their portable smart phone is enough.

Chapter 3

Background Information

3.1 What is Mixed Reality?

Virtual Reality has been differentiated from Augmented Reality in 2014 by Tech Times. Virtual Reality is a virtual world that users can interact with. And Augmented Reality is users will continue to be involved with the real world while interacting with virtual objects around them. Nevertheless, as more and more companies claim that their products utilize either advantage of the Virtual Reality and Augmented Reality. Another technology has entered the picture: Mixed Reality. All these three technologies are developed to fool our brains and make our minds perceive objects as part of our reality that we are involved in. Compared with Virtual Reality (VR) and Augmented Reality (AR), Mixed Reality has the following special characteristics:

1. VR has no direct interaction in the real world, the users are interacting with the pre-programmed digitized world which is delivered through the device. However, in Mixed Reality, the users are actually involved with the real world and interacting with the both real and digitalized object.
2. In AR world, images are initialized to overlap with the user's reality and merge with it. But it does not exactly care whether it fits in or not. It is simply there, but not affected by the users' movement. But in Mixed Reality, these objects will respond to the change of users' status. For example, when you walk far away from these images, and these images will get farer. They are able to change the angle by sitting, turning around or walking away. So, it will help the users to believe that these objects are real, and they exist around them.

That is why Mixed Reality is always presented as the technology which is aimed at taking the advantages of VR and AR, and immersing the user in a pre-programmed world while actually being anchored in the real world.

3.2 Existing Mixed Reality Application

The trend is more and more companies are focusing on Mixed Reality workspace. It will totally change the original working and studying behavior, improve the efficiency and help people to understand their work better. The following sections are some strong related researches about Mixed Reality Application which helps the design of Hybrid Desktop.

3.2.1 Mixed Reality Desktop

Based on some literature survey, a tangible mixed reality desktop has been implemented for digital media management in San Jose[18]. That system can support

for gesture-oriented interactions in 3D space. Instead of attaching some devices to detect user's hand or finger, that system uses computer vision techniques for hand detection, and location. But the limitation is it is a computer based program and it cannot provide the user an experience as immersed themselves in their real surroundings, and the gesture recognition is also limited. Inspired from this project, Hybrid Desktop is trying to discover a new way to interact with the real world in a more user friend way.

During the Leap Motion Hackathon 2015, a group was trying to augment a physical display with virtual widgets which strongly shows the prospect of interacting with real world in a brand-new way. They built an AR screen in the Oculus and use Leap Motion to interact with the windows. [3] This is labeled as the future of workspace and lots of people are eager to see what is going on. This new workshop frees people's hands and turns the 2D workspace into 3D. All the browsers can be dragged from the screen and float in the air visually. Users are able to interact with these digital objects by their hands.

"Augment" [4] is a company which is aimed at revolutionizing the way people preview, and edit. They are trying to display the designer's 3D model to the real world by using augmented reality. Their new application called augment desktop provides a new experience and makes it easy and efficient to adjust model, gives people the freedom to configure materials for their work.

Except these applications, HoloLens[5] which is developed by Microsoft gives the Mixed Reality development a new chance. HoloLens is the first self-contained, holographic computer, enabling the user to engage with their digital content and interact with holograms in the world around them. It goes beyond the desktop and immerses into people's life. The aim of this product is to bring ideas to life and transform the ways people communicate, create, collaborate and explore. Another similar headset Meta2[6] which is aimed at accessing to digital information and directing hand interaction with holograms. These two headsets have developed quickly last few years, made so many changes and overcame a lot of technical problems. But these two devices are sold in limited quantities and high prices. So not every university students are able to afford them.

3.2.2 Mixed Reality Application in Education

A search about Mixed reality in education, entertainment and training[19] indicates that the free learning education experience is the key to inspire curiosity, and it can help to create an optimistic attitude towards study. In the Mixed Reality space, the new world is equipped with a heightened sense of presence rather than just the projected image display, it surpasses the traditional visual projection system and presentation of information.

In the Arts Center of Christchurch New Zealand, a research[20] related with turning an empty space into an Augmented Reality world for educational experience. They asked people to use see-through head mounted display to view 3D models of scientific data collaboratively, and ask them to analyze the data and work together. The results show that Augmented Reality is very suitable for collaborative tasks, and through this new experience, users can find the interface more intuitive and conducive to real world collaboration. It indicates that AR interfaces can offer seamless

interaction between real and virtual world, and more researches should be involved in this field to explore how these characteristics can be applied in a school environment to enhance students studying experience.

Besides, desktop virtual reality has been considered as a powerful new technology for teaching and research in Industrial Education[21]. Because it enhanced the comprehension, increased student's learning performance, and reduced training time. This fully immersive experiences offer a convincing illusion of participation and attract more people to changing their studying habits. However, there still presents both challenges and opportunities for researchers interested in this technology. The primary challenge is that there has been no conclusive research data to guide the design, and how can these applications relate with students learning process. More detailed research should be done to help this technology make more contribution in Education industrial.

In conclusion, Mixed Reality Application used in Education is significantly necessary for improving the existing study experience in university.

Chapter 4

Project requirements

4.1 Hybrid Desktop with Mixed Reality survey

At the start of the project, a survey has been done to find the current requirements about AR/VR application among university students.

The survey involved the following questions: 1. Which way do you prefer to express your idea? 2. How do you usually revise your lecture notes? 3. If you don't like physical materials, which are the possible reasons? 4. Would you want to have an electronic bookshelf to organize all your course materials? 5. Where do you prefer to study? 6. Do you love your current study habit? If not, why? Participants are able to access this questionnaire by surveyMonkey (an online survey tool)[11], and this web link is shared by Messager (A chat tool created by FaceBook).

In October 11th 2016, 88 university students completed this survey. And the result(shown in Figure 4.1) indicates that although more people prefer to work with physical materials, most people work with electronic documents during their real study time. Participants think the reasons is physical materials are easy to lose and hard to organize, and the reason for their preference with electronic desktop is they can share their electronic copy easily and manage these documents on the cloud which provide wider and easier operation with documents. But the reason for their preference for physical materials are they are express their ideas easily and write something down on the notebook is convenient, they can write it down anywhere and anytime.

Because of the fast development of portable device, more students prefer to go to lecture with their iPad and take notes with iPad as well. Laptop is heavy to carry and the human nature is they prefer light and convenient belongs. The paradox is when they study at home, they prefer to study with laptop. Because the undeniable fact is laptop is much more powerful and it provides larger screen which gives better user experience. Furthermore, 68.18% students are not satisfied with their current study habit, and 78.3% of these people think the main reason is they are lazy and need someone to remind them all the time, so this project decided to provide a AI servant which can be served as an assistant to remind students stay focused. And if there is an electronic bookshelf (document list) to help them organize materials, 90.91% students are willing to have this application.

In conclusion, the current study habits among university students have some problems and because of the fast development of internet, electronic materials became an inseparable part of university study. The university students need a workstation

which can provide them the clearest structure of their materials, give them the easiest access to all their documents and it should be easy to carry and set up. Based on this survey, we can conclude that if we can figure these problems out, the future of Hybrid desktop is promising. Besides, different students in different major will have their special needs for the course. For example, mechanical students hope to see their models in a 3D way, data science students hope to visualize their data. By using Mixed reality technology, these dreams can come into reality.

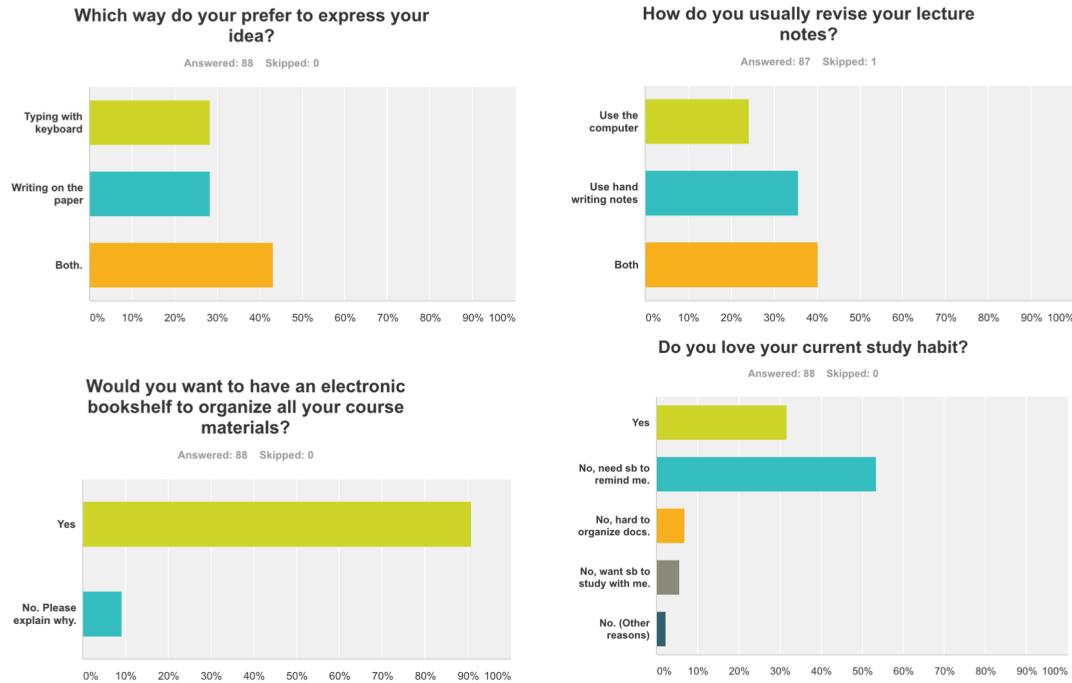


FIGURE 4.1: Some survey results among 88 university students

4.2 Scenario

Based on the background information and the survey, this project proposes the following scenario:

When students put their phone in the Google Cardboard or any other Cardboard they prefer, and wear their VR headset, by recognizing the “Hybrid desktop QR code”, all the digital objects like PDF/PPT reader, AI servant and bulletin board will display on the physical desktop.

AI servant is served as an office assistant which is a user interface that assisted users by the way of an interactive animated character. It is used to show users the status of imageTarget, their gestures recognition progress and give students the information of their hands to help them perform the targeted gestures accurately. And it can also be considered as the communication tool between the systems and devices.

And bulletin board is going to show user’s daily tasks and some general information about weather and date. Users can create and manage their tasks through the hybrid desktop website. This website can also be used as a tool for electronic annotation. When the user is typing in the textfield in the annotation web page, their text will

show on the electronic annotation box automatically. This hybrid desktop website is served as a platform to control any data which belongs to the users.

There is a large PDF/PPT reader on the right side of the desktop. Students can view their module materials in this screen or they can switch the slides by clicking some buttons like moving to the next slide or move back to the previous slide and the relative module materials will display in the PDF/PPT reader. In order to change the size of the PDF reader, the users can do a clockwise gesture, and it stands for zooming out the PDF reader. The gesture of counterclockwise stands for zooming in the PDF reader. By performing gestures, the PDF reader should be able to change position as well. Once, the camera recognizes the marker, it will display all the digital objects, even if it loses the track of the image target. So, when the user moves their head, they do not need to worry about there may cause the mess of these digital objects.

4.3 Proposed functionality

4.3.1 AR document list and PDF reader

Document list is used for displaying all the available materials for students. And there will be an arrow which points to the displaying PDF, so students can check what module he/she is studying in a clear way. Besides, it enables user to select documents by hovering their hands above the switch button. One of the special functions is user can write down the code of the documents to display that material, and the code of documents should be the same name on the documents list. The selected PDF will be displayed in the PDF reader, and it will enable user to change the size of the reader, and switch slides. It should be better if the users are able to move the PDF reader.

4.3.2 Bullet board

Bulletin board is displayed in the most noticeable place, so the project aims to let it give students the information which they need to check most frequently. For example, the weather, date information, and their tasks. Students can manage these tasks by using the hybrid desktop website, and all the information presented on the bulletin board should be the latest one.

4.3.3 Artificial Intelligence servant

AI servant is used for managing and reminding user's tasks and documents. The survey shows that most students are not satisfied with their study habits, so AI servant can be used to remind the students when they are not highly focusing on study. And it will add more fun to the desktop. It will also be an interface to tell students what gestures this application is recognizing and whether the imageTarget is trackable or not.

4.3.4 Electronic annotation displaying system

Users are able to make annotations for both electronic and physical materials, so these annotations need to be located accurately when the system retrieve the data. In hybrid desktop's website, users can check their notes by category and choose

which one to display in the virtual world. For better user experience, these electronic annotations should be able to move by the physical documents as well. So, these annotation is not positioned in the same place all the time.

4.3.5 Hybrid Desktop Website

This website is built for managing user's data and taking annotations. This website breaks the barrier of devices. In this project, because these annotations are stored on web server, if users want to make annotations, they can use whatever they want. For example, they can use their phone, pad or even raspberry to get access to this website and make annotation. Besides, this website has a further section which is waiting for future implementation. Users are able to send message to the developer and tell them what new features they want, and what improvement they hope for.

4.4 Platforms and Tools

Based on the proposed functionalities, the project selects the following platforms and tools.

4.4.1 Unity as developing platform

Unity has introduced built-in support for certain AR/VR devices, and it is the most popular and powerful platform to build a AR/VR application. And Unity can be considered as the multiplatform game engine. With Unity, developers are able to get one-click deployment to the full range of mobile and VR devices. The current platform of this project is mobile devices, based on Unity, the project does not need to use Android Studio and Xcode at the same time to develop these two mobile applications. It can build and run on both Android and IOS. So, this project chooses Unity as the development platform.

4.4.2 Leap Motion for supporting gestures

The future of virtual reality is truly immersing yourself in the virtual world with your hands. Leap Motion[12] is the device that helps the developers to reach this goal. This device senses how user naturally moves their hands, and gets the hand information like location of user's finger and recognizes some sample gestures (clockwise circle, swipe, and etc). The users are able to interact with those virtual objects just like they do in the real world. So, it is useful for deceiving users' sense that they are actually interacting with these real objects. Leap Motion is supported for VR headset like Oculus and Mac or other PCs. For better interaction with hybrid desktop, this project will take the advantages of LeapMotion and allow user's specific gestures to control the digital objects.

To explore Leap Motion SDK with standard tracking to control PDF reader by using different gestures, and interaction with electronic documents. It needs socket communication to support the data transfer. Furthermore, it requires new function for using Leap Motion's hand information to display and control virtual objects.

4.4.3 Software development Kit

There are two competitive open source augmented reality SDK, ARToolKit[7] and Vuforia[8]. Compared with ARToolKit, the special functionality of Vuforia is Vuforia has virtual buttons which allows some touchable zones in the tracking image and enable interaction with the device. Besides, Vuforia can support more platforms like windows app, and also for MS HoloLens. Although the current implementation is with IOS, future development will be run on other AR devices like HoloLens and Meta2 which can provide a clear and wider view. Because of the wide spread and relatively cheap price of smart phone, running hybrid desktop on smart phone gives more opportunities for students to get involved in this new experience.

Besides, vuforia has four advantages of being a leading AR platform: 1. Unparalleled reliability which enable vuforia delivers best-in-class computer vision, and providing robust experiences in a large amount of environments. 2. Creative empowerment which offer developers the creative freedom. 3. Maximum reach which supports most leading platforms. 4. Advanced vision which enables developer to use the most common thing as the marker. Based on all the concerns and superiority, Vuforia SDK can be considered as a better choice for this project.

4.4.4 Programming Languages

Scripting is an essential component of the project. Because this project chooses Unity as the developing platform, and Unity is preferable for C#. Considering about the maintainability and integrity, C# is preferable for this project as well. Then listing out the possible problems this project needs to figure out and thinking about whether C# is suitable for solving this problem.

The disadvantage of Vuforia is it cannot locate user's finger and return the track of user's finger. But when implementing with PDF reader like using some gesture to control the PDF reader, the track of user's finger is an essential information. To solve this problem, Leap Motion is introduced to this project. Nevertheless, Leap Motion cannot support with iPhone. So, there should be another implementation with exchanging information between Leap Motion and iPhone.

There are two good programming languages which support this problem, C++ and C#. At first, I choose C++ API of Leap Motion instead of C#. The reason is the functionality of API between these two languages have no difference. But Leap Motion C++ API is both recommended and supported for Xcode on macOS and Visual Studio on Windows, but Leap Motion C# API is strongly recommended to use with Visual Studio on Windows. Later, some problems with the implementation of C++ occurs. C# client in Unity is not the best choice of C++ server, and mono can solve the problem of developing C# application on macOS. Mono[9] provides the necessary software to develop and run ECMA CLI, C# and .NET client and server application on different platform. It perfectly solved the inconvenience of developing C# application on MAC.

4.4.5 Database selection

For the selection of database. At first, MongoDB was chosen to be the database for this project. However, after weeks of exploring the data structure of the project,

I decided to change the database to MYSQL. The reasons are as follow: 1. It requires complex multi-row transactions, and MongoDB is not a drop-in replacement for legacy application built around the relational data model and SQL. 2. In MYSQL, related information may be stored in separate tables, but associated through the use of joins. And data duplication is minimized which is suitable for this project.

So, this project selects the MYSQL as the database, and it needs to implement data storage and interaction with MYSQL and Unity. These data can be user based tasks, and the electronic annotations should be stored in MYSQL database as well. When users are making electronic annotations, information will be updated to the MYSQL database simultaneously, and the annotation box in hybrid desktop will have a HTTP GET request to get the information and display that in the Unity project. PHP files will be uploaded on the server, and it will be used to request data from MYSQL databased. So, by requesting these web pages, the bulletin board can get user's detailed information which is more suitable and easier to implement.

Chapter 5

Design

5.1 User Interface Design

This section is divided into two parts, graphics design which will focus on what the user can see and why they displayed in that order, and gesture interaction design which will focus on what gestures the user are able to perform and why this project chooses these gestures.

5.1.1 Graphics design

Because Leap Motion system used the right-handed coordinate system. So, when designing the user interface, this project assumes that most user are right-hander. But if some users are left-hander, this virtual environment should not cause much inconvenience for them. The QR Code is selected as a starter imageTarget for the project. And based on the right handed coordinate system and student survey, this project decides to display the PDF/PPT reader on the right side of desktop which obeys the rule of user friendly.

Below the PDF/PPT reader there is a 'blackboard', it is used for displaying the available documents. It saves the space on the desktop and provides a convenient way for user to get access to all the materials. The PDF reader is displayed vertically, and the document list should display horizontal to the desktop rather than vertical to the desktop. The reason is when user is looking at the PDF, their line of sight is horizontal to the desktop. If the document list is vertical to the desktop, the user needs to move their head to check the information. But they are wearing the headset, moving head always means that they will have more possibility to lose track of the imageTarget (imageTarget is on the left side of the PDF reader but if the document list is displayed vertically, it should be on the right side of the PDF reader). So, in order to keep the system more stable (even lose track of the imageTarget will not let the virtual object display, but may still have some possibility to cause a mess).

On the left side of the desktop, user can place their own physical materials and personal belongs. The laptop which is used as the Leap Motion's server and the Leap Motion device should be displayed on the right side of the Laptop which fit the right-handed coordinate system. The design of the bulletin board is focused on displaying the simplest thing but needs to remind user very often. So, this project chooses to display weather, temperature, date and tasks. Weather and date information is one of the most significant information everyone wants to check, and putting this information can avoid them to check it on their phone. Listing the tasks in a striking place is a way to improve students study efficiency. Because in the survey,

students reflect that when they can see their tasks all the time, they will have a motivation to follow their task and focus their mind.

The background of the bulletin board is a transparent image. Transparent background can let user be able to see what is behind the bulletin board, and this experience can help user to feel that this object actually immersed in the real world compared with an opaque background. Also, the desktop will display two large digital objects which are bulletin board and PDF reader, if both two are opaque, the view of user will be limited. And they will feel that there is a barrier in front of them which can cause a sense of repression after working in this environment for a long time. The design of the project can be explained like the following figure:



FIGURE 5.1: User Interface Design

5.1.2 Gesture interaction design

This application will be used for university students and its main goal is to help with their studying habit, so the gestures should be easy to perform and their meaning should be highly matched with the performance. Then, it needs to define the possible gestures which can be recognized by Leap Motion, because easy and simple gesture recognition rate is much greater than complex gestures. Some scenes are imaged: When people are performing zoom in or zoom out command, there are two usual gesture:

1. Using thumb and index finger to perform a stretching gesture for zooming out, and shrinking gesture for zooming in.
2. To do a clockwise gesture.

Compared with finger interaction, the application prefers hand interaction. Because the size of finger is much smaller than hand, so the capture of data will be less accurate. Also, in the Leap Motion's API, it has the gesture recognition for clock wise. So this application defines that clockwise gesture can be used for controlling the size of PDF reader.

Another import control of the PDF reader is switching the PDF to the next page

or back to the previous one. The most natural way to do this command is the swipe gesture. It is not complex to implement, the Leap Motion device can get the hand position, by analyzing the movement of hand, the application will be able to recognize these gestures. But for switching the PDF, when asking people which gesture they usually use for switching the PDF, they will have no idea. Because in real world, there is always a button for switching the PDF. So based on the user experience, the project defines a virtual button for doing this switching command, and the gesture for user is hovering their hand over this button.

5.2 System Structure design

In this section, it will discuss the project's framework design and the database design. Graphs will be used to illustrate the relationship between each component.

5.2.1 Framework design

There are three basic components of the project's framework one imageTarget for all digital objects, another imageTarget for annotation box and a Leap Motion Client Game Object. The following figure is the design of the framework, the round rectangular stands for the basic components and each ellipse stands for a digital object, and the rhombus stand for the backend action.

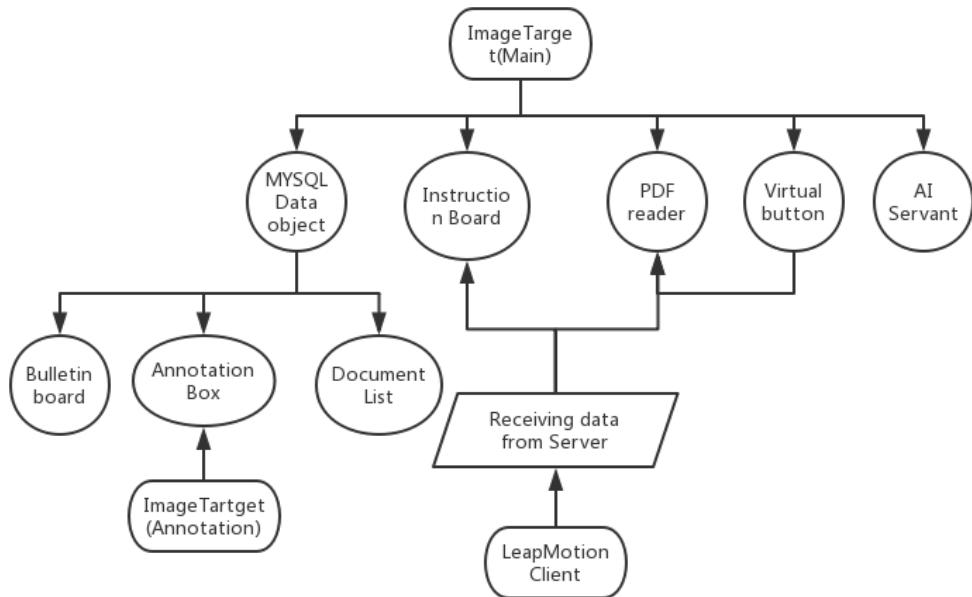


FIGURE 5.2: Hybrid desktop framework design

ImageTarget is the foundation of the project, and all the digital objects should belong to it and inherit its properties. What needs to be explained in special is the Annotation Box, it does not only belong to the ImageTarget(Main), and belongs to the ImageTarget(Annotation) as well, because it needs to move with another marker as well. In different situations, the project does not know where the physical documents are and in most cases, each physical document will have different appearance.

In order to improve the user experience, the project introduces another imageTarget, and let the annotation box inherit that. So, the application needs the user to put this special marker on the physical document, it can be a sticker or a printed symbol. So, the annotation box can appear in any place that the user wants. The main imageTarget is displayed in the extended tracking mode, so all the child of this object will still display on the desktop even if the camera loses track of the image. For the Leap Motion Client Game object, the project separates it from other components because from the functional aspect, this one is independent and it can also avoid some special cases. When the server is not set up or the server crashes, it will not cause trouble to other objects. Virtual button is a child of the ImageTarget (Main), but it interacts with another child of the ImageTarget (Main) which is PDF reader.

5.2.2 Database design

The E-R model of the database is shown in the following figure:

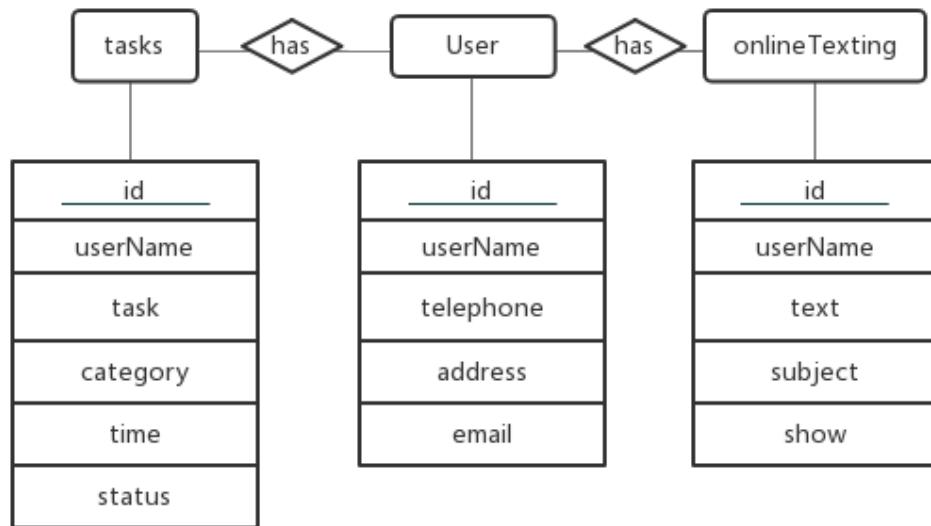


FIGURE 5.3: Hybrid desktop database design

Table User is the foundational one. Because each Hybrid Desktop's data only belongs to one user, so these three table will be connected through the userID (primary key). Each task must have an id, userName, task, category, time, and status. And it will connect with User by userName. Id is an automatically increasing index, time is a time stamp, and will insert by MYSQL program based on the current time. Status will have a default value which is 0 stands for that task has not been finished yet. And the table User is just used for storing the basic information of the user. For the online Texting table, it will connect with User by username. The show property stands for whether this annotation should be displayed in the annotation box or not, and it will have a default value which is 0. Besides, every property in the online texting should not be null.

Chapter 6

Software Implementation

Every AR project has a marker as a imageTarget. All the objects which are inside that imageTarget will inherit its attributes and display on the screen. For the image target behavior, this project enables extended tracking. The reason is the view of physical desktop is board and wide, users cannot stay their head in the same position steadily and do not move. If the application disables extended tracking, it will cause the problem which is when users move their head, it will lose the track of imageTarget easily and then the view will mess up and lose some objects. This extended tracking mode guarantees that the application will register the objects when the camera recognizes the marker at the first time, and then holds them.

Another problem caused by this mode is from the user aspect, they cannot see the code and do not know whether the camera has lost the track of imageTarget or not. So, the application introduces the instruction board. There is a colored circle for indicating whether the camera has lost the track of imageTarget or not. If it is red, that means lost track of the image. And if it is green, it means the camera is tracking with the imageTarget.

6.1 PDF reader and Document List

There is no PDF displayer developed by Unity. And although there is a PDFReader[13] in the assetstore, it is not suitable for this project. Because that PDFReader cannot be converted to a video see through type. In order to fix the problem of displaying PDF in the video see through type, there are two possible solutions to make a new PDF reader. The first one is to use webview, and assetstore has an available webview package. Because pdf can be stored on the server, the pdf can be displayed in the webpage. The second solution is to convert PDF into image, Unity has image displayer.

Based on some researches and advice from supervisors, the second solution is preferable. Because it is more flexible to handle with image than webview. For example, the implementation of switching PDF. If the PDF is displayed as an image, we just need to change the image. But for webview, we need to scroll the webpage which is harder to implement. Another reason is webpage needs to load the full PDF before being available to read, and the user experience is mainly depended on the speed of internet. But for image solution, while user is reading the previous slides, we can download the next images. And it can ensure that when they are switching these slides, all the information has already been downloaded. It guarantees the speed of displaying PDF by decreasing the time of loading each slide.

So, each pdf will be converted into image and all the images of one pdf will be stored in a List<Sprite>. If the user wants to switch to next slides, image component will display the next image in List<Sprite>. If the user wants to switch to another module's pdf, current pdflist will be assigned to a new List<Sprite> which is related with the module the user chooses.

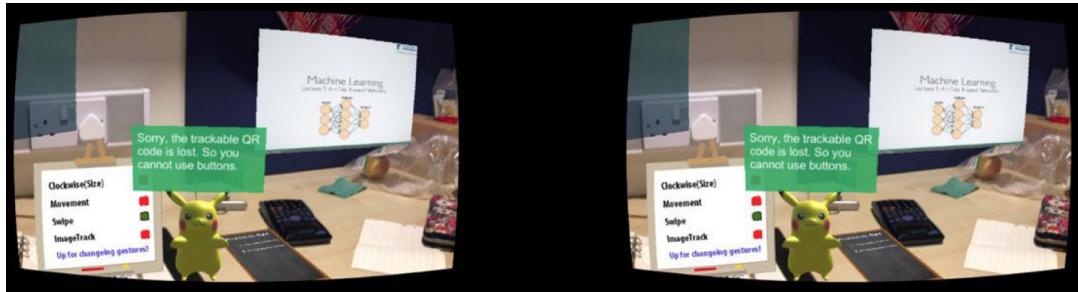


FIGURE 6.1: Implementation of PDF reader

Document lists will contain all the available materials, and it is displayed in a canvas as well. There is an if statement to check which PDF is displaying, and then update the string. For example, the user is viewing "G53MLE", when the program finds this course in the documents arrayList, it will convert the string "G53MLE" to "-> G53MLE". And from the user aspect, arrow point tells them title of PDF/PPT which is displaying.

6.2 Hybrid desktop website

In order to get access to this website(url), the user can not only type the URL in the web browser but also scan the initial QR code. Hybrid desktop website is used as the admin of this application. It provides a chance for the user to alter the database and get some basic information of this application. It is built with simple HTML, PHP and AngularJS. Besides, the website has a python Django server whose port is 8080 for making a python crawler to grab the weather information. It has four main sections: Introduction, task manager, online annotation and further.

Introduction and further section contains some simple HTML paragraphs and it is only used for showing new user a sketch of Hybrid Desktop and some potential implementation. Task Manager is the control board of tasks, all the tasks are displayed like a sticky notes. And at the top of the website, the user can type their new task and behind the screen, some javascript will be used to check whether the user has actually typed something and if the user selects "Please select your category", the user will be able to enter his/her new category, but if he/she selects something, the input box will hide.

These are coded with AngularJS's SCOPE. The advantage of using AngularJS is it will not reload the page which can speed up the processing time and improve the user experience. So when the user click the delete or finish of the sticky notes, the AngularJS code will send an HTTP request to execute the MySQL sentence and send the latest tasks back as an JSON array. Then the AngularJS code will assign these data to the SCOPE[17] which is an object that refers to the model of the application. It plays as the role of bridge between the view and the application controller which

guarantee they are linked and update the value simultaneously.

Another important section is Annotation, it is used to link the “keyboard” with the “Hybrid Desktop”. Based on the previous survey that people prefer real keyboard, Annotation part is to create a platform for user to type in what they want and display that in the virtual annotation box. That page will have a 3 seconds interval to send a HTTP request to update the MYSQL database which enable that the virtual annotation box can retrieve the latest data.

Below that typing section is an existing notes showing section. By selecting the category, the AngularJS code will request the PHP backend to retrieve the notes which belonged to the specific category and sent these notes back as a JSON array. By using ng-repeat, the user can see the selected notes without refreshing the pages. And the status button is used for helping the user to decide whether to display that note in the virtual world.

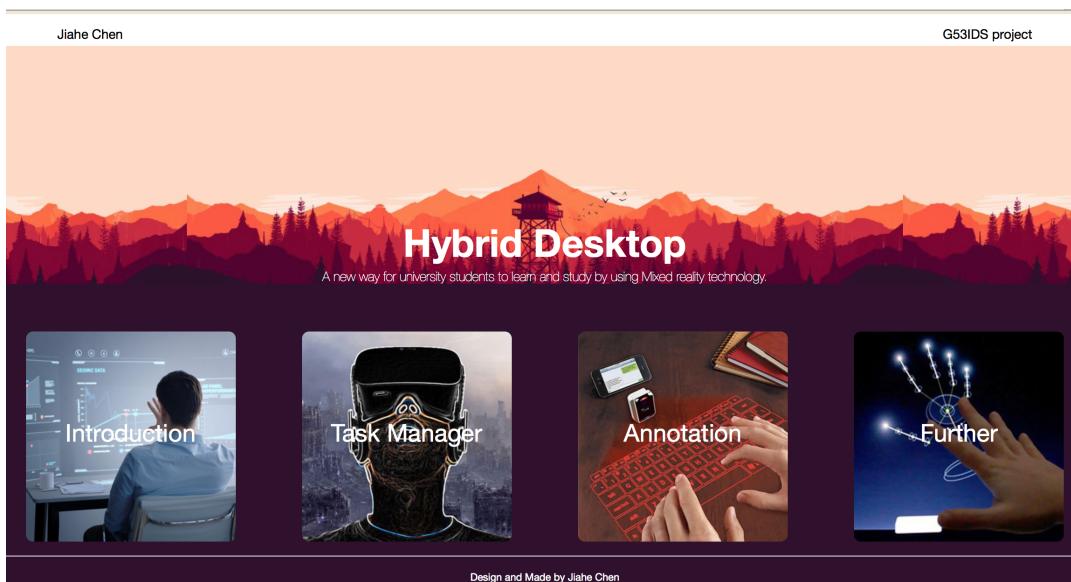


FIGURE 6.2: Hybrid desktop website main page

6.3 Bulletin board

This project uses Unity’s Canvas to build the Bulletin board. Bulletin board has a HTTP GET to retrieve the existing tasks in the MYSQL database. The Bulletin Board is only used for displaying. Besides the displaying of tasks, the Bulletin board also shows some information about the weather and date. The weather is based on a python crawler to grab the data from BBC weather. The application will also get this weather information by a HTTP GET request.

In order to get the latest tasks and weather information, it will call the HTTP GET request every 5 seconds which ensure that the display of tasks keeps synchronous with the databases and BBC weather. That means when the user add new tasks or the weather, the Bulletin board will refresh automatically. Also, the URL of Hybrid Desktop should be display as a string on it, and it will be more convenient for users

to get access to it. The following figures show two implementations: one is the task manager page in Hybrid Desktop, and another is the bulletin board display.

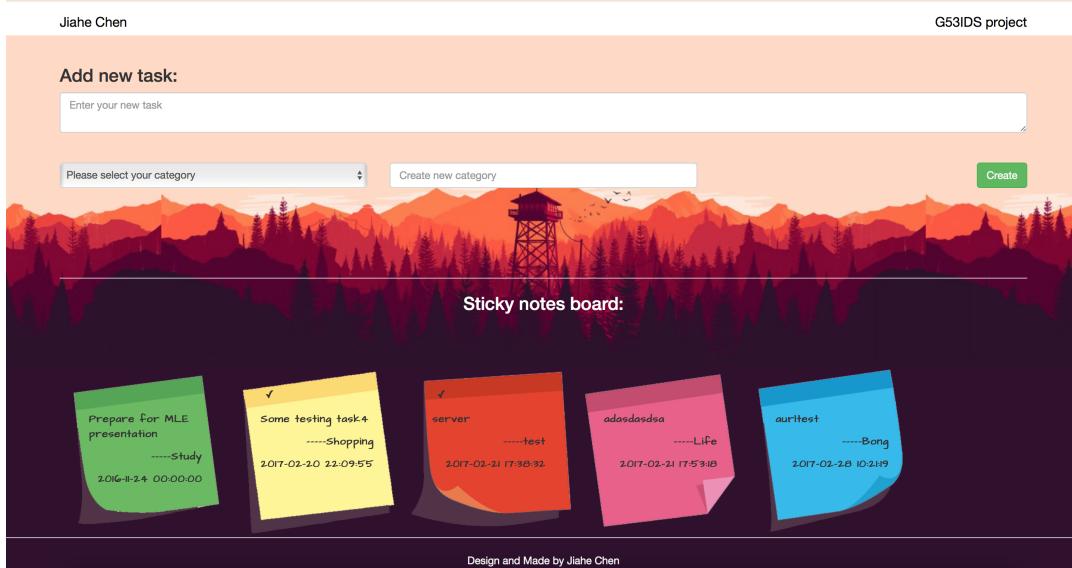


FIGURE 6.3: Hybrid desktop website task manager page

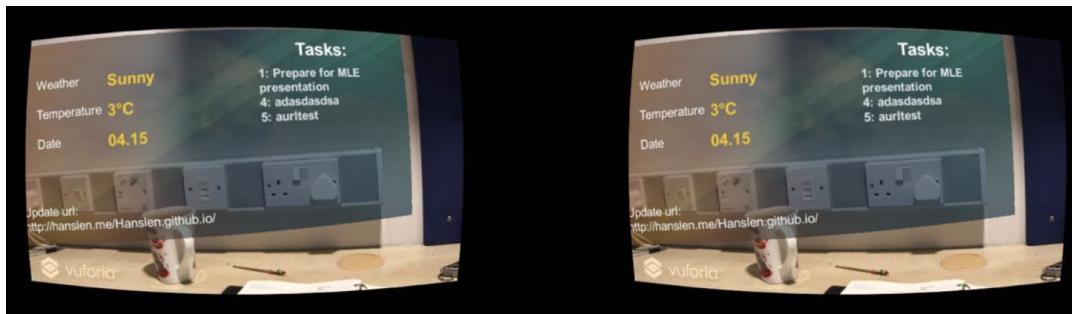


FIGURE 6.4: Implementation of Bulletin Board

6.4 Electronic annotation displaying system

The biggest problem of tracking these electronic annotations is where should they display. Because it should display in the correct position of the specific physical documents. There are two possible solutions: 1. Get the position of the annotation and store it in the database, when the user selects that annotation and wants to display that annotation, it requests a HTTP response and analyzes the position to help annotation display in the correct saved position. But the problem will cause by this implementation is the position is relevant to the position of camera. But each time, the physical documents may not be in the same place, and that can cause the annotation not showing above the physical document but in the wrong position.

Another solution is inspired by imageTarget. It is possible to create another imageTarget and assign the annotation box be a child of that imageTarget. So when the camera recognizes the imageTarget, the annotation box can be moved by the changing position of imageTarget. Inside the annotation box it has a script which is used

for updating what the user has typed. In the Hybrid Desktop website section, the methodology of online Annotation has been explained. And those AngularJs code ensures that the database contains the latest notes which the user is typing. And inside the annotation script, a WWW object of C# will get the JSON object which contains the online annotation data and assign it to the title and annotation GAMEOBJECT's text component's text value. This implementation helps the annotation box contains what the user is typing or wants to display and it can be moved by the imageTarget.

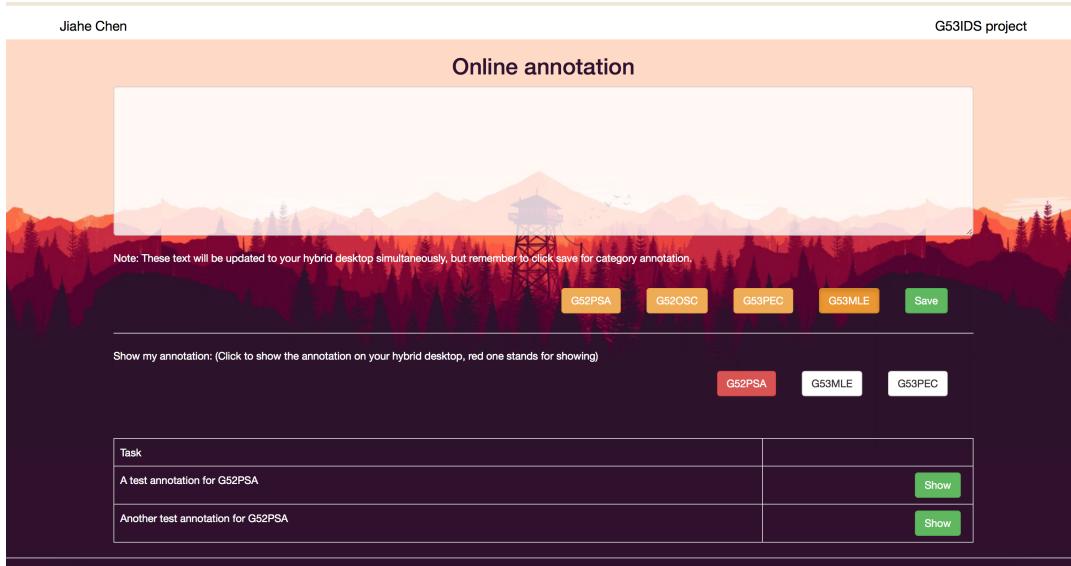


FIGURE 6.5: Hybrid desktop website online annotation page

6.5 Leap Motion with iPhone

Unlike Oculus which can use the Leap Motion API and Unity package directly. The current API of Leap Motion does not enable the developer to transfer data between Leap Motion and iPhone, but Leap Motion can be connect with Laptop and receive hand information. In order to control iPhone by using Leap Motion, socket communication could be used to transfer data. So in this section, some codes and methodology will be explained for how to make full connection with Leap Motion and iPhone.

6.5.1 Socket communication for server(PC) and client(iPhone)

The System.Net.Sockets namespace contains some available socket interface and provides a chance for connecting Laptop with iPhone. In this Socket class, synchronous mode will be used because what the iPhone application(Client) needs is to perform receiving data wait until the Laptop(Server) gets data, transfers them to an identifiable command and sends it to the client. Synchronous socket enables this server application is suspended until it connects with a client. [15] In a similar way, when the client is connected with the server, it will be suspended until the server return a response which contains a command.[16] Because the application does not split into multiple independent tasks and servers, and it only has one thread for handling data. It is clear that synchronous socket is much more suitable than asynchronous socket.

The basic principle of this implementation is like the following figure:

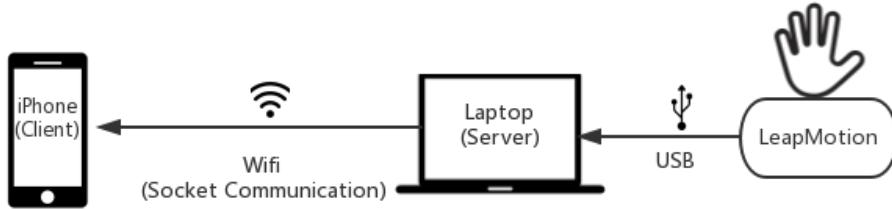


FIGURE 6.6: Leap Motion with iPhone data transfer model

6.5.2 Coordinate system and Motion tracking data

The coordinate system that used by Leap Motion system is right-handed Cartesian. In this project, users will need to put Leap Motion on the desktop rather than attached on the VR headset. In the virtual reality world, attached Leap Motion on the VR headset is preferable, and the reason is by analyzing these hand information, users are able to bring their bare hands in to virtual world, and what they can see and interact with is their virtual hands which is displaying by capturing their real hands and convert it to digital objects. But different from VR, this project is developed with AR technology which means users are seeing their real hands and interacting with their real hands. So because of different reference system, the position of hands will be a bit different in the virtual world and the real world. The information Laptop can received from Leap Motion is Frame Class which contains a list of tracked entities, and the entities this project are using are hands, fingers and gestures.

6.5.3 Conversion between gesture and command

From Leap Motion API, the data program can get is the position of hand and it can also recognize some simple gestures. In this program, two gestures which are clockwise and counterclockwise are selected. As proposed functionality, these PDF reader should be able to zoom in and zoom out. Clockwise is the one of the natural and convenient behavior of people to do this command. So when the Leap Motion recognizes the circle gesture, the server will send a STRING to the client which is "clockwise" or "counterclockwise".

For the swiping gesture, it is developed based on the position of the hands. When the Leap Motion recognizes that there is a hand over the device, it will start to insert its position X in a FLOAT array whose length is 10. When it gets to the array[9], it will start to update the first element(array[0]) of the array. By doing these, it can ensure that this continuous array stands for the changing positionX of hand. This array is the basic component to analyze which gesture the user is doing. If it is a continuous increasing array, the program will consider it as a swipe to next PDF gesture and send a STRING "next" to the client. If it is a continuous decreasing array, the program will consider it as a swipe to previous PDF gesture and send a STRING

“previous” to the client.

The problem will cause by only recognizing the positionX is when the user is doing a clockwise or counterclockwise gestures, it will have some probability that the array is continuous increasing or continuous decreasing. In order to avoid this wrong recognition, the application will have an enable and disable status for each gesture. For example, in the initial state, the enabling gesture is swiping and disabling gesture is circle and movement. If the user wants to change these status, he/she needs to hover his/her hand over the Leap Motion approximately 20cm (The reason for selecting this number is user performs their gesture almost between 0cm to 20cm, so when the hand is over 20cm, it can be considered as an uncommon position) for 3 seconds. When the program find that the position Y is over the defined constant, it will change the status (disable swipe and enable circle). From the user aspect, the status of these gestures will be presented in the instruction board as a virtual way. And the movement of the PDF reader is followed by the following principles:

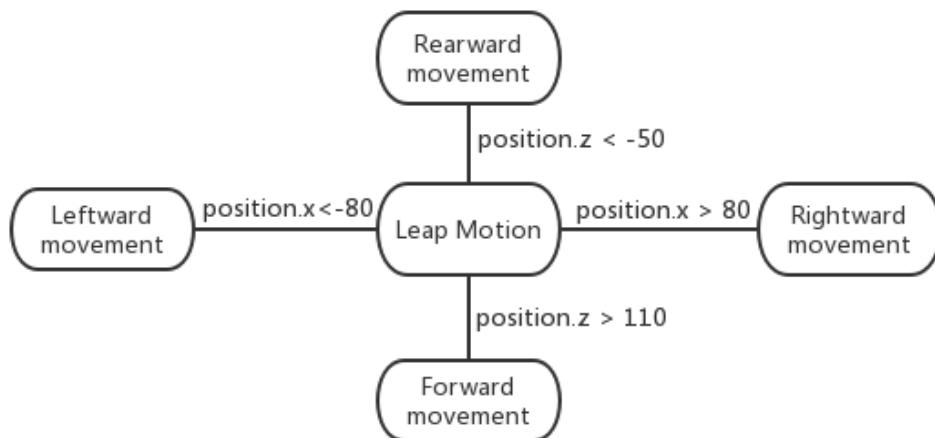


FIGURE 6.7: PDF reader movement principles

6.5.4 Performing Leap Motion controlling with iPhone

In the communication between Leap Motion and iPhone section, the iPhone can be considered as the client. And the data is received is not the position of hand but analyzed gesture of the user. This preprocessed conversion made the iPhone part more simple. It only need a switch case for implement different functions. And for future developers, they can send their gestures to the client and add more cases for performing their function. Because the client needs to be configured as the same IP as the server, and the WIFI port should not be blocked. In some WIFI environment, the C# socket communication will not work due to the problem of port prevention.

6.6 AI servant

The display of the AI servant is based on the imageTarget, and the message box of AI servant will be updated based on the two components. The track of imageTarget and the Leap Motion potential gestures. Looking back to the Vuforia script, the

project overwrites the 'DefaultTrackableEventHandler'. When the camera loses the track of the imageTarget, the message box will be updated to tell the user that it loses the track of the imageTarget. So, it will help the user has a clear view of the status of the digital objects.

Another useful implementation is the Leap Motion potential gestures. It will tell the user what possible gesture it is performing, so each time, when the Leap Motion Client receives a data from the Leap Motion, it will update the AI servant message box. Based on the user feedback, they report that it is hard to track the changing status of the Leap Motion. In order to improve the user experience, the AI servant will also be used to tell the user the status of their progress. For example, when the user wants to disable some gestures and enable others, they will hover their hands over the leap motion for some seconds. In the origin version, they will not know whether the height which the Leap Motion has recognized is available and it is registering this gesture or not. In this version, it will show the progress which is indicated by a percentage number. When the loading progress is 100%, it will start to enable and disable gestures. This is a clear view of the progress status.

Chapter 7

Evaluation of the project

The Hybrid Desktop study is a short lab based study to evaluate a new type of study environment by using Mixed reality technology.

7.1 Testing Methodology

Hybrid Desktop is tested with 7 university students which is the target group of this project. In the Hybrid Desktop study, students will be asked to perform some tasks which will take no longer than 10 minutes. And the tasks involve some gestures to interact with the Leap Motion device to control the display of documents, add tasks to the bulletin board, make annotations and experience the augmented surrounds. These tasks have been chosen to exploit system features and test whether it fits most students' habits. After these tasks, there will be a short interview about their experience.

The core structure of questions which will be asked during the interviews are:

1. Do you think the bulletin board can improve your study efficiency? If not, what information do you want to see from the bulletin board.
2. Do you think the interaction with PDF reader is easy and flexible? If not, what should it improve?
3. Do you think the management of task is easy and convenient? And In the future, the web browser will be brought to the hybrid desktop as well, so the user can interact with the website in a more direct way. What's your opinions about this implementation?
4. Do you like the electronic annotation? How to you feel about this feature?
5. How do you feel about the surroundings?
6. Except the current view is not so clear, are you willing to install this application and try to use it in your daily study? If not, why?
7. Do you have any suggestions about this project.

Besides, when students perform some interesting behaviors like they are unfamiliar with Leap Motion and it is their first time to interact with this device, what are their opinion about this device? Or when it comes with some unexpected situation, the instructor needs to monitor the students' behavior and ask the reason of their behavior.

These questions can evaluate whether students like the hybrid desktop, and make further improvement. So far, hybrid desktop has been tested among six students.

7.2 User testing and interview

The limitation of these tests is the resolution ratio. The headset this project using provides a vague view, so each time when interviewing with students, they are asked to get rid of this problem and think about if the view is good and clear, what's their opinion about this implementation.

7.2.1 Evaluation of PDF reader

First, students are asked to use Leap Motion to control the PDF reader or change slides. They are instructed to perform three gestures: Switching PDF, changing size of the PDF reader and moving the PDF reader. Besides, the test will also evaluate whether it is flexible for students to enable and disable gestures.

When they hover their hand on the Leap Motion, their behavior is not so nature, and looks stiff. The common thing is each time when they want to perform a gesture, they all try to perform exaggeratedly. For example, switching the PDF to the next slide: they only need to perform a smoothly swiping gesture, but some students do it very quickly or they move their hand from the very left to the very right. The problem caused by these unusual behavior is sometimes Leap Motion cannot capture the hand because of quick movement and unordinary position. The reason for this behavior is some students said "It is my first time to use Leap Motion and I don't know whether my gestures are recognizable, so I am a kind of exploring it." So, during the test, when students' gesture looks uncommon, the instructor will tell them how to perform more naturally and ensure their hands are in the recognizable zone of Leap Motion.

The accuracy of correct recognition of the Leap Motion gestures is 83%, and there are still some gestures that Leap Motion cannot respond very quickly. When this worst situation happens, student will choose to use the virtual buttons to switch the PDF slides automatically. They respond that these virtual buttons are very important because it seems to be an alternative for switching the slides. For the Leap Motion control, students think it is an interesting implementation and they prefer to choose Leap Motion switch rather than virtual buttons. But for enable gestures, most students have a problem which is they don't know the progress of the enabling progress (How long they still need to hover their hands above the Leap Motion). They suggest the AI servant can tell them more, for example, they can see the percentage of this progress.

Improvement: Adapted by their suggestions, the project adds the progress status to the AI servant. So, they can see the progress status will start at 0%, when it reaches 100%, the instruction board will enable "the current disable gestures" and disable "the current enable gestures".

7.2.2 Evaluation of Bulletin board

Students are asked to experience the bulletin board and evaluate the practicability of it. Firstly, some students say that they have the habit to use "todolist" (An easy task manager on phone or laptop), and they consider it as a very significant part of their study efficiency. When seeing these tasks, they tend to have more motivation to focus on study. Besides, students suggest that the bulletin board may be better

if they can customize the background of it. It will help desktop looks more personalized. When they are asked to interact with the website to manage the tasks, they think it is convenient and easy to interact. By looking at their behavior, this part is quite different from the Leap Motion test. Because every student is familiar with website, and their interaction is much more nature and common. And this part let the Hybrid Desktop has more confidence when students are familiar with these interaction, they will be easier to perform their gestures and do what they want.

Some student said, "It would be brilliant if the bulletin board could be a website itself or the hybrid desktop can provide the web browser. Because it can explosively increase the information I can get". The instructor explained the current the limitation of this implementation of iPhone, and web broswer will be developed in the future. After hearing these possible implementation, students express their satisfactory about the future of Hybrid Desktop. And they hope whether the Leap Motion can use to control the bulletin board as well. Sometimes, they want to move the position of the bulletin board.

Improvement: Provide the user a chance to customize their background of the bulletin board and enable the Leap Motion movement of the bulletin board. (These two improvement will not be added to the hybrid desktop yet, because the technique is same as the movement of the PDF reader. So, these two will be left as the further improvement.)

7.2.3 Evaluation of AI servant

AI servant is served as the reminder or instructor. Based on the evaluation of Leap Motion, Hybrid Desktop add the progress status to the AI servant. Students think it is an important part, because as a user, they don't know the backend of the project, and sometimes, they want to know whether the camera has tracked something and whether the Leap Motion is doing the correct recognition.

The disadvantage of the current version is the view. Students respond that it is unrelated with the project itself, but the headset cannot provide the view very clearly. But the AI servant's message box is small, so they cannot read the words. It doesn't mean that the message box needs to be bigger, because AI servant is a supplement component of the desktop, and the current size is enough. Besides, they suggest more intelligent program should be implemented with the AI servant. The current AI servant does not look very intelligent, and it is just an interface between backend and frontend.

Improvement: Develop more Artificial Intelligence components to the project and let the AI servant be a true assistant of Hybrid Desktop.

7.2.4 Evaluation of Hybrid Desktop website

This test is mixed with the bulletin board, because it is an interface of the bulletin board's task manager. For the convenient aspect, it is easy and flexible to handle. The task manager is satisfied by every student, and there is no direct suggestion.

Students are interested in the online annotation section. When the instructor asks them which one do they prefer: Augmented keyboard or physical keyboard. And

the answer is still they prefer the physical keyboard. Some students are the one who this project asked before, and when they experience the real project, they love it, and think it is interesting to note with augmented annotation. However, it still exists the problem with the display of the cardboard. Because the size of the annotation box is small as well, so they need to look very carefully.

Improvement: More sections can be opened in the website and develop this website as a control panel. Because in the future, the bulletin board should be a web browser and the information inside it is just the Hybrid Desktop website.

7.2.5 Evaluation of my project

The final application which was evaluated was the project proposed in this report. As some students commented that how they love this idea and implementation, this studying experience is a brand new one and really combine the advantages of physical and electronic desktop. Although the resolution ratio currently is not satisfied, students express that with the development of virtual glasses, the prospect should be useful. A student said that "It seems this project stores my materials inside my phone, and when I wear a virtual glass, they can all jump out of my phone. This experience is amazing, and strongly hope that more and more application can be developed for hybrid desktop. I hope I can even don't carry my laptop to library one day." And most students agree that this hybrid desktop provides them a brand new study experience.

7.3 Successes and Limitation of the project

For the success of this project, all the listed proposed functionalities have been completely achieved. The most challenging task which is interaction between Google Cardboard and Leap Motion has been achieved as prospected as well. Based on this technique, it makes the gesture control of the PDF reader possible. The electronic annotation displaying system used to be another challenge task of this project, and I used to implement it with many ideas. Finally, I choose to develop it with another imageTarget and using real keyboard to do typing. And it gives the user a chance to move it as they want and real keyboard retain the typing pleasure. So, it can be evaluated that the project is completed as it should be.

For the limitation of this project, last few weeks before the deadline, I was improving the accuracy of Leap Motion gestures recognition. Leap Motion is a necessary tool to help students experience better about this desktop. However, based on the user tests, many students have not used it before. So, when they are interacting with this device, they will do some exaggerated gestures, and Leap Motion cannot respond very accurately about these gestures. Although the accuracy of Leap Motion gesture recognition can be 83%, it should be approximately above 95%.

Another limitation is the virtual glass, I develop and test this project with Google Cardboard whose resolution ratio is low. It strongly influences the user experience, and during the interview with students, all most every student mentions the view is not clear and said if the view is clear, it should be much more useful.

Chapter 8

Further work

8.1 Improve experience with new device

The limitation of the current project is the resolution ratio of the device and the comfort level of the headset. Because the current view is the camera view, so compared with seeing the real world, the quality of camera view is limited. Based on some research, Meta2 and HoloLens are two MR headsets which can solve this problem. When putting on them, the user is looking through the real world rather than the camera capture world. And it can only improve the resolution ratio but also expand the view. Also, the cardboard provides a lower user experience which will cause uncomfortable pressure around the head. The new device can also provide more comfortable wearing experience.

Based on better wearing experience, users will be more willing to put themselves in Hybrid desktop for a long time and study in this environment. The implementation of Hybrid desktop can be moved to other platforms easily. Because Vuforia is compatible with HoloLens as well, it is convenient to rebuild the project and install it to a new device. HoloLens has its own gesture frame and voice input which will help the developer to implement more advanced functions.

8.2 More Usability improvement

The ultimate goal of the Hybrid desktop is to enable people work in this Mixed reality workstation, so all the laptop based application needs to be have a substitution in this Hybrid desktop. For example, there should be a web browser, Microsoft Word or Excel, Music player, etc. Anything can be done on laptop will be able to be done in the Hybrid desktop as well.

When the web browser is accessible in the Hybrid desktop, the old bulletin board is not useful any more. It should be replaced by the Hybrid Desktop website. In other words, the bulletin board will be a web browser which display the Hybrid Desktop website as the default page. Besides, based on the user feedback, they hope they will be able to interact with the website more directly. So, replacing the bulletin board with the hybrid desktop website can help user to immerse themselves in this new world.

Another implementation this project is eager to explore more accurate location of hands. This project uses Leap Motion to sense the hands and respond with the gestures. However, the relative position of hands to Leap Motion is not the same as

the relative position of hands people see. So, in the current project, the user is performing gestures to interact with the digital objects rather than grabbing it. In the future, this project hopes to let the user locate their hands more accurately and perform more advanced implementation, like grabbing objects and click objects.

Currently, there are limited number of PDFs in the application. But different student will have different PDF's, and they all hope to access their own materials and manage it through a platform. This can be a further work based on the Hybrid Desktop website. People can upload their PDF on the website and then download it to the application. The application will convert the PDF to images automatically and then display it in the PDF reader.

8.3 Introduce 3D printing to Hybrid Desktop

People always dream about they can have their 3D model in real world. And it will be extremely useful for mechanical students. They can view their 3D model in the Hybrid desktop and adjust the parameters to design the best model, and when they finished their design, they can use 3D printing to get the real model directly. Then, they can compare the real one and the virtual one together. Besides, 3D printing can also be used for the function of copying and paste in Hybrid desktop. In the electronic world, people are only able to copy the electronic words, image, etc. But in Mixed reality world, except these digital objects, people will have the requirements to copy real objects. And 3D printing can help their dream to come true.

Chapter 9

Summary and personal Evaluation

9.1 Project management

The project management is divided into four parts based on the timeline: before Christmas vacation, during Christmas vacation, before Easter vacation, and during Easter vacation (Because deadline has been extended to April 24th, more testing will be done during that period).

The Gannt Chart for Hybrid Desktop is shown like the following figure:

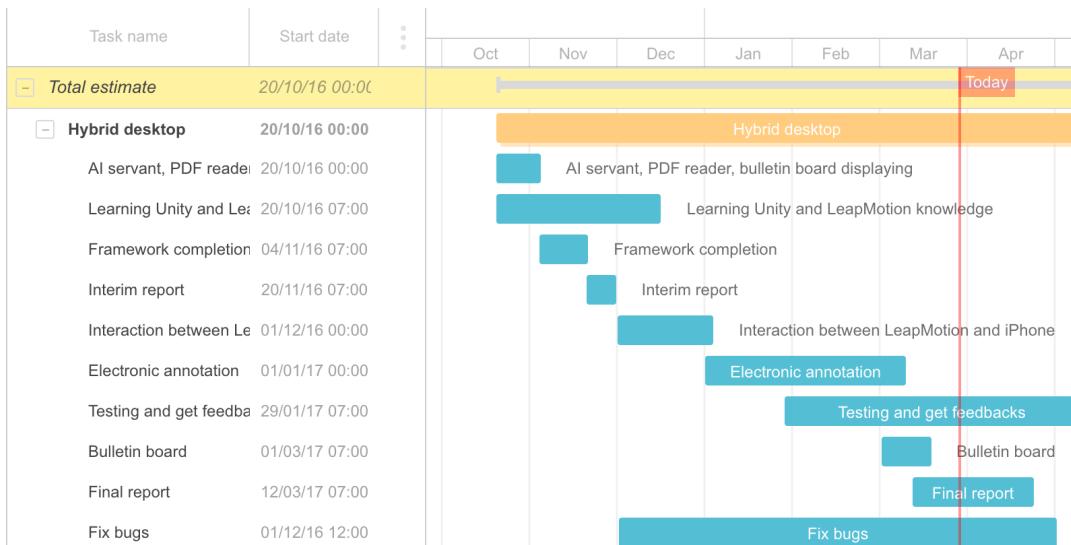


FIGURE 9.1: Gannt Chart for Hybrid Desktop project management

Before Christmas vacation, the main goal is to define the requirements and design the structure and framework of the project. Meanwhile, it is also very significant to learn Unity techniques and Leap Motion API. Some basic implementation like AI servant, PDF reader and bulletin board displaying should be done. Complete the framework of the project, obtain the necessary knowledge of Unity and Leap Motion and finish the interim report before the Christmas vacation.

During the Christmas vacation, time is much more sufficient, so some challenging goals, such as, exploring the interaction between Leap Motion and iPhone can be appointed, and using this new technique to perform interaction with the PDF reader. Another challenging goal is electronic annotation, during the Christmas vacation, trying to do some literature surveys and reading some articles related with this idea to explore a better solution for this problem.

Before the Easter vacation, because some functionalities have been implemented,

the main goal is to do some tests with students, get feedbacks from them, list some improvements and modify the program. During this period, there are weekly lectures, the time is relatively tight. So, another task is completing the bulletin board which is necessary but not so challenging. Meanwhile, implementing the AI servant and adjust its functionality based on user feedback, such as what other information that students hope they can get from the AI servant. At this stage, the project should be almost completed. Final report should be started to write. Complete each chapter, get feedback from the supervisor, and improve it each week.

During the Easter vacation, the main goal should be get feedback from students continuously, fixing bugs and perfect the final report. There should be no major change to the project, and the most important thing is to ensure this project works well and will not cause any crash.

9.2 Self reflection

Personally, I feel this hybrid desktop project is a success, as it solved the main issue which is conceived to solve. And it meets all the functional and non-functional requirements which are listed at the start of the project, and the feedbacks which I get from the prospected users (university students) are almost positive. Another reason that I believe this project was successful is that I explored the Leap Motion by myself, implemented some new features to meet the new requirement and I really feel enjoyable through this experience.

During this project, I learned a lot from my supervisor. At the start of the project, I was totally interested in the Mixed reality but had no experience in this aspect. My supervisor and I have weekly meetings, I expressed my ideas and talked about the hybrid desktop in my mind and some prospected functionality it should have. Supervisor gives me feedback and email some useful websites and articles to me. I grew very quickly through this experience. And it laid the foundation for my further implementation. Talking more with supervisor and do some demos are two important lesson which I learn from this project. It is not only a way to show what you are doing, but also a direct way to learn what can I improve and how can I improve.

It is the largest project that I had ever worked all by myself. From design to implementation, I use some clever method like Gantt chart to divide my time and make periodic goal. Every week, I have specific tasks to do, and this well-arranged plan makes the project go well.

One of the areas I feel was weak in this project, was the research part. I think my literature survey about the Leap Motion and Unity is not enough. Leap Motion and Vuforia are still new for most developers, so there are limited sources about it on the Internet. When I face some difficulties, it always costs a long time to search for an answer and trying to figure it out. And I should do deeper comparison for the choice of programming language as well, during my development, I changed my language because some problems arise later. And this should not happen, I need to plan it well at the beginning of the project.

If I could work on this project again, there are several changes that I will make.

Firstly, I need to define a more rigorous framework and design of the project. So, I will not face some problem which may caused by the unsuitable choice of the programming language. Secondly, I will think about the user test through my development. Because in this project, I started to consider the what should I test with the students when I almost finished most functionalities, and it may let me miss something. It should be much better if I consider it earlier. Next time, during my development, after I finish each task, I will store it and when I need to do user test, I can check these functionalities easily and help me to design more structured user tests.

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