VIRTUAL REALITY SYSTEM WITH HAPTICS INTEGRATION

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THESIS
Submitted in fulfillment of the requirements for ECE 499
2015

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Virtual Reality (VR) has shown its great potential from the video game industry to scientific research in recent years thanks to the advancement of VR enhancement devices like Oculus Rift and the Leap Motion. To demonstrate the usage of VR in research, this project describes a system that enables human-computer interaction through haptic feedback. In experiment, subjects can receive feedback of vibration provided by a pair of haptic gloves when touching virtual objects and then respond with the help of immersive enhancement devices.

This project offers a prototype of VR haptics integration that can be applied to various fields, in which designers are allowed to add different functions to tasks based on their own needs. In the end, we hope to build a complete VR project that can help a social cognitive research project conducted by the SCoPE Neuroscience Lab.

Keywords: Virtual Reality, Haptics, Gloves, Integration.
ACKNOWLEDGEMENTS

First of all, I would like to thank Professor Minh Do for giving me the opportunity to be involved with this project, and for the guidance and help when I had trouble. I am very fortunate to study under him because from this project I have learned a lot that I would not have learned in class.

I would like to thank Duc Huy Phan, who has supported me in finishing this project and given me valuable advice during these two semesters. I would not have been able to finish this project without his help.

I would like to thank John Capozzo for helping me learn to use Unity and training me to be better at programming.

I would also like to thank Zehua Li for helping me build the virtual environment for the experiment.

And I would like to thank Yuta Katsume and Matthew Moore for allowing me to participate in the social cognitive research so that I can have the chance to test the VR system.
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CHAPTER 1
INTRODUCTION

1.1 Motivation

Recent years have witnessed the fast development of VR technology. With the emergence of immersive enhancement devices like Oculus Rift, Project Morpheus, and Leap Motion, VR is becoming realizable. Because of the advantages for allowing researchers to create stimuli with unlimited possibilities and the abilities to provide a wide range of virtual environments, VR has spread into domains from video games to psychological research and has been firmly established as an experimental tool [1]. For example, it not only offers a safer simulation-based environment than the real world in which conditions change frequently, crises can occur rapidly, and human life may be at risk [2], but also provides cost-efficient cognitive treatments for people who would otherwise not be able to afford them [3]. Therefore, VR has been and will be more comprehensively adopted to solve problems that can hardly be solved in real life. Provided with the common usage of VR in various fields, it is constructive to build a general prototype of VR device that can be expanded into different models with explicit functions defined by other designers. By tentatively integrating our prototype into a psychological research, we hope to examine the compatibility of the customized system and evaluate the functionality and effectiveness of the prototype. After repeated experiments conducted in the research, we will be able to find drawbacks of the current prototype and improve it to have better performance, so that the prototype can be applied to other potential platforms satisfactorily. This exploration into
VR application with proper development will help researchers who are not familiar with VR technology to build their own testing system faster. In addition, further and diversely developing this prototype with the usage of other cutting-edge equipment to make it a mature product will add to its potential in the market.

1.2 Proposed Method

The proposal for this project is build a VR system with integration of a pair of haptic gloves. The VR system consists of two parts: hardware and software. First, the hardware part comprises an Oculus Rift, a Leap Motion and the haptic gloves. Oculus Rift provides subjects with an immersive environment though visual sense, in which subjects can make movements in first person perspective; Leap Motion can help subjects track the position of their hands; haptic gloves offer feedback to subjects via vibration the levels of which can be adjusted to give subjects a distinctive experience. For the software part, we use Autodesk Maya to create characters and define their actions, and we apply Unity 3D to render the virtual environment, animate characters, and integrate all hardware devices to the VR system.

Generally speaking, the VR system works like this: when a subject wearing a pair of haptic gloves “enters” the virtual environment with the aid of Oculus Rift, he or she can make social interactions with pre-defined virtual characters. Once the virtual character has performed a certain behavior, like a hand-shake, the subject can feel it though vibration of motors in the haptic gloves. And then subject can react properly based on the virtual character’s behavior. The reaction done by subjects will reappear synchronously in the virtual environment by virtue of the function of positioning of Leap Motion.
After finishing the prototype, we will test the functionality of the VR system through cognitive research. In the end, we hope to improve the prototype by adding new features and fixing bugs we find in the testing stage.

1.3 Thesis Summary

Chapter 2 gives a short introduction about the development of VR and some background on the device and software we use in this project. Chapter 3 provides an outline of our VR system followed by detailed description of every part in the prototype as well as each development phase of this project. Chapter 4 discusses the application of the haptic-based VR system and the experiment where we applied the prototype in a cognitive research project by the SCoPE Neuroscience Lab. Chapter 5 presents conclusions we draw from this project based on the performance of the system and expectations we have for this prototype in the future.
CHAPTER 2

BACKGROUND

2.1 History of Virtual Reality

Although VR has just been brought back to the market and become popular within recent years, the idea was actually formed long ago. In the 1950s, Stanley G. Weinbaum wrote the science fiction novel named *Pygmalion’s Spectacles*, which is considered one of the first books related to VR. In this book, he discussed how to obtain sense of, for example, touch and smell by wearing a goggle-based VR system.

In the 1970s, Ivan E. Sutherland, a professor from the University of Utah, invented the first head-mounted display (HMD), the Sword of Damocles, which could create three-dimensional illusions by placing two-dimensional images on the wearer’s retinas [4]. Although this HMD was heavy and lacked modern design elements, the Sword of Damocles is very significant in the VR industry because it allowed humans to partially immerse into a virtual world for the first time.

In 1984, Jaron Lanier, one of the pioneers in the VR field, founded VPL Research to develop VR products including the Data Glove and the EyePhone. The Data glove was designed to track movements and orientation, of which the data would then be transmitted to computer to be processed so that the information could be duplicated virtually. The EyePhone was a HMD that aimed to help people immerse into 3D simulation.
Since the 1990s, with the fast development of computer graphics and sensor technology, an increasing number of companies have entered the VR field, especially gaming and hardware manufacturing corporations. For example, the Sega VR headset was produced by Sega to work in tandem with arcade games and the Mega Drive console. In 2012, Oculus VR announced its development kits (DK1), a prototype of Oculus Rift which startled the world with its outstanding immersive performance. After that, more and more VR products were produced, like Sony’s Project Morpheus and HTC Vive developed by HTC and Valve Corporation.

2.2 Oculus Rift

Oculus Rift is a VR HMD that can present users with 3D illusion images. The type of Oculus Rift we used in our project is Oculus Rift DK2, which is the latest development kit. It has a field of view of 100 degrees with 1080p overall resolution (960 × 1080 per eye). It is equipped with sensors like a gyroscope, accelerometer and near infrared, which enables 3D rotation tracking.
and position tracking. Fortunately, Oculus Rift is embedded well with Unity 3D. When connected to a computer with a proper driver, the device gives users a good immersive experience with the simulation done by Unity 3D.

2.3 Leap Motion

The Leap Motion controller is a small device that is plugged into a computer using a USB cable. The controller can track the position of fingers or hand and project the motion onto a computer screen in 3D space by using its cameras and infrared sensors inside. Because the sensors are able to detect very subtle movements in a 150 degrees range of view, we can simulate actions like grabbing virtual objects, shaking hands and other common movements in real life. With the
help of the Leap Motion, we can duplicate the movements by wearing haptics gloves to virtual space.

2.4 Unity 3D

Unity 3D is a cross-platform game engine that allows designers to develop games and simulation with great freedom. Users can design their own environment and use any figures or characters in Unity 3D as well as write scripts to control them. One of the greatest features that benefits our project in Unity 3D is that we can create self-designed animations using a state machine with which we can easily make the action of character transit efficiently to different stages. In addition, Unity 3D offers a way to link peripheral devices such as Oculus Rift and the Leap Motion together, so we can let users communicate with virtual characters in virtual space by controlling the transmission of signals frame by frame.
2.5 Autodesk Maya

Autodesk Maya is a 3D computer graphics software used to generate 3D assets for film, game and animation. In our project, we used Autodesk Maya to create characters, animations and other 3D assets that would be handled in Unity 3D.
3.1 Overview

The system is designed so that it can present subjects with a virtual environment where they can move around and make interactions with virtual objects by performing pre-defined actions. In addition, this system can provide haptic feedback for subjects when they touch virtual objects.

The flowchart of the system is shown in Figure 3.1:

![Flowchart of Integration System](image_url)
As the flowchart shows, one of the inputs comes from the subject’s hand movement. As they move their hand, Leap Motion can detect the change of the position of their hands and fingers and will calculate the current position intermediately, and then pass the information to Unity 3D waiting to be updated. On the other hand, Oculus Rift IR Camera collects data of rotational and translational position of Oculus Rift which will be processed by Oculus Rift afterwards. Next, Oculus Rift will transmit the processed information to Unity 3D as well. In Unity 3D, information of current hand position and view is updated per frame so that subjects can see their movements timely through Oculus Rift HMD. When Unity 3D finds there is a collision or significant change of hand and finger position, it will send signals to the hardware system to control vibromotors on the haptic glove, thereby changing the channel and intensity of the vibromotor. If there is no need to update the vibromotor, then Unity 3D only needs to render the current virtual environment.

3.2 Haptics Glove

Carlin et al. in 1997 [10] used VR and mixed reality, tactile augmentation in this case, to successfully treat a female with severe and incapacitating fear of spiders, showing that vibration is able to increase the immersive experience for subjects in virtual environments. Because of this, we chose the haptic glove as one of the components in our system to provide haptic feedback which will add to the immersive feeling for subjects.
As shown in Figure 3.2, there are five vibromotors put on the spot of each finger on the glove, and each vibromotor is wired to the circuit of the system. In general, the circuit consists of an Arduino Uno board, an Adafruit PWM Driver, and a breadboard in which a transistor and capacitors are added to ensure the feasible transmission of the signal, as Figure 3.3 shows.

The vibromotor is controlled by a pulse width modulation (PWM) signal sent by the Adafruit 16-Channel 12-bit PWM/Servo Driver. The PWM signal is a periodic rectangular wave, of which the average value of voltage can be controlled by turning the switch of the Adafruit PWM Driver on and off at a fast rate, by which we are able to control the intensity of the vibration of the vibromotor.
3.3 Circuit and Programming of Haptics Glove System

As described in the previous section, the circuit consists of an Arduino Uno board, an Adafruit PWM Driver and a breadboard. The goal of designing this circuit is to control the vibration of the vibromotor properly given a signal from a script in Unity 3D. At a certain time, Unity 3D transmits a 1-byte signal through the serial port to the Arduino Uno board in which the 1-byte signal will be processed. The way we use the 1-byte signal is that we take the first four bits to
represent the channel to which the current vibromotor corresponds, and the remaining four bits to represent intensity level varying from 0 to 255. (Note that the reason why in Figure 3.5 we multiplied the intensity level by 250 is to let vibromotors reach the vibration limit when the level is 255.) Then, the Arduino Uno board will pass the eight bits to the Adafruit PWM Driver to generate the appropriate PWM signal.

In terms of generating PWM signal, we took advantage of a library, Adafruit_PWMServoDrive, provided by Adafruit to help us control the inter-integrated circuit in it. With this library, we are able to use the Arduino Uno board to govern the interface with each channel and intensity efficiently.

```cpp
class Adafruit_PWMServoDriver {
    public:
        Adafruit_PWMServoDriver(uint8_t addr = 0x40);
        void begin(void);
        void reset(void);
        void setPWMfreq(float freq);
        void setPWM(uint8_t num, uint16_t on, uint16_t off);
        void setPin(uint8_t num, uint16_t val, bool invert=false);
    private:
        uint8_t _i2caddr;
        uint8_t read8(uint8_t addr);
        void write8(uint8_t addr, uint8_t d);
    }

    void loop() {
        if(Serial.available()) {
            receivedDataArray[0] = Serial.read();
            Serial.print(receivedDataArray[0]);
            intensity = (int)(receivedDataArray[0] & 0x0F)*255;
            channel = (int)(receivedDataArray[0] >> 4);
            pwm.setPwm(channel,0,intensity);
        }
    }
};
```

Figure 3.4-Class definition of Adafruit_PWMServoDrive  Figure 3.5- Arduino Code Snippet

Since the PWM signal itself is insufficient to drive a vibromotor, it is required that we design a circuit to provide enough current to the vibromotor, which is the breadboard part in Figure 3.3(iii). This part consists a Darlington transistor (ULN2803A) and capacitors. Darlington transistor arrays can provide high voltage and current for eight channels, with peak collector current of 500 mA [13], while capacitors can absorb any of the voltage spikes that are produced by the Adafruit PWM Driver or Darlington transistor [14].
3.4 System Integration

Now we have our hardware system prepared, but how can we use it? The answer lies in Unity 3D. Unity 3D is a cross-platform game engine that allows users to access an integrated development environment (IDE) so they can compile applications onto different operating systems like Windows, Mac OS, Linux and so on. For example, MonoDevelop IDE comes with Unity 3D. With MonoDevelop, developers can write C# and JavaScript code to make Unity implement various tasks. Thanks to the popularity of Unity 3D, some major VR related companies, like Oculus Rift and Leap Motion, have already provided consumers with their own SDKs so users can easily import SDKs to Unity 3D and develop projects with the hardware they purchased.

![Virtual Character Shaking Hands in Unity 3D](image)

Figure 3.6- Virtual Character Shaking Hands in Unity 3D

In our project, we used Unity 3D to build a virtual environment, like an office environment or lab environment. Also, we created virtual characters in Unity 3D and wrote scripts to control their movements. For instance, we wrote a script to control a virtual businesswoman to shake hands with subjects (Figure 3.6). This movement is achieved by certain steps. First, we have to build the virtual character either by downloading the character asset online or by creating the
character using software, which will be discussed later on. Second, we have to attach animations to the character. Third, if the character has to complete a series of movements, a state machine has to be designed so the character can perform all movements without randomly entering different states. Finally, a script has to be attached to the character so we can control it frame by frame.

A state machine is shown in Figure 3.2. In this state machine, there are three different routes a character can follow after the state transits to Idle from Sitting. For example, the first one is to shake hands, pat and stretch arm; the second one is to shake hands and stretch arm; the third one is to push forward and stretch arm. The merits of making a state machine are obvious. It can not only enable the designer to establish a clear sequence of events, which decreases the possibilities of producing errors, but also makes it possible for designers to use animations efficiently by simply adding a new transition between two states with new conditions that do not violate previous ones.
After the character definition and haptic glove system have been accomplished, we can start integrating the two to become a prototype of a VR system. To do this, we have to figure out when to tell the haptic glove to vibrate. Since one of the functions of this VR system is to make the virtual environment more immersive, we decided to give subjects a sense of touch when they are interacting with virtual characters, especially when physical contact happens. For example, we can set the haptic glove to vibrate when the subject is shaking hands with the businesswoman in the case above. When the state is transmitting from Idle to Shaking Hands, scripts attached to the businesswoman set certain variables to true, thereby telling the Arduino Uno to turn on channels of Adafruit PWM Driver so it can generate pulses to make vibromotors on the glove vibrate. To simulate the scenario of shaking hands more precisely, we can actually change the intensity level of vibration at different timing to reflect the real process of shaking hands.

3.5 Character and Animation Design

As discussed in the previous section, one way to create virtual characters and animations is to apply the software. There are several game designing products available, such as Autodesk Maya for making animations, and Fuse for creating virtual characters. Fuse allows users to design characters that meet their needs. For example, one can use Fuse to design characters of different races, professions, ages, and genders. The other one, Autodesk Maya, allows users to make animations frame by frame. An advantage of using Maya is that it can import character assets directly from Fuse. Additionally, Autodesk Maya provides sphere coordinates for different parts of a character so one can easily make the character show gestures at certain frames. Thanks to the universal utility of Unity 3D, Autodesk Maya provides an option to import as Unity assets, so
we do not have to worry about the compatibility problems of importing game asset into Unity 3D.
CHAPTER 4

EXPERIMENT

4.1 Overview

As is discussed in previous chapters, our VR system can be applied to simulations with research and education purposes. To examine the functionality of our prototype system, we collaborated with researches from the Beckman Institute SCoPE Neuroscience Lab which focuses on studying neural mechanisms that underlie emotion-cognition interactions. According to Dolcos et al. (2012) [15], nonverbal communication, or body language, can effectively influence first impressions and evaluations by other people. However, little is known about the neural correlation of processing these subtle social cues that are dynamic in a virtual world. In order for us to learn the implications of nonverbal communication to social response in virtual reality, we decided to replicate the same experiment done by Dolcos et al. and compare the subjects’ social reflection in the two contexts.

The reason that this experiment is worth to be conducted is that haptics feedback, based on Wang et al. (2010) [16], together with visual feedback can provide more plausible illusions than those VR systems with visual feedback only. They suggest that given vision and haptics, the experienced plausibility of simulations with physical contact, such as handshake and patting, by subjects will be improved. Furthermore, by introducing new haptic rendering algorithms into our prototype system, we can increase the information richness of the visual scenario, which is one of the aspects we will focus on researching in the future.
4.2 Experimental Design

Our experiment will set up several scenarios in which subjects will be provided with different behaviors by virtual characters during social interaction. For example, subjects will be tested on approach and avoidance behaviors with each of them having two levels, mild and strong. After that they will evaluate the interaction partner (host) on three rating categories: Trustworthiness, competence, and interest in doing business.

Based on the result of Dolcos et al. (2012), positive social interaction, or approach behavior, shows higher rating than avoidance behavior over all these three categories with interest having the biggest variance. It suggests that nonverbal communication will cause difference in social interaction. Another testing scenario (Figure 4.2) shows that by adding handshake, subjects rate higher than that without handshake. As is also seen in the picture, handshake can increase the rating even in the negative social interaction, or avoidance behavior.

Figure 4.1-Behavioral results: Positive impact of Approach compared to Avoidance [15]
In order for us to compare the results of social interaction from real life and virtual reality, we have to replicate exactly what was conducted in reality and run simulation in Unity 3D. That is, we will build the similar office environment in which subjects will explore, and different virtual characters who will perform approach or avoidance behaviors. By having subjects rating the effectiveness of different social interactions, we will be able to find out the relationship between real life and virtual reality in terms of effects on social interaction.

4.3 Design and Implementation of VR Experiment

There are a couple of things we need to do in order to build the VR system for this experiment. First, we need to build an environment where we have subjects tested. The requirement for the environment is that it has to be similar to the place where Dolcos et al. (2012) did their experiment. Figure 4.3 shows the virtual environment of an office that we imported into Unity
3D. We also added a few pieces of furniture like table, chairs, projector screen, etc. to the scene so that the “office” looks like a real one.

Second, we created virtual characters of businessman and businesswoman as discussed in chapter 3 through Fuse, and then attached corresponding animations to them so they can perform a series of actions in certain states. In addition, Unity 3D will give signals to the haptic glove system to control the vibration if there are interactions between subjects and virtual characters happening in the scene.
Finally, we designed different routes for virtual characters to follow so that they can provide subjects with approach and avoidance behaviors with mild and strong levels using the finite state machine in Unity 3D.

When putting subjects under test, we will use devices like EEG and GSR to measure their brain activities to determine how nonverbal communication will affect the first impression under different social interaction contexts, so that we can actually compare quantitatively the results from our VR experiment with the one performed in reality by Dolcos et al. (2012).
CHAPTER 5

CONCLUSION

In sum, this thesis discusses two major parts of our prototype virtual reality system with haptics integration: one is the composition of the system, and the other is the application the system can be applied to.

In the first part of the thesis, we introduced virtual reality and the devices we would use in this project. Then, we gradually transited to the system part and discussed how we can integrate the hardware and the software into a whole so that the system can work properly. And in the second half of the thesis, an experiment was introduced to test the functionality of our VR system.

It can be seen through the experiment that our VR system is able to offer both visual and haptic feedback, which means it has satisfied the requirement of an immersive device. However, this is not the end. In order to optimize our system and to make it more extendable, we have to collect data in the experiment to analyze how we can improve, for example, haptic feedback so that the system can provide a more immersive experience. Moreover, we will continue polishing our environment, virtual characters, and animations, since all of these account for the success of a VR system. Furthermore, we will research how to make it easy to add additional functionality to the current system and make it compatible across more platforms.
REFERENCES


APPENDIX

LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>VR</td>
<td>Virtual Reality</td>
</tr>
<tr>
<td>DK2</td>
<td>Development Kit 2</td>
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<tr>
<td>HMD</td>
<td>Head-Mounted Display</td>
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<td>PWM</td>
<td>Pulse-Width Modulation</td>
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<tr>
<td>SDK</td>
<td>Software Development Kit</td>
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<tr>
<td>IDE</td>
<td>Integrated Development Environment</td>
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<tr>
<td>SCoPE</td>
<td>Social, Cognitive, Personality, and Emotional</td>
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<tr>
<td>EEG</td>
<td>Electroencephalogram</td>
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<tr>
<td>GSR</td>
<td>Galvanic Skin Response</td>
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