HANDS ON DESIGN

Integrating haptic interaction and feedback in virtual environments for enhanced immersive experiences in design practice.

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Abstract. The usability of virtual reality (VR) controller interfaces are often complex and difficult for first time users. Most controllers provide minimal feedback which relegates the potential for heightened interaction and feedback within virtual experiences. This research explores how haptic technology systems partnered with VR can deliver immersive interactions between user and virtual environment (VE). This research involves the development of a haptic glove interface prototype that incorporates a force feedback and vibrotactile feedback system. It focuses on determining a workflow that communicates in real-time user interaction and environmental feedback using Unreal Engine and the produced haptic glove system. Testing and calibrating the prototype feedback system provided a baseline for developers to rationalise and improve accuracy of current real-time virtual feedback systems. The evaluation of this research in industry unfolds new technical knowledge for implementing a wider range of haptic technologies within VR. This further development would involve reviewing the usability and interaction standards for VR users in the design process.

Keywords. Virtual Environments; Haptic Technologies; Feedback; Interaction; Usability.

1. Introduction

Virtual Reality (VR) has provided new and evolving opportunities to a wide range of industries in their design processes. Allowing designers, creators and clients into an environment to convey a spatial experience of designs. VR has influenced new ways of design that architects, engineers and contractors
are not used to. These include collaborative workflows, employee training and showcasing experiences of final design concepts. These current VR uses provide a suitable medium for communication of spatial ideas but often provide minimal input or feedback due to the complexity behind the application and the interface. This complexity is capable of disconnecting users to the virtual experience. Minimising the complexity behind virtual reality systems and interfaces can lead to the potential for heightened virtual experiences and drives the idea of “virtual simulation” (Naimark, 2018). Current VR systems within architectural visualisation is limited as interaction with virtual objects are difficult and haptic feedback is limited due to controller interfaces. It is evident that at this stage in VR’s integration in the Architectural, Engineering and Construction (AEC) industry, that user interaction and feedback remain limited due to the technology still being relatively new.

Considering the circumstances, the current research aims to contribute to encourage further VR adoption in the AEC industry by developing a framework for developers and designers to integrate haptic technology systems within virtual environments. By establishing VR fundamentals, exploring hand tracking systems and testing haptic technologies a real-time haptic feedback system was developed which was tested within virtual environments. The haptic feedback system allows the removal of current controller interfaces which are difficult for first time or unfamiliar users and allows users to interact in virtual environments with their hands through hand tracking techniques.

2. Research Aims

This research situates the validity of VR systems, future research and exploration in industry. Accordingly, the aims of this research are as follows; to determine the variables of haptic feedback within current technology systems; to distinguish a clear understanding of core components needed for achieving real-time communication of a haptic feedback system within a virtual environment; and to propose an addition for virtual experiences to include a wider range of immersive techniques, while encouraging various industries to encompass haptic technologies and VR in their design workflows and processes. The overarching goal is to develop a framework for integration of haptic feedback within virtual environments to further improve the experience and design process. Typical understandings of VR consists of the visual medium, but introducing physicality such as haptic feedback allows for heightened virtual experiences. The framework is aimed at having the ability to incorporate practical uses in both sides of the industry, this includes designers or architects and clients. Therefore, the initial objective is to determine VR’s technological and design-driven limitations by testing tasks of hand tracking, gesture recognition, and serial communications in real-time.

3. Research Questions

The projects research questions are as follows:

1. In what ways can we make use of haptic technologies to mediate the
interaction between virtual objects and the user in virtual environments?

2. How can haptic feedback and interactions in a virtual design enhance and benefit an architect’s, designer’s or client’s virtual experience?

4. Methodology

This research adopts an action research framework that is defined through a mixed method that applied theoretical knowledge to evaluate and test the design of three iteration stages. Each iteration is influenced by various areas of the research methodology to consolidate the framework and prototype testing.

4.1. THEORETICAL INVESTIGATION

An extensive literature review of VR and haptic technologies was undertaken. The review covered key principles of VR and development and integration of haptic technologies. The review informed the elements needed to develop a haptic feedback system and explained how one can be tested and compared. The findings were organised into four areas of compare, standardise, benchmark and quantify (Figure 1).

4.2. DESIGN DEVELOPMENT

Each theoretical investigation supported the development of iterations set in three subsequent stages: ‘Hand Tracking and Communications’, ‘Tactile Feedback’, and ‘Resistance and Force Feedback’. Initial understanding of hand tracking techniques was fundamental to master the simple implementation of virtual hands and serial communication in a Virtual Environment (VE). To test the effects of outlined principles and techniques gained from the research methodology, iteration 1 was directly influenced by the conducted technology review and comparison study of existing applications. Exploration of implementing tactile feedback to a user was the core foundation of iteration 2. From this, real-time vibration feedback
development was key in testing the speed of serial communication between the Arduino and Unreal Engine 4. The process involved performance analysis through quantification, in particular calibrating the updating speed of the serial so real-time or close to instant vibrations was received. This process involved computational methods to track and adjust communication speeds. Iteration 3 involved the development and testing of resistance and force feedback systems, that later was collaborated with iteration 2. Iteration 3 relied heavily on qualitative survey gained from user testing. The feedback gained was independent of quantification results from iteration 2 and aligned with the current result as a framework to be built upon.

Figure 2. Prototyping Workflow Diagram.

4.2.1. Data Collection Methods

A mixed methodology involved in combining multiple tools to receive results and depicts areas of refinement relatively. For the testing of each prototype, quantitative and qualitative forms of data was collected and reviewed. Quantitative data was collected through serial readings gathered and recorded within Unreal Engine after participants completed a number of tasks within the VE with and without the glove. Further data was gathered through observation of the users view on an external display and video recordings of participants using the prototypes testing the time to complete set tasks. Qualitative data was gathered within the questionnaire in a written form to gather comments of difficulties within the VE and the preferred calibration of the prototype.

5. Background Research

VE systems engage only the visual and auditory senses of the user are limited in their capability to interact with the user (Srinivasan, 2005). Haptic interfaces are a relatively established technology, with increased use for human interaction with VE’s since the early 1990s (O’Malley & Gupta, 2008). Commercial application of haptic and tactile devices have been simple and inexpensive, such as vibrations of a mobile, or force feedback joysticks common in gaming. These have improved usability and interaction of devices making our sense of touch ‘haptic’ an important part of everyday life.
5.1. HAPTICS

The sensation of touch is one of the most informative senses and allows us to relate to the world around us through perception. Haptic interfaces are employed for tasks that are usually performed using hands in the real world, such as manipulation and manual exploration of virtual objects. Researchers define three sub-areas within haptics; human haptics, machine haptics and computer haptics. The underlying principles of haptics is force and pressure which actuate feedback through skin and muscle receptors. Current VE systems only engage the visual and auditory senses of the user are limited in their capability to interact with the user. This enables a greater gap between environment and the user, making it an area of research that is poised for rapid growth (Srinivasan, 2005). Haptic technologies are heavily recognised with the idea of ‘hyperrealism’ also known as ‘full immersion’, where the user interacts with the VE replicating and rendering real-world physics and feelings. Many studies depict that the level of realism currently in VE’s have extremely progressed in the past decade and predict that as technology advancements come, the level of realism is heightened (Figure 3).

![Figure 3. Sensory Spectrum.](image)

5.2. VIRTUAL REALITY

5.2.1. The Uncanny Valley

The uncanny valley is a hypothesised relationship between the degree of an object’s resemblance to a human being and the emotional response to such an object. Better understanding how realistic touch sensations can break the VR illusion may help developers create more engaging VE’s for games and VR therapy (McMahon, 2016).

5.2.2. Technology review

Prior to the development of the research project a technology review was conducted to subjectively understand the potential of VR and haptic integration technologies. The review’s scope explored different developer software, programs and tools that were based on their interoperability and functionalities. From this, a comparative data based ranking system was implemented to frame the technologies most suitable for design based research.

5.3. GAME ENGINES

Game Engines such as Unity and Unreal play a critical role in providing capabilities for more than what they were designed for, game building. One major capability includes the content creation and programming for VR systems. This is because game engines have the power of fast rendering, real-time interactions,
the ability to be programmed and the ability to be compatible with a wide range of file types. Making it a perfect utility for VR systems to be used with whilst enabling users the ability to create highly dynamic, custom and interactive visual experiences. Majority of industry standard headsets such as the Oculus Rift or HTC Vive are compatible with leading game engines as they provide VR/AR templates and examples.

5.3.1. Collision detection
VRE’s can simulate a physical environment in such a way that humans can readily visualise, explore and interact with virtual objects. Since physical environments are inherently geometric based, algorithms and physics-based engines are built within Gaming Engines and VR programs that enable collisions (Zachmann, 2000). One important problem with physics-based environments is the ability for real-time interactive collision detection, as large computing power is needed to accurately render constantly changing geometries.

5.3.2. Photogrammetry mapping
Photogrammetry mapping is a technique to create 3D model of a real-world object or scene using multiple photographs that are overlaid. As VR/AR systems become more proficient in the AEC industry where multi users environments, virtual objects and avatar creations are involved (Kan, Duffy, Su, 2001).

5.3.3. Motion and hand tracking
The Leap Motion is a hand tracking system is a most common development tool to track finger dexterity and fidelity in real-time. It has been used through applications from gaming, VR/AR, robotics, training, interfaces to rehabilitation applications. The Leap Motion’s SDK is compatible with a wide range of software’s and gaming engines. The SDK allows for developers to incorporate a range of interfaces, rigged hand characters and custom hand animations.

6. Case Study
This case study outlines a framework for integration of haptic technologies to allow immersive and interactive experiences in VE’s. This study involves exposing the methodology for users to interact and manipulate architectural designs within the Unreal Engine VR application. Interaction data from the users within the VE is processed and sent to a serial communication system. The data is to be read by an Arduino microcontroller and output actuated haptic feedback to the user.

6.1. ITERATION 1: HAND TRACKING AND COMMUNICATIONS
6.1.1. Leap Motion Hand Tracking
This research design incorporated methods of tracking hands, finger movements, dexterity and gestures to decide what feedback sent to the user using the VR system. It is beneficial to start by understanding the capabilities and API systems behind the Leap Motion and its use in game engines particularly for Unreal Engine and
Unity. In Unreal, rigged hands are determined by having mesh geometries being constantly updated inside the engine and are fed 3D location data from a user’s tracked hands in front of the sensor. The plugin consists of prebuilt character blueprints accompanies with rigged animations.

![Figure 4. Testing Leap Motions capabilities through Blocks application (left) and Leap Motion gesture commands (right).](image)

Testing was done in allowing a user to trigger an output such as a print string component that allows the user to read on screen when a grasping event has occurred or has stopped. This setup the framework for a Leap Motion event to send data to an Arduino microcontroller through Unreal. The actuation would be dependent on data such as pinch distance, bone, finger, hand or arm location, hands or finger widths, direction of members, state of gestures and count of fingers pointing, etc.

6.1.2. Connection of Unreal and Arduino

UE4duino is a plugin for Arduino COM port communication, this allowed serial data from Unreal Engine to be translated into actuation of a connected device to a user via the Arduino COM port. Extensive testing in Unreal which involved opening the serial, sending a string to Arduino IDE and closing the port once the scene was stopped in Unreal Engine. The Arduino IDE was used to allow an output from the data sent from Unreal and actuate a connected device from specific data inputs. The Arduino IDE allows various libraries to be added whilst allowing it to read incoming data from its port. This method consisted of three steps; adding libraries, inputs and outputs pins to the microcontroller, begin serial use whilst setting up the Arduino pins that were used, reading the serial and performing certain actuation’s according to what strings are read within the serial port.

6.2. ITERATION 2: TACTILE FEEDBACK

6.2.1. Vibrotactile Feedback

Through further background research, allowed for the incorporation of vibrotactile feedback. This then led to the implementation of vibration coin motors, that same device that allows mobile phones producing vibration feedback in a compact design. Incorporating these motors in a glove system design also allowed actuation and speed controlled through a Pulse Width Modulation (PWM) signal as the input lead. PWM signal pins are built within the Arduino microcontroller and
can be adjusted according to a transistors applied voltage. The design lead to one vibration motor attached to each finger tip of a nylon glove. Each motor consisted of lead wires that were all connected in a parallel connection to the transistor and Arduino.

Figure 5. Coin Vibration Motor Structure and Developed Vibrotactile Glove.

6.3. ITERATION 3: RESISTANCE AND FORCE FEEDBACK
The custom development led to the prototype of a channel pulley mechanism that uses the hands natural joints to be used as channel guides for a fixed string attach to each fingertip on a glove.

Figure 6. Force Feedback Channel Mechanism Design and Prototype.

The design applies resistance throughout the channels and onto the user’s hands to limit their hand closure. This purpose was to simulate shape and volume of virtual objects. Testing this designed mechanism determined a better solution on applying resistance to a user’s hand with a confined and lower profiled design.

6.4. FINAL PROTOTYPING
The final prototype included the method of collaborating the vibrotactile glove design with the force feedback channel mechanism into one system. Extension cables were made for compatibility between the Arduino microcontroller and the servo and vibration motors with also having a significant amount if length allowing
as users hand not be constricted when wearing the prototype. The Leap Motion
uses infrared sensors to determine depth or height of hands and position of finger
joints. This makes it difficult to detect dark fabrics that reflect minimal light, to
work around this complication the haptic glove prototype was used inside of a
white nylon glove. This allowed more accurate hand tracking.

6.4.1. Arduino and Unreal setup and communication
Setting up the Unreal project included the incorporation of importing various
objects with different volumes, so a user could test different actuation’s of the
resistance feedback. The predefined grasp strength linked to each object ID
controlled the actuation sent to the servo. The user picking up a virtual object with
a large volume or shape restricted their hand to minimal closure, whereas picking
up a small volume object allowed maximise closure of a user’s hand. With the
object ID’s being read by the Arduino IDE consisted of variable speed actuation of
the vibration motors that simulated feedback of differentiated surface interaction.
Objects with assigned smooth surfaces included a consistent and even rumble of
the vibration motors where as objects with assigned rough surfaces feedback a
jittery and uneven rumble. The collaboration of a vibrotactile and force feedback
system determined a real-time feedback to a user’s hand being tracked constantly
through the Leap Motion sensor.

Figure 7. Real-time Testing with Haptic Glove Prototype and Unreal Project.

7. Significance of Research
By focusing on integration of haptic technologies within in virtual environments,
this research contributes to a wider incorporation of VR in the design process
as an intuitive tool with interactive capabilities rather than designing through
‘clicks’. The potential for VR technologies can be defined through its capabilities
and flexibility within the industry, giving users the ability to input and visualise
content, walk through it and design in real-time. Communication between
drawings, plans and amendments are difficult to explain to different disciplines
within the design process or even clients, this is where VR has the potential
to bring productive communication between users across the whole design
process. Through an iterative design process and testing, it is evident that
the methodologies in achieving virtual immersion do reflect the performance of
real-time haptic interaction and feedback within virtual environments. However, by targeting haptic interaction feedback and providing a baseline for development and integration within VR, this research encourages further exploration of sensory interactions to such a fast-developing technology and design tool.

8. Conclusion

Conclusively to the research, the outcomes have reflected the overarching goals in defining, relevant research methods in VR and its relation to haptic technology systems. The objective of this research has set out to explore the use of haptic technologies in a VE providing a user to interact with the surrounding context. The prototyped haptic glove system allows a user to determine a level of sensory feedback with touch to determine the communication between the user and VE. Through the iterative steps taken within the methodology in achieving user interaction and feedback in VR expresses how future developments of sensory interaction and feedback can support design in the built environment. This research determines the level of integration needed to allow significant feedback from the VE through the mediation enabled by haptic technology systems.

References