An Application for Interaction Comparison between Virtual Hands and Virtual Reality Controllers

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***Abstract*—This paper presents an application for Virtual Reality (VR) interfaces for virtual hands which will allow us to compare interaction between virtual hands and VR controllers in Virtual Environments (VEs). Development for human-computer interaction in VEs needs improvement to accommodate the growth and need for applications inside VR. Virtual hands are growing more prevalent with many devices detecting the location and mimicry of the user's own hands inside the VE. Virtual hands can also be implemented via VR Gloves to more precisely pinpoint the movements of hands. This work also implements interaction mediums that can be used by virtual hands or VR controllers to directly manipulate and control virtual objects and virtual interfaces. Unity was used to generate the VE and to render the input mediums and interactable objects. SteamVR was used to connect the input mediums to Unity. The HTC Vive Pro Eye was used to connect the user to the VE. The two input mediums that were compared are the HTC Vive Controllers and the HI5 gloves. All of these components come together to form an immersive and consistent means to compare input mediums in different kinds of interactions.**

Keywords: Virtual Reality, Virtual Environments, Human Computer Interaction, Virtual Hands, Virtual Interaction, HTC Vive

I. Introduction

Virtual Reality (VR) has seen rapid development recently with its rise in the consumer market for entertainment and its practical application in education. VR applications have been accustomed to using tracked controllers. Tracked controllers have added drawbacks of cost, time-to-learn, and energy. These problems are beginning to be addressed with virtual hands as virtual hand tracking improves and becomes integrated onto more devices. Virtual hands have the added benefit of being able to transition between VR and augmented reality as they shift into any virtual world much easier than the controller as a physical device. Virtual hands are an emerging technology that allow for the user's hand's location and orientation to be mapped to a Virtual Environment (VE). This work implements virtual hands using the Noitom Hi5 VR Gloves [7] as a means to accurately track finger movement, hand position, and gestures. Virtual hands are typically mapped via a series of sensors, such as a visual sensor like a camera or by VR gloves that have sensors to determine where the user is moving their hands. New virtual hand technologies such as the Oculus hand tracking [5], Ultraleap [12], and VR gloves are seeing their usage in more virtual world applications. The use of virtual hands as a medium of interaction within VEs needs development as more applications in the future are likely to incorporate this more accessible method of interaction.

A key component in both the research and creation of VR interaction is analyzing how people interact with both real objects and their virtual counterparts. Two main differences exist between interacting with a physical object and a virtual object. One is the lack of physical stimuli inherent with a virtual object, for example, the weight or texture of an object. The second is the lack of direct mapping between virtual and physical interaction. This difference is very apparent when looking at the VR controller as, due to it's length, it doesn't have the same degrees of freedom that a person's hands/arms have. The controllers also don't allow the user to "grab" anything, the closest action to this is pulling the trigger on the controller. The virtual hands have this problem due to the lack of resistance a user feels, or rather does not feel, when trying to touch or grab an object. This means the user doesn't know where to position or close their hands when interacting with an object. For example, if a person is physically opening a door, they close a hand around the door handle, the door handle provides resistance, a physical stimuli, which tells a person that they have grabbed the door handle and don't need to squeeze any harder. If this same example is to be used when virtually opening a door, the user has no way of knowing when they have successfully grabbed the door handle. A VR controller uses the click of the trigger or the physical resistance of the trigger to simulate this, but with virtual hands there is no inherent indicator.

Another key component of applying virtual hands to VEs is finding a way to translate ready-made VR controller applications to use virtual hands. Many VR applications incorporate object interaction where the user needs to press a button on the VR controller to correspond to an action done onto an object in the VE. This work proposes a method to allow this shift to take place in relation to virtual menus, virtualized everyday objects, and rigidbody physics objects. Virtual menus are seeing more use in VR as they provide an easy means of selection for user interface, typically done with laser pointing using the VR controller, further necessitating the transition to virtual hands. With these methods of interactions, a direct comparison of VR interactions using virtual hand technology could be made as a contrast to the commonly used VR controllers.

The rest of this paper is structured as follows: Section II presents background on VE interaction mediums and the

Human Computer Interaction elements (HCI) that affect VE input. It also showcases related works in the area involving Virtual Hands, VR Gloves, and virtual interaction. Section III highlights the methodology of the HCI VE elements considered in the application as well use cases of both virtual hands and VR controllers. Section IV discusses the details of the application, the uses of the application, and the interaction elements that can be examined with this application. Section V summarizes the uses of the application and the methods of interaction inside VEs. Section VI highlights areas of future work based on this research.

II. Background and Related Works

A. HCI VE Considerations

In the process of making a VR application, there are a several general baselines of achieving a successful HCI interaction. Shneiderman [10] details how there are five usability measures to consider with interactions, those being: time to learn, speed of performance, rate of error, retention over time, and subjective satisfaction. This work implements the application to highlight some of these usability measures in relation to input into VEs with these usability metrics taken into consideration. The measures chosen were performance, presence, and ease-of-use, which are a slight modification of general HCI usability features proposed by Shneiderman, with a focus on VE interaction. The user should be able to perform the task required at hand in an efficient manner, achieving speed of performance and low rate of error. The user should be able to feel immersed into the VE. As a result, presence was also chosen as it highlights the user satisfaction, while simultaneously examining the user's ability to be immersed inside the VE. Finally, ease-of-use was chosen because it considers time to learn, expected outcome, and rate of error.

B. VE Interaction Design

The design of object interaction and UI interaction are the primary means of human input into a VE and are critical to the core of a virtual world. Sutcliffe *et al.* [11] discusses the human-computer interaction (HCI) challenges that are native to a VE experience. The authors went through multiple case studies and determine design processes and associated design trade-offs for each case study. The authors find that immersion inside of VEs is imperative. They also found that a good way to keep immersion while allowing users to read information or interact with a user interface (UI), is to integrate this UI into context-sensitive pop-ups that are translucent. They also found that audio/speech inside of these case studies should be accompanied by or replaced with pop-ups or readable interfaces.

Another consideration within interaction is whether or not an interaction medium needs remapping to occur. Actions executed in a virtual environment do not necessarily need to mirror real life in order to achieve the same goal. As a result, some interaction methods can use remapping, a method in which an action in the VE leads to an outcome that may not always lead towards the same outcome in the real world [4]. An example of this is having a user snap their fingers to open a virtual door; in the VE the action of snapping your fingers are "remapped" to open a door, whereas in real life the user is just producing sound. A common implementation of remapping that we selected was to use a laser pointing system for the menu interaction. We also decided to implement remapping for grabbing objects. This was used to allow the user to perform the grip action, with either virtual hand or controller, to take hold of the object to interact with them.

C. Virtual Input Devices

VEs can have many methods of interaction inside the applications to immerse the user into the virtual world. These range from microphones and speakers, to eye tracking and mouth tracking. Another method of immersive interaction is by allowing the user to interact with objects using everyday hand movements. This research uses the Noitom Hi5 VR Gloves [7] to accurately map the location of fingers, hand movements, and gestures into the VE.

A significant portion of the considerations of interaction in VE is whether or not the response triggers haptic feedback. In VEs, the lack of haptic feedback is apparent because there are a limited amount of devices that can interact inside a VE [9]. We decided to create an application where the lack of haptic feedback would be apparent with the usage of virtual hands but not so apparent with the usage of controllers. The user may experience some haptic feedback with the click and the physical presence of the controller but may experience the empty hand entirely differently. We also decided that, in terms of accessibility for VR/AR devices, virtual hands should be used as they are more likely to be a common medium of interaction in VEs. Our work could also allow for the potential of comparing haptic vs. non-haptic virtual interactions to determine their level of usability

Fahmi et. al. [3] preformed a user study on the experience with VR controllers, the UltraLeap's Leap Motion Controller, and the senso glove for anatomy learning systems. In this study, they concluded that the Vive controllers [2] were rated higher in terms of user satisfaction when compared to the other two controllers. Our work aimed therefore to create an application that can allow for these differences to be highlighted and examined; also, to confirm whether or not the controllers are more satisfying to use in many diverse types of interactions.

D. VR Gloves

Bowman *et al.* [1], described interaction techniques used in different VEs specifically designed for *PinchGloves*. The authors pointed out limitations of VEs that are still major hurdles for any modern VR application to overcome. One such limitation being that interactions within VR/VEs should mainly be designed around physical interactions, or interactions within a menu. Data entry and the completion of certain tasks, like typing a sentence, are generally much slower to complete within VR/VEs, and should generally be avoided when designing an application.

Luzanin *et al.* [6] discusses the use of probabilistic neural networks in the use of static gesture recognition for data gloves in VR. The authors found great accuracy within their testing of static gesture recognition, even with users who were not part of the neural network's training. While this approach to gesture recognition seems to be very accurate, using a neural network in conjunction with a VR application with multiple input mediums is rather computationally expensive and time consuming for both the developers and the users. Thus, more gloves are being created with built-in SDKs/APIs that will do basic static gesture recognition or allow the developers using the gloves to create their own gestures. Among these, the Noitom Hi5 VR gloves [7] and the SensoryX VRFree VR gloves [8] are notable examples of gloves suited for this type of gesture recognition.

III. METHODS

A. Virtual Input Usability Factors

There are important usability factors to consider for an interaction to perform effectively in a VE. The factors we decided to focus on are performance, presence, and ease-of-use. While there are other factors to consider when analyzing the virtual input, these were chosen as they could most likely be affected from the transition from input type. **Performance** is the ability for the user to perform a specific action, and the rate at which that action is performed. Virtual applications need to have users understand and perform any given task effectively. **Presence** is the ability to feel immersed in a virtual environment. Presence was chosen because of the need to evaluate how realistic it is to perform an action with your hand vs. the drawback of not having that touch stimuli. **Ease-of-use** was chosen to evaluate if the input actions on the virtual hand or the controller are easier to understand and use for users. It would also be useful to evaluate the intuitiveness of input design using ease-of-use as metric.

B. Detailed Use Cases

The use cases illustrated in Figure 1 describe interactions between users and the system that are shared between virtual hands and VR controllers. This is typically illustrated with theoretical actors and things they can do within the system. These use cases were defined in relation to how a user would interact with a VE given these input devices. A more descriptive account of these actions is as follows:

1) **Virtual Input** The user will input their actions into the VE using either virtual hands, implemented via VR gloves, or VR controllers. The location and orientation of both are mapped from the physical world into the VE relative to their position of the user.
2) **Locomotion** The user will move in the Virtual Environment using some motion or action on the user's hands. Depending on the action of the user, the player will move corresponding to the input and the direction the user is facing. Using the touchpad or joystick on the controller, the user will move in the virtual environment according to the movement on the controller.

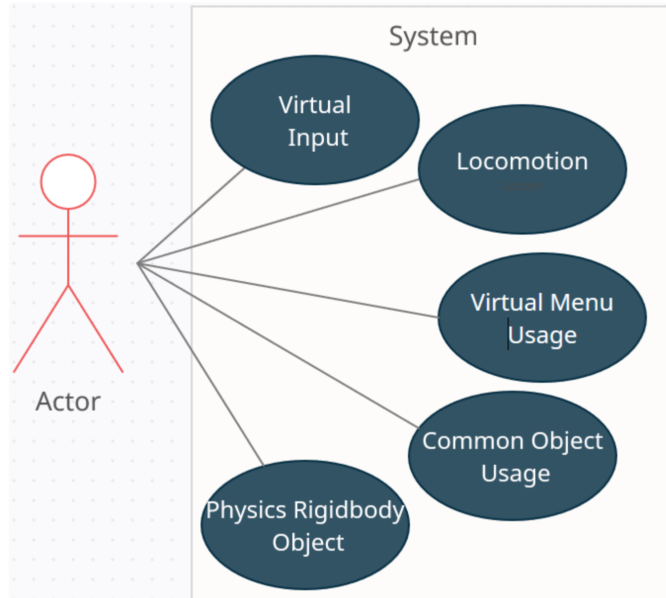

Fig. 1. Use case diagram showcasing the interactions shared between virtual hands and VR controllers

3) **Virtual Menu Usage** The user will use buttons on a virtual menu in VR. The buttons will have noticeable effects to notify the user that they have been successfully pressed. The user can point to the menu via a laser pointing system attached to their virtual hand/VR controller. The virtual menu will have UI buttons, sliders, drop-down menus, and more.
4) **Common Object Usage** The user will use and interact with virtualized common objects that people experience on a day-to-day basis in the real world. The user should be able to intuitively interact with these common objects, like they would normally.
5) **Physics Rigidbody Object** The user will be able to either throw, catch, pick up, or hit an object that moves corresponding to the physics of the VE. The user will need to grip the VR controller or virtual hand to be able to grab the object. The objects location in the virtual environment will determine its collision with the virtual object.

IV. IMPLEMENTATION

The application was divided by creating three stages that encompass the core aspects of methods of virtual interaction inside VR. Each stage focuses on key aspects differentiating VR controllers and VR gloves and their usage in a virtual environment. The three stages are **UI interaction**, **ubiquitous object interaction**, and **object coordination and interaction**. By dividing the application, there could be a variety of simple, but key, interactions that could be useful for determining user input while allowing for each stage of interaction to be independent of another. The order of execution can be seen in Figure 2, which showcases the steps the user will take in this application.

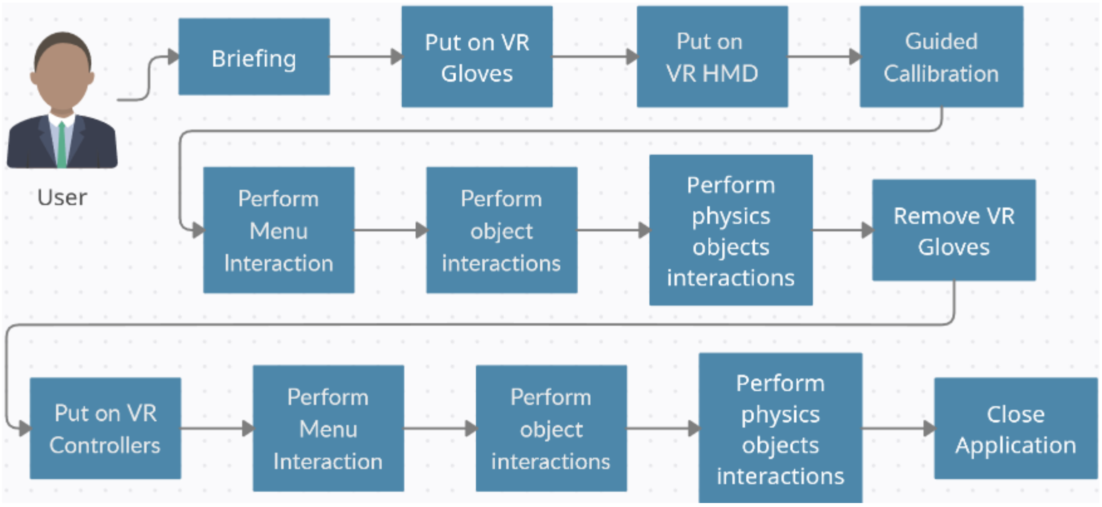

Fig. 2. Order of execution of the user's activities in the VE

Fig. 3. Stage 1 menu interaction UI sample, containing a button, slider, and a drop down menu

The following sub-sections describe in detail the processes in which a user will perform the application. Each stage allows for the analysis of usability features within the applications between virtual hands and VR controllers. Each stage also describes the purpose of the interaction method that will aid to represent the HCI elements of objects in virtual environments.

A. *Stage 1: Menu Interaction*

The menu interaction of the application allowed for a pointing system using a laser system for both VR gloves and VR controllers. The VR gloves pointing system was implemented as if the user would be holding a laser pointer. To select or click on the application, the user would be required to make a fist with their opposite hand. A left mouse button click would occur as the user would make a fist. The click would remain until the user unclenches their fist. This action would be similar to clicking and letting go of a click on a mouse. From this, it was decided that this method of interaction was sufficient for interacting with the virtual menu interface, since it is rare to find VR interfaces that contain options for right click, middle mouse click, or scrolling. With the VR controllers, a laser pointing system was put in place, which allows the user to point using their left controller and allows the user to left click on the menu by pressing the controller's trigger button, after pointing at an option in the UI.

As seen in Figure 3 the menu system's architecture incorporated a basic canvas UI object with three components attached to it that indicate basic user actions. The first component is a standard button, which turns a darker color when hovered over, and an even darker color when pressed. The second component is a slider, where the user can move a small circle along a line that would similarly change color, depending on what was currently happening to it. The last component is a simple drop down menu that, when clicked, allows the user to choose between three options.

This stage was chosen to help differentiate the intuitive use of a pointer system to interact with virtual menus in VEs. This will allow for the comparison of ease-of-use when it comes to determining pointing systems. Some users may find the VR controller easier to point as it could be considered a wand while others may prefer the virtual hand as they can point with their hand as if they were to be holding a laser pointer instead of an object. This will also allow us to evaluate performance using the application. With this, we can determine if the user is able to perform the desired actions using both methods of input.

B. *Stage 2: Virtualized Everyday Objects*

For the second stage, a common physical object to interact with was integrated into the virtual world that would allow the user to use both input methods. The common physical object that was implemented was a door to represent a mechanical operation. This is because a door is something that everyone is accustomed to interacting with on a daily basis in the real world, however implementation in a virtual world is an area which has not been used frequently in VR applications. An example of the usage of the door's implementation can be seen in Figure 5, in which the lone button on the wall is inviting the user to press it to open the door.

Fig. 4. Stage 2 A user reaching for the doorknob

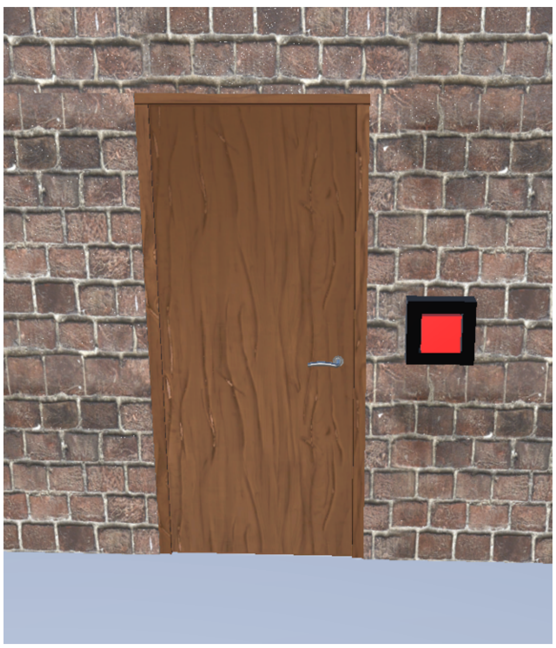

Fig. 5. Stage 2 Virtualized Everyday Objects Interaction with a door and an ADA button

There are three different parts to stage 2: the first, where the door is opened by turning a simple door knob; the second, where the door is opened by pressing a disability access button; and the third, where the door is opened by pulling a lever. By using a door knob, if the user is using VR gloves, they would approach their hand to the virtual door knob, as seen in Figure 4 and then, by making a fist, they could turn the knob which then opens the door. The door would work in a similar way, except the player would grab the lever and pull it down. For pressing a disability access button, the user would need to push the button with their hand in the virtual world. The implementation of VR controllers is nearly identical except that, instead of grabbing, the user would press down on the trigger.

Fig. 6. Stage 3 A user preparing to catch a ball

This stage was chosen to understand how users translate real, common objects into virtual objects and to analyze if they experience these interactions differently in the virtual world between the controllers and their virtual hands. Analyzing the level of presence is a key part of this step since the virtual hands input method will have no haptic feedback, while the user may experience such feedback with the controllers. This input may lead towards a change in the user's perception of their presence in VR. Another consideration is that this stage allows the examination of the ease-of-use of real objects that are virtualized into the VE. This standardization will determine if the direct translation of real objects to virtual objects is something that the users are comfortable with using or if there should be a level of remapping that occurs to allow for interaction. With this, it could be useful to determine if having a level of remapping occur could be more useful to the user for ease-of-use, because without remapping the user may not feel the expected haptic feedback.

C. Stage 3: Rigidbody Physics Object Interactions

For stage 3, the implementation of objects and the interactions with them was done by having the user interact with a series of objects with different properties. The final stage's implementation was split into three parts. A simple ball was implemented that the user would interact with in a variety of different ways, depending on the part. The first part would have the user catch a simple ball, as seen in Figure 6, the second would have the user tasked with throwing a ball, and the third would require the user to hit a ball that was bouncing in front of them.

If the user is using VR gloves, they would grab the ball to catch or throw by clenching their fist slightly. The ball would then be attached to their fist. For hitting the ball, the collision for the VR glove will be enabled that will move the ball depending on how the user hits the object. Similarly, when the user is using VR controllers, a user will hover over the ball and then click on the trigger to pick up the ball in order to catch or throw it. In the case of hitting the ball, since the controller will be displayed inside the virtual world, the ball would need to collide with the display of the controller in the virtual world.

This stage was chosen to analyze how users interact with physics objects in the virtual world. People typically have an expectation of how to catch a ball or dynamic objects in the real world, but this stage should help quantify if those expectations help the performance of that action in the virtual world. Quantifying performance with physics objects is critical in high fidelity applications of VR such as sports training. Therefore, it is important to understand if the level of remapping that occurs is relevant to the outside experiences one may reproduce in a VE. Currently, a level of remapping is required as the user expects haptic feedback when touching an object that never occurs. This effect could be mediated with haptic gloves in high fidelity scenarios.

V. Conclusion

Methods of interactions in VE need to be accommodated in order to account for new input medium for VEs. Virtual hands are a new input medium that may be more commonly used in the future. This work made an application to showcase the mediums of changing between virtual hands and VR controllers on interaction. This work applies HCI principles in VEs to allow for the examination of controllers and virtual hands as mediums of interaction and input in VR.

VI. Future Work

First, a user study using this application is of the utmost importance. The user study would be used to validate, using quantitative measures, how effective this application is at comparing the two input mediums.

Second, creating locomotion techniques for the VR gloves and comparing them to common locomotion techniques found for the controllers is likely a significant way to expand this application. Locomotion is integral to many games and applications. This would help to further compare the gloves and controllers using new metrics.

Third, almost every existing VR application can bring motion sickness to the users of that application. This application is no different. Therefore, it is important to test not just the usefulness of these input mediums, but also their effect on the persons using them.

VII. Acknowledgments

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