The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
Paper ID #41907

Comparative Analysis of Haptic Gloves for Custom-Developed VR Applications

Dr. Michael Michael Ulan Genialovich Dakeev, Sam Houston State University

Dr. Michael Ulan Dakeev is an Associate Professor in the Engineering Technology Department at Sam Houston State University. His areas of research include Virtual and augmented Reality, renewable energy (wind energy), quality in higher education, motivation, and engagement of employees

Dr. Iftekhar Ibne Basith, Sam Houston State University

Dr. Iftekhar Ibne Basith is an Associate Professor in the Department of Engineering Technology at Sam Houston State University, Huntsville, TX, USA. Dr. Basith has a Ph.D and Masters in Electrical and Computer Engineering from University of Windsor, Canada.

Dr. Suleiman M Obeidat, Texas A&M University

Dr. Suleiman Obeidat received his Ph. D. in Industrial Engineering from University of Oklahoma in 2008. Dr. Obeidat joined the Engineering Technology and Industrial Distribution Department at Texas A&M University in Fall 2015. Dr. Obeidat teaches differen

Dr. Reg Recayi Pecen, Sam Houston State University

Dr. Reg Pecen is currently serving as a Quanta Endowed professor of Engineering Technology at SHSU and he served fourteen years at the University of Northern Iowa (UNI) as a professor and program chairs of Electrical Engineering Technology and graduate programs where he established an ABET-ETAC accredited 4-year engineering technology program. He also served 4 years as a President and professor of a small, non-profit North American University in Houston, Texas. Dr. Pecen were awarded many grants from state, federal, and private agencies. Majority of Dr. Pecen's grants were in the areas of designing and implementing solar and wind hybrid power systems. Some of his previous grants included "Design and Implementation of 33.6 kW PV-based fast charging station on SHSU campus", "Promoting of Renewable Energy, Environment Education and Disaster Storm Relief through a state-of-the-art Mobile Renewable Energy Support (MRES)" from Entergy EIF 2021 and 2019. During his tenure in Iowa, Dr. Pecen designed and built a 12-kW hybrid wind-solar power systems on UNI campus, and a 6 kW wind-solar-micro hydropower system to provide green energy to RVs and Campers in Hickory Hills State Park. Dr. Pecen was recipient of 2022 service excellence award in the Engineering Technology at SHSU, 2011 UNI C.A.R.E Sustainability Award for the recognition of applied research and development of renewable energy applications at Iowa. Dr. Pecen was also recognized by State of Iowa, State Senate on June 22, 2012 for the excellent service and contribution to Iowa for development of clean and renewable energy and promoting diversity and international education between 1998 and 2012. Dr. Pecen served as past chair (2013-14), chair (2012-13), chair-elect (2011-12) and program chair (2010-11) of ASEE Energy Conversion Conservation & Nuclear Energy Division (ECCNED). Dr. Pecen also served on the U.S. DOE Office of Clean Energy Demonstrations (OCED) Energy Improvements in Rural or Remote Areas (ERA) FOA 3045 grant review and again U.S. DOE Energy Efficiency and Renewable Energy (EERE)'s merit grant, and U.S. DOE Rural Energy Development review committees to promote Grid Engineering for Accelerated Renewable Energy Deployment (GEARED) and Rural renewable energy initiatives.

Dr. Faruk Yildiz, Sam Houston State University

Faruk Yildiz is currently a Professor of Engineering Technology at Sam Houston State University. His primary teaching area is in the field of Engineer Technology.

Alyona Maliassova, Sam Houston State University
Paige Horton, Sam Houston State University

Comparative Analysis of Haptic Gloves for Custom-Developed VR Applications

Introduction

Virtual Reality (VR) technology has witnessed remarkable advancements in recent years, offering immersive experiences that transcend conventional forms of interaction [1]. One pivotal aspect of enhancing immersion in VR environments is the integration of haptic feedback, allowing users to feel and interact with virtual objects. Haptic gloves represent a crucial interface between users and virtual worlds, enabling a sense of touch and dexterity within immersive experiences [2]. As VR applications proliferate across diverse domains such as education, training, and entertainment, the selection of appropriate haptic gloves becomes imperative for optimizing user experience and achieving desired outcomes [3].

In response to the burgeoning interest in haptic technology, this paper presents a comparative analysis of three prominent haptic gloves: Manus Prime 3, SenseGlove Nova, and bHaptics TactGlove. This study aims to evaluate the performance and suitability of these gloves in real-world applications simulated in custom-constructed virtual environment. Central to our investigation is the hypothesis that the superior glove will exhibit enhanced capabilities in facilitating realistic motion and control, thereby broadening its applicability across various industries and use cases. In our previous studies, we introduced a VR robotic arm simulation to improve muscle memory for engineering students. In this study, we want to incorporate how haptic gloves may improve overall experience within the VR laboratory setting.

The significance of this comparative analysis lies in its potential to offer valuable insights to practitioners and researchers alike. By elucidating the relative strengths and limitations of different haptic gloves, this study seeks to inform decision-making processes regarding glove selection and deployment strategies.

Background

As the need to incorporate VR in the education is growing in medical fields [2], [4], [5], [6] the authors of this paper are developing two structured instructional frameworks in engineering education: 1 – Theoretical Conceptualization, and 2 – Practical Application. In the theoretical conceptualization phase, the authors involve students to theoretical principles and concepts through schematic representations of engineering processes and procedures. In this regard, the team has developed a custom-constructed virtual reality environment to build fundamental engineering theories, principles, and methodologies around haptic gloves functionalities. This phase involves students to learn about each selected haptic glove, investigate their manufacturer properties, and test their limitations within the VR environment to receive a superior tutoring attitudes during student performance [2], [5]. The practical application phase follows the theoretical phase, where the students move on to hands-on training and experimentation of selected 3 haptic gloves within the VR simulation. This practical experience is crucial to two different groups of students in this study: 1- student developers, who are the undergraduate junior to senior level students that assisted with the VR environment development, research on the haptic gloves, and set them up for the user students. They are responsible for setting up the

VR environment and the haptic gloves for the user students. Their involvement in the project equips them with valuable skills and experience for future applications in real-world engineering projects. Their engagement in the practical application phase, they gain hands-on experience in VR development and deployment strategies. This experience is crucial for their academic and professional growth, preparing them for future roles where VR technology is utilized, such as in engineering projects or research settings. 2- user students, who are the randomly selected students throughout campus with various majors that will use the haptic gloves to perform predetermined tasks within the developed virtual environment. They participate in hands-on training and experimentation with haptic gloves to perform predetermined tasks. This practical experience allows them to interact with technology and gain insights into its capabilities and limitations. Moreover, the VR environment serves as a platform for them to enhance their learning experiences, whether it's in education, training, or research. For example, in the context of the VR robotic arm simulation, user students may improve their muscle memory and understanding of engineering concepts by using haptic gloves within the VR laboratory setting. The practical application is expected to equip student developers (student group 1) for future applications in real-world engineering projects and supervise in practical settings in research. Additionally, the practicality of haptic gloves with VR can automatically record the outcomes and associated kinematic data on how the task is performed [6]. Therefore, both sets of students are integral to the learning objectives outlined in the paper. The student developers benefit from the hands-on experience in VR development, while the user students benefit from the immersive learning experiences facilitated by the integration of haptic gloves within the VR environment.

Methodology

To meet the study objectives, the team employs a multifaceted evaluation methodology that encompasses both quantitative and qualitative measures. Through the development of custom VR applications spanning medical, manufacturing, and entertainment domains, undergraduate students engage in hands-on experimentation with the three proposed haptic gloves. The team has been collecting feedback from randomly selected participants across campus and conducting statistical analyses to discern patterns and nuances in user experience, comfort, and efficacy across different glove models. Upon arrival, the student is greeted and provided with a brief introduction to the task at hand. They are informed that they will be testing out some haptic gloves and instructed to put on both the gloves and goggles, then notify the tester when they are prepared. Instructions for the task are indicated in purple (Figure 1) on a prominent stand within the testing environment. Once the user signals readiness, the tester initiates a 10-minute timer along with a stopwatch. The objective is for the user to utilize the gloves within the environment to manipulate a robotic arm via a remote control, lifting a small item from its stand and depositing it into a designated bin.

Figure 1. Participants reading instructions in VR.

The experiment evaluator records the time when the user successfully lifts the object and again when the participants release the object into the bin. The allotted time frame of 10 minutes accounts for any unforeseen challenges that may arise during the task; failure to complete the exercise within this timeframe is duly noted. Following the completion of the task, the user is requested to complete a survey (Figure 2a) regarding their experience with the tested gloves (Figures 2 b, c). Should the user opt to test another pair of gloves, the aforementioned procedure is repeated. Subsequently, the user is asked to fill out a demographics survey before being free to depart.

The decision to utilize the robotic arm project in the virtual environment was rooted in its prior success and validation through previous manuscripts[3]. Rather than embarking on the development of a new environment from scratch, leveraging the established and proven concept offered a pragmatic approach to assess the efficacy of haptic gloves. Additionally, it's noteworthy that the current project is concurrently developing a medical environment tailored for medical students, slated for implementation in the future. The rationale behind this choice was twofold: firstly, to explore the immediate impact of haptic gloves within the existing project, providing valuable insights into their effectiveness; and secondly, to inform the development of the forthcoming medical environment by understanding how haptic gloves enhance user experiences and learning outcomes. By evaluating haptic gloves in the context of the current project, we can better ascertain their potential benefits and challenges, thereby informing the design and implementation of future educational environments, particularly within the medical domain.

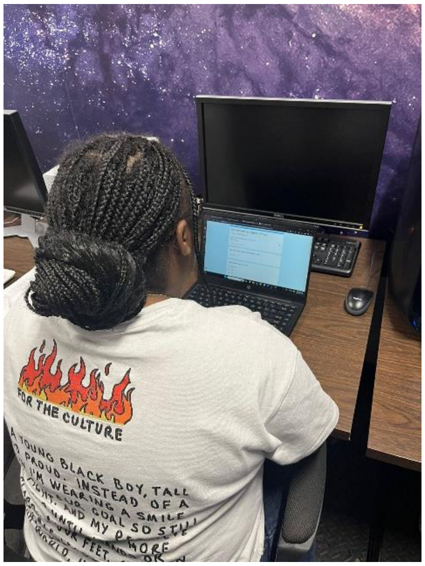

Figure 2a. Participant impressions on the VR experience.

Figure 2b. bHaptic Glove experience in VR.

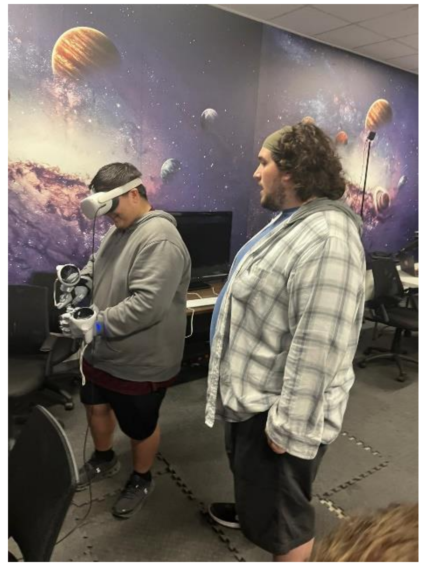

Figure 2c. SenseGlove experience in VR.

Data Collection

The pictogram in Figure 3 illustrates a sequence of steps involved in a user simulation scenario. Initially, the user enters the simulation area where they are provided with concise instructions. Subsequently, the simulation commences. The tester initiates a 10-minute timer and a stopwatch simultaneously to monitor the duration of the task. The user then proceeds to pick up an item within the simulation environment. The tester meticulously records the time taken for this action. Following this, the user unclamps the item, prompting the tester to record this time as well. Once the 10-minute timer elapses, the tester stops it, signaling the end of the task period. Finally, the user concludes the simulation by engaging in surveys or feedback sessions, likely aimed at evaluating their experience or performance within the simulated scenario. A structured process for conducting user activities highlights key actions and monitors mechanisms involved throughout the simulation task for each participant.

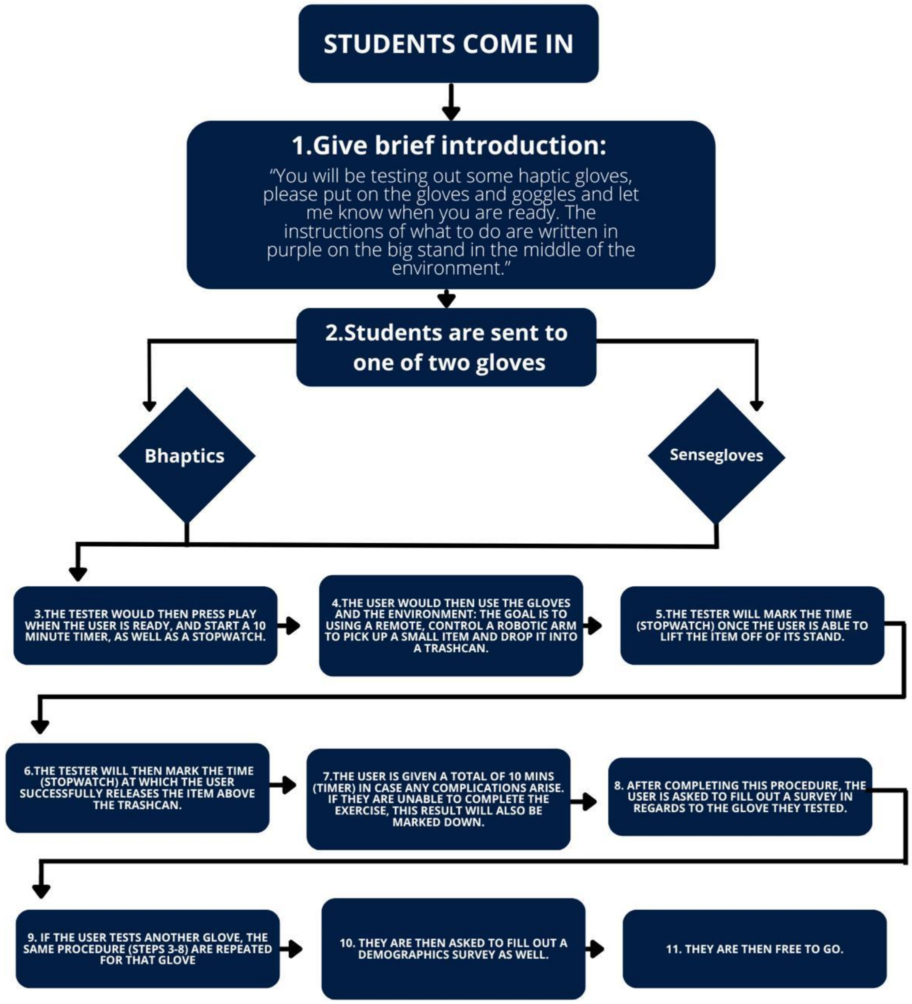

Figure 3. Participant's activities in data collection

Preliminary Data Analysis

As illustrated in the flowchart (Figure 3) this study has started data collection from two haptic gloves. Both gloves are set up in a similar fashion within Unity Engine and similar computers with identical hardware and software properties. Randomly selected students completed the given tasks in different time frames. The fastest time to pick up an object was 51.13 seconds with Sense Glove and it took 1:18:52 minutes to drop the object into the designated bin. Table 1 shows descriptive statistics for the pickup time for extrapolated number of participants.

Table 1. Descriptives for Pick up time in seconds.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
PickUpTime	99	33.9833	263.3333	131.678280	72.3776679
Valid N (listwise)	99				

Table 1 presents descriptive statistics for the pick-up time in seconds. The minimum recorded pick-up time is 33.9833 seconds, indicating the shortest duration observed in the dataset. Conversely, the maximum pick-up time is notably higher at 263.3333 seconds, representing the longest duration recorded. On average, the pick-up time stands at 131.678280 seconds, providing a central measure of the dataset. The standard deviation of 72.3776679 seconds suggests a moderate level of variability around the mean pick-up time, indicating that pick-up times vary somewhat from the average value. These descriptive statistics offer valuable insights into the distribution of pick-up times, including their range, central tendency, and variability, which can be useful for understanding the efficiency and performance of the pick-up process.

As this study is still in progress, we have collected 5 data points for the drop off time for the object in virtual reality. Since the collected data is small, we wanted to calculate how much this group deviates from the mean, therefore we calculated standard deviation for this data. Five participants values are as follow for each participant, where x1 represents participant 1.

- $x_1 = 78.86666667$
- $x_2 = 229.2833333$
- $x_3 = 236.2333333$
- $x_4 = 106.0333333$
- $x_5 = 180.55$

That yields standard deviation s = 71.343

A more detailed calculation is in the next page.

1. Mean ($\bar{x}$):

$$\bar{x} = \frac{78.86666667 + 229.2833333 + 236.2333333 + 106.0333333 + 180.55}{5} =$$

1. Deviation from the mean:

$$\begin{aligned} d_1 &= 78.86666667 - 166.39339998 = -87.52673331 \\ d_2 &= 229.2833333 - 166.39339998 = 62.88993332 \\ d_3 &= 236.2333333 - 166.39339998 = 69.83993332 \\ d_4 &= 106.0333333 - 166.39339998 = -60.36006668 \\ d_5 &= 180.55 - 166.39339998 = 14.15660002 \end{aligned}$$

1. Squared deviations:

$$\begin{aligned} d_1^2 &= (-87.52673331)^2 = 7661.333237 \\ d_2^2 &= 62.88993332^2 = 3958.453625 \\ d_3^2 &= 69.83993332^2 = 4885.550088 \\ d_4^2 &= (-60.36006668)^2 = 3643.313274 \\ d_5^2 &= 14.15660002^2 = 200.428543 \end{aligned}$$

1. Sum of squared deviations:

$$7661.333237 + 3958.453625 + 4885.550088 + 3643.313274 + 200.428543 =$$

1. Divide by $n - 1$:

$$\frac{20349.078766}{5-1} = \frac{20349.078766}{4} = 5087.2696915$$

1. Standard deviation (s):

$$s = \sqrt{5087.2696915} = 71.3431291511$$

From Table 1, we observed the standard deviation was 72.377 seconds for the pickup time of a virtual object with SenseGlove haptic gloves. Additionally, a preliminary data from 5 participants showed data ranged from min = 78.866 seconds to max=236.233 seconds, which resulted in standard deviation of 71.343 seconds. Therefore, we decided to continue to collect more data as the two standard deviations are not too far apart from each other (std pickup = 72.377 – std drop off = 71.343 = 1.034 seconds. Descriptive statistics for drop off time data is presented in Table 2 below:

Table 2. Descriptive Statistics for Drop Off Time in seconds

	N	Minimum	Maximum	Mean	Std. Deviation
DropOffTime	5	78.8667	236.2333	166.193333	71.3043405
Valid N (listwise)	5				

The feedback from participants regarding their experience with the SenseGlove varied. Participant 1 noted that the glove felt heavy and experienced some buzzing sensations, although they found it cool to use. Participant 2 also mentioned that the glove felt heavy, particularly over time. Participant 3 expressed interest in the potential of the glove for future projects but suggested improvements in size options and finger tracking capabilities, especially for individuals with specific needs like severe arthritis. Participant 4 acknowledged the weight of the glove but found it manageable, highlighting some difficulties with putting on the gloves and tightening the straps.

Participant 1: *"It was heavy, it started buzzing when I wasn't touching anything and the buzzing didn't feel very realistic. But it was cool to use."*

Participant 2: *"The glove gets really heavy really fast."*

Participant 3: *"Big good much cool this would be great to use in furture projecs if the gloves came in different sizes and could track my finger movements better. I could never get the gloves to fully open and or close. Think about a 90 year old with severe arthirtis."*

Participant 4: *"The glove is a bit heavy but manageable. It is a bit diffcult to put gloves on and tighting the staps."*

This study will involve both independent sample t-Test and One Way ANOVA tests as the evaluators collect more data. We are hopeful that we will have solid number of participants before the conference and present the outcomes there. Additionally, the outcomes will also follow in the future manuscripts. This paper focused on outlining user experience and comfort that collected feedback from randomly selected participants and manual calculation of the preliminary data. The statistical analyses primarily focused on aspects such as pick-up time for virtual objects, where descriptive statistics were used to analyze the efficiency and performance of the pick-up process. Additionally, preliminary data analysis included calculating standard deviations for drop-off times to compare the performance of different haptic gloves. These analyses provided insights into the distribution of pick-up times and drop-off times, offering valuable information on the efficiency and variability of users' interactions with the virtual environment.

Discussion

This study has provided valuable insights into the performance and suitability of different haptic gloves within a custom-developed virtual environment. While the primary focus has been on evaluating the capabilities of haptic gloves in facilitating realistic motion and control, it's imperative to consider the educational implications of this research. The study explores the performance and suitability of three prominent haptic gloves, namely Manus Prime 3, SenseGlove Nova, and bHaptics TactGlove, in real-world applications simulated in a custom-constructed virtual environment. We started to evaluate the gloves' capabilities in facilitating realistic motion and control, with the hypothesis that the superior glove will broaden its applicability across various industries and use cases within the custom developed virtual reality application. The significance of this analysis lies in its potential to offer valuable insights to practitioners and researchers for informed decision-making regarding glove selection and deployment strategies. The study encompasses both quantitative and qualitative measures, collecting feedback from participants and conducting statistical analyses to discern patterns and nuances in user experience, comfort, and efficacy across different glove models. Preliminary data analysis reveals descriptive statistics for the pick-up time in seconds, showcasing insights into the distribution of pick-up times, including their range, central tendency, and variability, which are crucial for understanding the efficiency and performance of the pick-up process. Further data collection is planned to compare these findings with two more gloves for pick up time and drop-off time statistics, ensuring a comprehensive understanding of haptic glove performance in VR applications. We are planning to complete collection of data for bHaptics and Manus Prime gloves so we can report their comparative results to SenseGlove at ASEE conference in Portland, OR in 2024. These outcomes may benefit engineering students who are involved in hands-on laboratory simulations via virtual reality.

The involvement of student developers, predominantly undergraduate students engaged in the development of the VR environment and research on haptic gloves, presents a unique opportunity for experiential learning. Active participation in the design, setup, and testing phases of the virtual environment, these students gain hands-on experience in VR development and deployment strategies. This practical exposure equips them with valuable skills and insights that are directly applicable to real-world engineering projects and research endeavors. Moreover, through iterative refinement and troubleshooting processes, student developers enhance their problem-solving abilities and critical thinking skills. Thus, the experience of working with haptic gloves within the virtual environment serves as a formative learning experience for student developers, preparing them for future roles in VR technology and engineering fields.

Similarly, the engagement of user students—randomly selected participants from various academic backgrounds—in hands-on training and experimentation with haptic gloves offers unique learning opportunities. Their interaction with technology within the immersive virtual environment, user students not only gain practical experience in utilizing haptic feedback for task completion but also enhance their understanding of complex concepts and processes. For instance, in the context of the VR robotic arm simulation, user students may improve their spatial awareness, hand-eye coordination, and problem-solving skills. Moreover, the incorporation of haptic gloves into laboratory learning processes fosters an interactive and engaging learning environment, promoting active participation and knowledge retention among students.

Furthermore, the process of selecting a haptic glove can be seamlessly integrated into laboratory learning processes, enhancing students' understanding of technology evaluation and decision-making. Involvement of students in the comparative analysis of different haptic gloves, help educators facilitate discussions on factors such as performance metrics, user comfort, and suitability for specific applications. This experiential learning approach not only empowers students to make informed decisions but also cultivates their critical thinking and analytical skills. Additionally, incorporating haptic glove selection processes into laboratory curricula may provide students with practical insights into the iterative nature of technology adoption and evaluation within professional settings.

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