Utilizing Commodity Virtual Reality Devices for Multi-user Training Simulations

Jack Miller, Austin Hanus, Eliot Winer
Iowa State University
Ames, Iowa
jackm@iastate.edu, ajhanus@iastate.edu,
ewiner@iastate.edu

ABSTRACT

In 2019, the US Military requested $8.8 billion for the training and education of soldiers for operations and maintenance to fund programs such as recruit training, specialized skills training, and flight training. One method to decrease the cost and improve the efficiency of training is to utilize commodity virtual reality (VR) technology. Studies have shown that this technology can be used in a variety of fields to improve training and learning outcomes with cost and performance benefits. Although previous VR environments have been developed to train personnel, these environments are geared towards a single user, include limited input capabilities, and require expensive hardware preventing them from large scale use. Developing VR environments for multiple users with real-world, passive haptic interactions on low-cost commodity devices will broaden the applications of VR training environments for the military.

To investigate this, a framework was developed to explore the capabilities of the HTC Vive in a multi-user training simulation. In various scenarios, trainees may interact with a plethora of virtual objects. While the Vive provides tracked wands for user input, the physical motions needed to grasp and move the controllers rarely represent the actual motions required to interact with a virtual object. To address this, passive haptics were implemented to provide sensory cues. Furthermore, to support a multi-user experience, the physical and virtual environments were synchronized to allow both users access to the same passive haptic cues. This was accomplished by establishing a common frame of reference through a shared tracking system. To evaluate this framework, informal tests were performed on a simulated maintenance operation. Participants reported high levels of immersion through intuitive interactions with their partners. By combining low-cost commodity devices, this framework provides the benefits seen in expensive VR environments to the US Military at a fraction of the cost.

ABOUT THE AUTHORS

Jack Miller is a graduate student in Mechanical Engineering and Human-Computer Interaction at Iowa State University's Virtual Reality Applications Center. He is working on developing Augmented Reality work instructions for complex assembly.

Austin Hanus is an undergraduate student in Computer Engineering at Iowa State University. He is currently work as a research assistant for Dr. Eliot Winer at the Virtual Reality Applications Center and is developing virtual training environments.

Eliot Winer, Ph.D., is an associate director of the Virtual Reality Applications Center and professor of Mechanical Engineering, Electrical and Computer Engineering, and Aerospace Engineering at Iowa State University. Dr. Winer has over 20 years of experience working in virtual reality and 3D computer graphics technologies on sponsored projects for the Department of Defense, Air Force Office of Scientific Research, Department of the Army, National Science Foundation, Department of Agriculture, Boeing, and John Deere.

Utilizing Commodity Virtual Reality Devices for Multi-user Training Simulations

Jack Miller, Austin Hanus, Eliot Winer
Iowa State University
Ames, Iowa
jackm@iastate.edu, ajhanus@iastate.edu,
ewiner@iastate.edu

INTRODUCTION

With the ever-changing equipment and procedures of the US Military, they requested $8.8 billion for the training and education of soldiers for operations and maintenance ((Comptroller), 2019). Currently, programs for training new recruits basic and specialized skills are in place to maintain peak performance for the soldiers and equipment. However, due to fast moving technology, the soldiers require continual training to properly use new equipment. Frequent training becomes time consuming and expensive. Many of the procedures are complicated and require one-on-one training from a professional. Traditionally, this training was accomplished using tablets or two dimensional (2D) instructions. However, virtual reality (VR) technology has been proven in various scenarios to improve the efficiency and effectiveness of traditional training techniques for these operations and maintenance procedures (Boud, Haniff, Baber, & Steiner, 1999; Chung, Shewchuk, & Williges, 2002).

Previously, the solutions created with VR were made for custom devices specific to a lab and primarily for research. Many of the custom devices were very expensive, required experts to maintain, and were limited to a single user at a time. However, recent advancements in VR technology have made Head Mounted Displays (HMDs), such as the HTC Vive or Oculus Rift, cheaper and accessible to more people. These commodity HMDs provide the benefits of traditional VR technology for training simulations but at a fraction of the cost. They are easily maintained and can be adapted for multi-user simulations, overcoming the limitations of the traditional VR devices, such as cave automatic virtual environments (CAVEs). The HMDs can also employ passive haptics, allowing users to freely use their hands throughout the simulations. Passive haptics increase immersion and enable more robust virtual environments for training.

This paper presents a framework for developing training simulations using commodity HMDs in a multi-user environment with passive haptic feedback. This framework fully utilizes commodity devices and does not depend on expensive specialized equipment, such as an additional tracking system. As a demonstration, an expert-novice tire changing simulation was developed to display each of the benefits of the framework. The HTC Vive and Leap Motion devices were used to implement the framework because of their ease of development, low cost, and hardware advantages. The framework was then evaluated and iterated with informal testing. The feedback from this study showed that multi-user capabilities and passive haptics increased engagement among all users. These preliminary results show promise for the potential of this training framework for a variety of training scenarios.

BACKGROUND

VR technology enables the placement and manipulation of three-dimensional (3D) objects in a virtual space. This environment can be viewed through a variety of devices, such as a computer screen, tablet, or more recently, head mounted displays. The HMDs bring new excitement to the virtual reality industry and create a variety of new uses for this technology. For this paper, we created a framework for utilizing this new technology for realistic training applications. A multi-user experience was also included to enable a larger variety of simulations. The framework also provided the ability to implement passive haptics to allow the creation of hands-free training simulations.

Virtual Reality Training

Virtual reality training is increasingly popular for teaching procedural tasks. As seen from Boud et al., VR has been shown to outperform traditional 2D engineering drawing instructions (Boud et al., 1999). Boud et al. developed a training tool for assembly tasks and performed the same training using various mediums to teach the participants. Although the augmented reality system produced the best results, the VR medium still showed a significant increase over the traditional 2D engineering drawing instructions. However, Chung et al. found that the largest perceived limitations for implementing virtual environments in the manufacturing industry were cost and lack of present staff skill (Chung et al., 2002). This shows that historically, the cost of the virtual technology has been the biggest factor in not implementing the technology in manufacturing industry.

VR technology also is effective in training operating room procedures. Seymour et al. created a VR trainer for transferring technical skills to an operating room (Seymour et al., 2003). They found that VR-trained residents were 29% faster, 9 times less likely to fail to make progress, and five times less likely to injure the gallbladder or burn non-target tissue. Overall, the group mean errors for VR-trained residents were six times less likely than through traditional training methods. Ahlberg et al. created a VR training simulation for laparoscopic cholecystectomies (Stefanidis, Korndorffer, Markley, Sierra, & Scott, 2006). Their results showed the VR-trained group made significantly fewer errors, as well as used 58% less surgical time. VR technology has shown great promise in the medical field and should be investigated further for other procedural based training.

The United States Army has explored the use of VR training for a variety of simulations through their Synthetic Training Environment (STE) (USAASC, 2019). The STE utilizes many realistically environments and scenarios to allow for multi-user training. Furthermore, in some cases the physical world is utilized for haptic feedback in addition to virtual content. While the research described in this paper also allows for multi-user training and haptic feedback, the focus varies significantly. First, this research seeks to utilize low-cost hardware and passive haptic props to achieve the same affects as custom-built, expensive simulations at a fraction of the cost. Second, the multi-user capabilities of this paper are meant for multiple users within the same physical space. This allows them to interact with the same physical props, environment and each other to accomplish novel tasks. While these systems may have similar goals, very different approaches and outcomes are achieved.

Virtual Reality Hardware

Maintenance and operations training are often taught through handbooks or instruction manuals. However, due to advancements in VR technology within recent years, virtual environments are becoming more realistic and easier to implement. Historically, VR technology was custom built, and research focused, making it difficult to develop and expensive to maintain. With the creation of commodity head mounted displays, such as the HTC Vive and Oculus Rift (Oculus, 2019; Vive, 2019), VR is increasingly accessible. These devices provide comparable quality to the custom-built devices, such as CAVE systems, at a fraction of the cost. They can track head position as well as various devices throughout the physical world and place them in a 3D environment that the user can explore.

Multi-user experience

Multi-user virtual environment research has showed that the collaborative environment can assist in the development of problem-solving skills (Rogers, 2011). Rogers created a multi-user virtual environment for clinical simulations and found that the environments were ideal for proactively engaging students. The study showed promising results for developing understanding of problem-based decision-making skills. Johnson et al. presented a virtual world for elementary students to learn environmental concepts in a multi-user CAVE system (Johnson et al., 2002). Although it was difficult to measure the learning capabilities of the environment, they found that the students understanding of environmental concepts increased by 23% after using the simulation. This shows promise that multi-user environments are beneficial to overall learning outcomes, but it is necessary to explore the interactions further.

Passive Haptics

The use of passive haptic feedback in immersive interactions is an important avenue for improving realism and immersion in virtual environments. Haptic feedback provides the physical sensation of touch. Specifically, passive haptics involves using physical props to provide the same sensation to virtual objects that a user would expect when interacting with similar physical objects. Therefore, the sense of touch provided by passive haptics gives the user physical feedback which helps relate their body to the virtual environment they are present in. The use of passive haptics makes more enjoyable and realistic environments (Cheng, Chang, Marwecki, & Baudisch, 2018; Nagao, Matsumoto, Narumi, Tanikawa, & Hirose, 2018). Furthermore, it has been shown that adding passive haptics can greatly improve presence (Insko, 2001). Presence is generally defined as the feeling of "being there" when within a virtual environment (Sanchez-Vives & Slater, 2005). This is critical for training as the user must be able to relate their actions to the physical space they will be working in after finishing their training. When using passive haptics, it is crucial that the virtual and physical objects are synced together within the virtual environment that the user is viewing. Since the virtual object is their only reference for the position of the physical object, a mismatch between their locations causes confusion and frustration.

METHODOLOGY

The goal of this research was to develop a multi-user training framework in which users may capitalize on the benefits of passive haptics for training applications. To achieve this goal, the physical and virtual environments were synchronized to properly co-locate the users and passive haptic props within both environments. This allowed both users to interact with the same physical props in addition to each other. The following section will describe the approach taken to achieve this system.

Hardware

In recent years, numerous commodity VR HMDs have become commercially available. Some of the most notable VR HMDs include the HTC Vive (Vive), Oculus Rift, Samsung Odyssey, and PlayStation VR. All these HMDs feature similar specifications and therefore provide similar VR experiences as shown in Table 1. The HTC Vive was selected due to its lighthouse tracking system. This lighthouse tracking system utilizes an outside-in approach meaning that external sensors track the HMD and other devices within a given space. While many other HMDs utilize a similar outside-in tracking approach, the Vive lighthouses allow for multiple Vive systems to be tracked using the same pair of Vive lighthouses. This advantage is critical to the functionality of the multi-user training framework later described in this paper.

The Leap Motion was utilized within this framework to give users a virtual representation of their hands within the virtual environment. This device utilizes of two RGB cameras and three infrared LED cameras to capture information about the user's hands. For most VR use cases, including this framework, the device is mounted on the front of the headset to ensure hand detection whenever possible. Leap's propriety software analyzes the raw data from the five cameras on the device and outputs the pose of the user's hands and fingers in real time.

Table 1. Popular Commodity Virtual Reality HMDs Specifications.

Specifications	HTC Vive	Oculus Rift	Samsung Odyssey	PlayStation VR
Field of View	110	110	110	110
Resolution	2160x1200	2160x1200	2880x1600	1920x1080
Tracking	Outside-In	Outside-In	Inside-Out	Outside-In
Computing Requirements	VR Capable Computer	VR Capable Computer	VR Capable Computer	PlayStation 4
Price	\$500	\$400	\$500	\$250

Development Tools

The development tools used for this project included Unity3D, Photon Unity Networking (PUN), SteamVR software development kit (SDK), and Leap Motion SDK. Unity3D was chosen as the development platform as it provides a toolkit for all functionality required for a virtual reality application. This allows developers to go through quick development iterations. PUN was used to network multiple instances of the application and synchronize all the objects within the virtual environment enabling the framework to incorporate multiple users. This application program interface (API) was chosen as it provides a robust and reliable platform for networking within a Unity3D environment.

SteamVR was chosen for extensive compatibility with the HTC Vive virtual reality hardware platform. SteamVR provides the functionality to develop for the Vive using Unity3D, as well as some basic functionality often used in virtual reality applications. Finally, the Leap Motion SDK was used to communicate with the Leap Motion device within the application. This SDK provided ample documentation to quickly integrate and utilize the Leap Motion for hand tracking within the framework.

Multi-User Training Framework

To enable a collaborative training environment, multiple users needed to be co-located within the same virtual environment. While this has been done many times in the past, this framework enables the use of passive haptics to enhance training outcomes. Since passive haptics utilize physical props within the real world, users would need to have access to the same physical props. Furthermore, if users were in separate physical locations, active haptics would be necessary to synchronize the pose of each prop. To overcome these limitations, this framework synchronizes the virtual and physical environments. Through this synchronization, users can interact with the exact same physical props and perform collaborative tasks such as carrying an item together or passing on object to a partner.

This effect was achieved through the Vive's lighthouse tracking system paired along with the networking capabilities of PUN. Vive lighthouses send out a signal that Vive headsets and trackers detect and calculate their pose from. Therefore, it is possible to have multiple Vive systems being tracked by the same lighthouses. For this framework, the authors limited the number of users to two due to space constraints of the tracked area. Despite both users being tracked by the same lighthouses, the world space coordinates and axis of each Vive system are arbitrary and do not align, see Figure 1. Therefore, to ensure an accurate synchronization, the transform of each tracked object's pose relative to the pose of the lighthouse was calculated. This transform is then passed over the network to the other user's system where it is then transformed by the pose of their lighthouse coordinate system. Through this synchronization, the virtual environments and tracked objects are properly aligned relative to the real world for both users, shown in Figure 1.

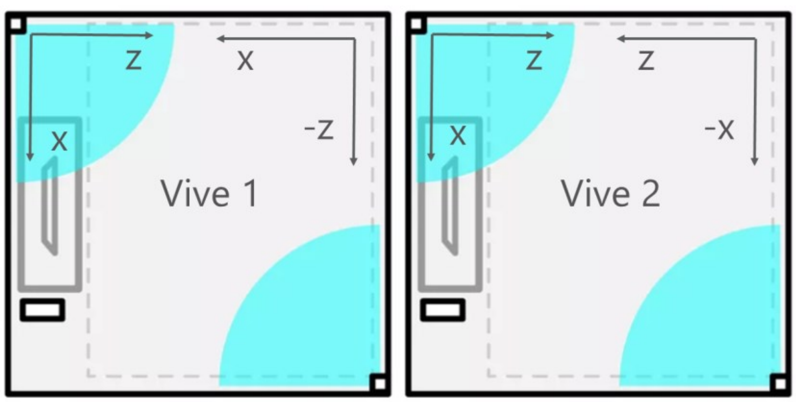

Figure 1. Dissimilar world coordinates synchronized through lighthouse pose.

Passive Haptics Implementation

To enable passive haptics within this framework, Vive controllers and trackers were used to accurately position virtual content relative to their real-world props. Trackers were placed on real world props and then the necessary offset was applied when authoring the training simulation. Due to the flexibility of this framework, the possibilities of these passive haptics are limitless, see Figure 2 for examples. This may range from very literal props such as a physical bike pump for a virtual bike pump, to very abstract props such as a wheeled cart with cardboard to simulate rolling a tire, see Figure 2. Other examples include using a controller and cardboard tube to simulate the feeling of an impact driver while using the controller's additional tactile feedback during operation or using multiple trackers to simulate a car jack, both shown in Figure 2.

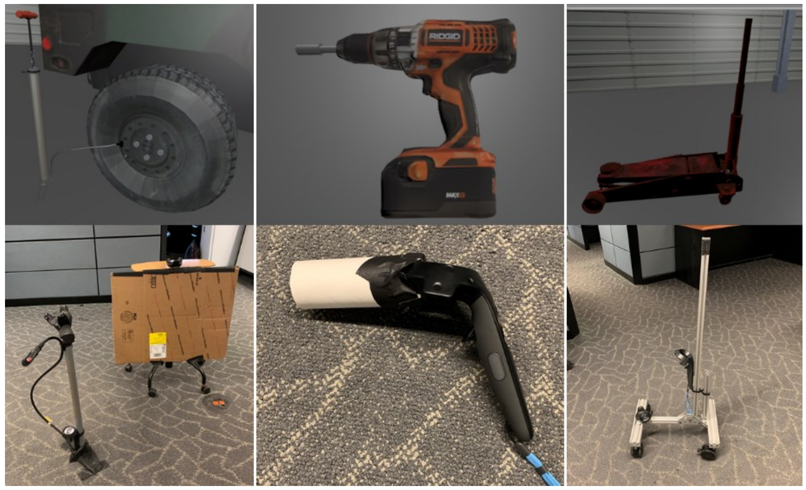

Figure 2. Example passive haptics.

Since passive haptic props are used within this framework, users needed to be able to intuitively understand where their hands were relative to the physical props and virtual content. Since the Vive headset fully occludes the real environment, users are not able to see their hands. To overcome this, the Leap Motion was implemented to give user's a virtual representation of their hands. This provides users with the necessary proprioceptive cues in order to interact with the passive haptics. Additionally, the hand's pose was networked so users can see each other's hands as well. This allows for additional interactions such as hand signals, passing objects back and forth or even shaking hands, see Figure 3. Finally, as every object within the virtual scene does not have a passive haptic prop associated with it, users needed a cue to understand when they couldn't physically touch an object. To achieve this, a custom shader was written to visually increase the transparency of the object when the user tries to touch an object that isn't physically interactable.

Avatars

Avatar appearance often makes an impact on how users perceive themselves and others within virtual environments. As previously described, the pose of the user's head and hands may be ascertained through this multi-user training framework. From that information, an avatar of the user's hands and head is rendered in that exact position. For this research, a generic androgynous head wearing an HTC Vive headset was rendered for the user's head and a basic hand model for their hands. Since the focus of this research was the underlying framework to allow for such interactions, it was decided that the avatars should be simple and not distracting.

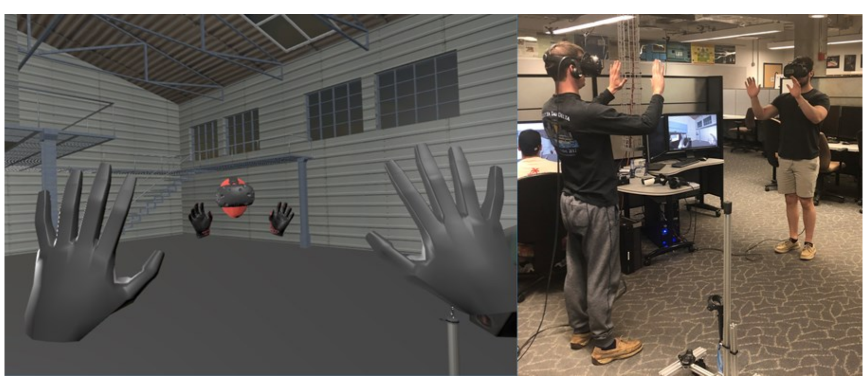

Figure 3. Avatar Appearance.

Authoring Simulations

This multi-user training framework may be used for a large variety of training simulations and applications. However, each new simulation must be authored using this framework. Unity3D is utilized as the current authoring tool so a designer would be able to import a range of models, animations, environments and scenarios. Through this framework, the environment will automatically synchronize relative to the lighthouse. Furthermore, to track a physical prop, the designer would only have to provide an offset of the virtual content relative to the prop. Any additional content and interactions would require additional scripting for their respective purpose.

EVALUATION

Tire Changing Task

To evaluate the multi-user training framework described in this paper, an expert-guided training simulation of a tire changing task was developed. This simulation involves a six-step process including: jacking up the car, removing lug nuts with an impact driver, rolling the old tire out of the work area, rolling the new tire into the work area, replacing the lug nuts, and inflating the tire. To guide the trainee through the tire changing task, the multi-user aspect of the framework was utilized to enable an expert to exist within the same environment as the trainee. The expert can demonstrate, work with, and guide the trainee through the tire changing task, see Figure 4. Through the described framework, this simulation was successfully authored with no additional development needed. This scenario shows the potential of this framework to be used in a large variety of multi-user training simulations.

Figure 4. Expert demonstrating tire inflation, passing the impact driver to the trainee, and guiding the trainee through the installation of the lug nuts.

Informal Testing and Iteration

To assess the effectiveness of this framework, informal tests were performed on five users. These users consisted of five males that were all heavily experienced with VR applications. Each user performed the tire changing task previously described and shown in Figure 4. An experimenter acted as the expert and guided the user through the tire changing task. Through these tests, each user successfully completed the task and feedback, in the form of comments about the experience, was taken to further understand how they performed and how they felt about the training scenario. All five participants noted that they felt that the passive haptics drastically increased their presence within the training simulation. Furthermore, the participants found that the expert was useful in understanding the task and they felt they were able to have a successful dialog despite the minimalistic avatar implementation. The main issues found included poor tracking of the passive haptic props when they were fully or partially occluded from the lighthouse tracking system. Similarly, participants reported that the calibration of the physical props was not always perfect, but they were still able to find the physical prop and complete the task. The feedback from these tests were then used to further iterate and refine the multi-user training framework. Formal user testing including the collection of quantitative data would be useful in the future. However, this preliminary testing was used to better understand how users would use this system. Overall, these results are promising for the use of this training framework for multi-user training simulations. Despite the drawbacks, the participants generally reported positive comments. The successful multi-user functionality allows for a large variety of training simulations, while the increase in presence from the passive haptics may lead to better training outcomes.

CONCLUSION AND FUTURE WORK

This work seeks to reduce the amount of time and money the U.S. Military spends on Operations and Maintenance specifically for training, currently at $8.8 billion. Through this multi-user training framework, the high costs behind U.S. Military training can be greatly reduced through more effective and efficient VR training. Furthermore, by utilizing low-cost commodity VR devices and passive haptics for a multi-user simulation, this framework would be viable for vast number of scenarios at a much lower cost.

The research presented in this paper provides a novel approach to multi-user training simulations using only low-cost commodity VR devices. The tracking system of the HTC Vive lighthouses was leveraged to provide a multiple user experience with synchronized virtual and physical worlds. Furthermore, passive haptics were introduced to provide more realistic haptic feedback potentially increasing muscle memory learning outcomes. Through this multi-user tracking framework, the passive haptic props were available to both users and they may physically interact with each other as well. The evaluation of this framework through the tire changing training simulation showed promising results. The successful implementation of the tire changing task itself demonstrated the extensibility of this framework while the informal tests showed the potential of such a system. Through this framework, commodity VR devices such as the HTC Vive will allow for extensive multi-user training scenarios.

Future work of this research would seek to improve the capabilities and usability of this multi-user training framework. Perhaps one of the most beneficial directions would be to develop a standalone authoring tool to create new training scenarios. Currently, scenarios are authored on top of the framework within Unity3D. This process would require the author to have experience with Unity3D and may take a considerable amount of time. By developing a standalone authoring tool, this could streamline the process and allow a greater range of authors to develop training scenarios. Furthermore, while this framework currently supports two users, this would easily be extended to any number of users as the main constraint is physical space. With new tracking systems, such as the Vive 2.0 lighthouses, the tracked range extends considerably and would allow for more users within a training scenario. With the addition of more users, it would be possible to develop more complex situations that involve large teams to interact with each other and the environment. It would also be conceivable to utilize inside-out tracking systems to further extend the tracking range. However, since these tracking systems are independent of each other, an additional tracking system would be necessary to reconcile each user's position relative to the others. While this framework utilizes passive haptics for many interactions, it would be beneficial to explore other haptic techniques such as active haptics or even sensory substitution. Active haptics would allow for more dynamic interactions but has the drawbacks of traditionally being very expensive and bulky. Sensory substitution has shown promise for a variety of applications, including training, by substituting the cues normally given by haptic feedback with other senses such as visual cues, audio, and reduced tactile cues. Finally, a user study would be critical to fully evaluate the effectiveness of this system against traditional training methods. With the greater capabilities of multi-user training simulations provided by this future work, the authors would seek to provide more functional, usable and immersive training simulations utilizing commodity VR devices. Using this framework, the military would be able to capitalize on the vast benefits of VR training while drastically reducing cost.

REFERENCES

(Comptroller), O. of the U. S. of D. (2019). *DoD Fiscal Year 2020 Budget Proposal*. Retrieved from http://comptroller.defense.gov/.

Boud, A., Haniff, D., Baber, C., & Steiner, S. (1999). Virtual Reality and Augmented Reality as a Training Tool for Assembly Tasks. *IEEE International Conference on Information Visualization*, 32–36. https://doi.org/10.1109/IV.1999.781532

Cheng, L.-P., Chang, L., Marwecki, S., & Baudisch, P. (2018). iTurk: Turning Passive Haptics into Active Haptics by Making Users Reconfigure Props in Virtual Reality. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18* (pp. 1–10). New York, New York, USA: ACM Press. https://doi.org/10.1145/3173574.3173663

Chung, K. H., Shewchuk, J. P., & Williges, R. C. (2002). An analysis framework for applying virtual environment technology to manufacturing tasks. *Human Factors and Ergonomics in Manufacturing & Service Industries*, *12*(4), 335–348. https://doi.org/10.1002/hfm.10023

Insko, B. E. (2001). *Passive Haptics Significantly Enhances Virtual Environments*. *University of North Carolina at Chapel Hill*. University of North Carolina at Chapel Hill.

Johnson, A., Roussos, M., Leigh, J., Vasilakis, C., Barnes, C., & Moher, T. (2002). The NICE project: learning together in a virtual world, 176–183. https://doi.org/10.1109/vrais.1998.658487

Nagao, R., Matsumoto, K., Narumi, T., Tanikawa, T., & Hirose, M. (2018). Ascending and Descending in Virtual Reality: Simple and Safe System Using Passive Haptics. *IEEE Transactions on Visualization and Computer Graphics*, *24*(4), 1584–1593. https://doi.org/10.1109/TVCG.2018.2793038

Oculus. (2019). Oculus Rift: VR Headset for VR Ready PCs. Retrieved May 11, 2019, from https://www.oculus.com/rift/#oui-csl-rift-games=mages-tale

Rogers, L. (2011). Developing simulations in multi-user virtual environments to enhance healthcare education. *British Journal of Educational Technology*, *42*(4), 608–615. https://doi.org/10.1111/j.1467-8535.2010.01057.x

Sanchez-Vives, M. V., & Slater, M. (2005). From presence to consciousness through virtual reality. *Nature Reviews Neuroscience*, *6*(4), 332–339. https://doi.org/10.1038/nrn1651

Seymour, N. E., Gallagher, A. G., Roman, S. A., O'Brien, M. K., Bansal, V. K., Andersen, D. K., & Satava, R. M. (2003). Virtual Reality Training Improves Operating Room Performance. *Annals of Surgery*, *236*(4), 458–464. https://doi.org/10.1097/00000658-200210000-00008

Stefanidis, D., Korndorffer, J. R., Markley, S., Sierra, R., & Scott, D. J. (2006). Proficiency maintenance: Impact of ongoing simulator training on laparoscopic skill retention. *Journal of the American College of Surgeons*, *202*(4), 599–603. https://doi.org/10.1016/j.jamcollsurg.2005.12.018

USAASC. (2019). Synthetic Training Environment (STE). Retrieved June 16, 2019, from https://asc.army.mil/web/portfolio-item/synthetic-training-environment-ste/

Vive. (2019). VIVE Virtual Reality System. Retrieved May 11, 2019, from https://www.vive.com/us/product/vive-virtual-reality-system/