A Systematic Analysis of Graphics-Based Hardware and Software for Virtual Reality Instructional Framework

Magesh Chandramouli
Computer Graphics Technology
Purdue University Northwest

Ge Jin
Computer Graphics Technology
Purdue University Northwest

Daniel Cubillos
Computer Graphics Technology
Purdue University Northwest

Justin Heffron
Computer Graphics Technology
Purdue University

Abstract

This study explains in detail a review of the graphics-based Virtual Reality (VR) hardware and software that were evaluated systematically for use in the NSF-funded study (Project MANEUVER). Project MANEUVER (Manufacturing Education Using Virtual Environment Resources), is developing an affordable VR framework to address the imminent demand for well-trained digital manufacturing (DM) technicians. This paper explains the various important factors including instructional, graphics-based, immersive, and interactive aspects that need to be carefully considered in the decision making process for the NSF Maneuver project, and this can serve as a reference for other similar projects. 3D Virtual worlds can be visualized by means of an extensive array of interfaces such as CAVE (Computer Assisted Virtual Environments), desktop VR, HMD (Head Mounted Displays), etc. The other factors that are important especially from a graphics-perspective include: Hardware (CPU) and graphics requirements, cost, standalone possibility, software compatibility/support.

Introduction

DM refers to the use of computer systems to model, simulate, and analyze models/scenes in order to help design and test in an easier and more cost effective manner than in real life (Holmstrom, Liotta, & Chaudhuri, 2017). Typically, DM employs manufacturing technologies driven by a computer (digital) framework. DM facilitates prototyping, manufacturing, and assembling and is closely connected to computer-integrated manufacturing (CIM), flexible manufacturing, lean manufacturing, and design for manufacturability (DFM).

NSF Funded study project MANEUVER, was created to train DM technicians by using VR to provide the necessary training in a cost-effective and convenient manner. The study uses a VR environment to show users three different 3D printing machines using Fused Deposition Modeling (FDM). Users are able to view accurate representations of commercially used 3D printers and view an interactive tutorial. This is done by allowing users to navigate (walk, pan, and fly) around the printers, viewing them from all angles, observing an animated tutorial on how each printer creates 3D prints, and having interactive head and arm controls to choose settings on the tutorial, which include the ability to select a specific model of printer and a specific process. These are delivered to the user through VR-based simulations alongside tutorials corresponding to instructional modules.

For the purposes of this study, simulation refers to the representation of the 3D printing system through the use of 3D VR models and environment (Figure.1), to facilitate instruction and virtual interaction to understand digital manufacturing processes. Users can understand the needed information using this method, as VR provides effective training to accurate 3D models, interactive controls, and the participants' active involvement (Toth, Ludvico, & Morrow, 2014). While the simulation is important, the system that the users interact with the simulation is also important. It is just as necessary to have a thorough understanding of the VR hardware and software that are available. Several systems intended for VR exist; however, they have different instructional, graphics, immersive, and interactive aspects (Table.1).

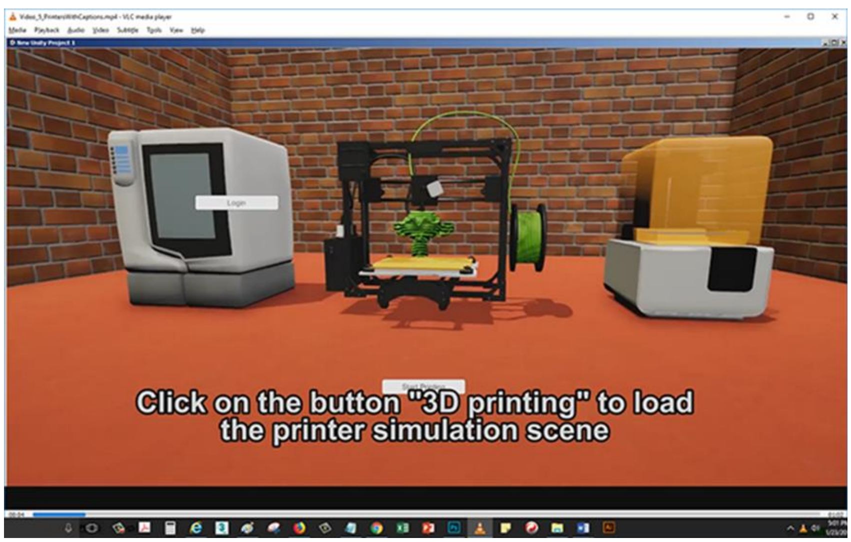

Figure.1: VR Simulation of Manufacturing Processes

Literature Review

The reason that VR has been effective means of training is due to the benefits it provides in reduced time and cost as well as minimizing risk. VR allows companies to train employees on hazardous situations/objects without exposing them to the danger in the real world.

VR training is used to teach by creating a virtual world that the user can interact with using a headset and motion controls to simulate arm and hand movement. Often entire environments along with the machinery are created in the virtual world. The VR helicopter training program developed by Virtalis for the British Armed Forces to assist in training pilots (Ergürel, 2016) is a good example of such VR worlds. Another real world example is the Juguar land Rover using VR to test the designs of their vehicles and better visualize user interaction (Steed, 2017). VR has been applied in various other engineering and technology (ET) disciplines including introductory programming in automotive industry (Attridge, Williams, & Tennant, 2005) engineering courses (Chandramouli, Zahraee, & Winer, 2014), 3D Design Process for manufacturing (Elbadawi, 2014), construction (Leinonen & Kähkönen, 2000), ET education (Chandramouli, Takahashi, & Bertoline, 2014)

VR training simulations have also been used in a variety of fields for training outside of engineering (Gallagher et al., 2005). Wiet et al., 2002, used a virtual bone dissection simulator to help students obtain a similar experience to performing the activity in a laboratory, providing a quicker and easier method of performing the experiment than the real life counterpart. This type of training can also be performed for complex operations such as Neurosurgery (Delorme, Laroche, DiRaddo, & Maestro, 2012), and laparoscopic surgery (Grantcharov et al., 2004), and has been proven to be an effective teaching method. This shows that VR is a useful training tool for a variety of fields.

Methodology

At the beginning of the study, the Oculus/High Tech Computer Corporation (HTC) Vive was the initial hardware chosen, however, due to multiple factors during the study the hardware had to be changed. When first beginning the study, the Oculus/HTC needed a high-end laptop or desktop with Windows 10 Operating System, Intel i5 Quad Core Processor, NVIDIA® GeForce® GTX 1050 with 4GB GDDR5 with HDMI output, 8GB DDR3 Memory, and Bluetooth v4. However, technical issues were often experienced when attempting to run the system on the laptop.

One important requirement for the VR headset is that it supports high-quality positional tracking. Positional tracking involves capturing the player’s real world position in 3D space and translates this to the virtual world, allowing them to walk around within the given confines of the defined play area. The HTC Vive utilizes two infra-red trackers placed at opposite ends of the play space, allowing for much more accurate tracking when facing away from the computer. However, this has the drawback of being fairly non-portable and potentially causing issues with multiple headsets running in close proximity. The Windows Mixed Reality technology headsets use “inside-out” tracking which captures images from the real environment using cameras on the front of the headset, thus alleviated the need for external sensors. The software then uses data from when the play area is first set up and boundaries are defined to calculate the player’s position in space (Aaron, Zeller, & Wojciakowski, 2017). The ability to have accurate tracking is essential to almost all VR experiences as it allows the player to not only look around by rotating their head, but also to be able to have movements in the real physical space translate to the digital. The usage of positional tracking increases the user's sense of presence and immersion in the virtual world.

The HTC Vive head set needed a large amount of room for the boundary, the space needed for the player to move freely. Spaces such as a living room in someone's house would not create much trouble, but in a classroom with several students using the system at once, it becomes chaotic due to the limited space. Because of these issues, it was decided that a new system should be used.

The options that were considered for the replacement VR system were the Samsung Odyssey, Google Card Board Headset (GCBH), and Dell Visor (Figure.1). In order to determine the best system for the study, a comparative analysis was created using the Oculus/HTC as the basis to compare the other systems.

Figure 2. VR Systems Assessed for Project MANEUVER

However, selecting the correct VR system is a multifaceted problem. The system must be able to meet the instructional, graphics-based, immersive, and interactive aspects needed for users to receive necessary instruction while being immersed in the simulation.

These aspects are the ability to move and look around the virtual scene, the ability to move arms and hands to pick up objects and select options, play sound, and have accurate field of vision for the user to tell depth in the scene.

Moving around and interacting with objects both aid with user immersion and help create a sense of presence in the scene. Additionally, it is hoped that such levels of interaction help facilitate "hands-on" learning and aid with user retention. 3D objects and audio compose the scene and the instruction which the user is expected to learn from. In the case of Project Maneuver, this virtual environment involves several elements of the digital manufacturing process.

This is due to the need to balance educational necessity with the goal of motivating learners with interaction and graphics (Chandramouli, Takahashi, & Bertoline, 2014). Factors to be considered include:

1. Hardware (CPU) and graphics requirements: System requirements must be considered in order to determine if currently available computers are compatible with the system or if they will require a better graphics cards, CPU, etc. As the visual learning style is critical, the system requires the necessary tools for learners to properly interact with the simulation (Chandramouli, & Heffron, 2015).
2. Cost: Understanding which system is most cost effective while achieving the intended goal is vital, as staying within budget is necessary.

3. Standalone: A Standalone system can function independent of additional hardware/devices and server support is not required; standalone is useful for testing new software before being deployed to company servers.
4. Software compatibility/Support: Software compatibility/support refers to the support form the company/community that the system is associated with. How often the company releases new versions of the software or if an available library of online support to help trouble shoot a problem determine if there is strong support.

The ideal system will consist of CPU and graphic requirements compatible to render 3D models, cost within the average range for VR systems ($300-$500), is standalone to remove additional hardware and cost requirements, and is compatible with widely acceptable software, such as Unity. Unity was used as the development platform due to the support of this platform from companies and online communities, and is recognized as a common development language. Unity works very well with VR due to the Unity VR and Steam VR packages, which are free to use applications that allow Unity to be compatible with HMD and desktop VR. The issues/system requirements that we experienced with the Oculus/HTC were used as a base on which the criteria were chosen. The way that the systems are able to solve or improve the flaws experienced during the MANEUVER simulation, will help to determine the best option for the project.

Results

The following table displays all the systems characteristics. This was created based on the previously mentioned aspects considered for the systems.

The Oculus and HTC are the resource-intensive (graphically) and costly systems of all the listed systems. This is due to the needed laptop and high cost of the systems. Google Cardboard (GCBH) is a headset that is able to be folded and arranged into a headset visor. Because of this, it is relatively inexpensive to buy, however it does require a smartphone to be placed into the headset to be act as the device running the VR scene.

Samsung Odyssey and GCBH both need a smartphone, because it has to be compatible with the system, and only the last few generations have the capabilities. However they also require that the phone have a plan as well, so it also has a reoccurring cost to maintain plan for at least the next two years due to plan contracts.

Dell Visor can be plugged into any PC and desktop that is able to run windows 10. However, an adapter and dongle are needed to properly have the system run with a desktop. The adaptor has to a Mini display port to HDMI video adaptor converter; we choose this also, because it needs to be able to support 4K. The dongle is a Bluetooth 4.0 LE + EDR to plug into a USB port; this is needed if the computer does not have built in Bluetooth.

Table 1: Comparative Analysis of Systems Assessed for Study

	Hardware/Graphics	**Cost**	**Standalone**	**Software**	**Suggestion For Use**
Oculus	NVIDIA® GeForce® GTX 1050 with 4GB GDDR5 with HDMI output	$400 /System, $1,500 laptop separate purchase	Requires additional laptop	High graphic capability and interaction.	Use if need for high end graphics or high level of precision
HTC	NVIDIA® GTX 1060 graphics card, Intel core i5-4590 CPU Oculus- Intel i5 Quad Core processor	$500 / System, $1,500 laptop separate purchase	Requires additional laptop	High graphic capability and interaction	Use if need for high end graphics or high level of precision
Samsung Odyssey	Intel core i5 6th generation CPU, NVIDIA® GTX 1050/AMD RX graphics card.	$400/system Phone$300-500, plan varies	Requires smartphone with a plan	Accurate controls, requires a smart phone to interact	Good all-around system. Smartphone with a plan will incur cost over time
Google Cardboard	Simple Setup. Requires modern phone with 360 scene view function.	$15 Cardboard, Phone $300-500, plan varies	Requires a modern smartphone with a plan	Limited interaction, most affordable system.	Use if you have smartphone, or limited interaction is acceptable when using VR
Dell Visor	Intel i5 quad core processor, NVIDIA® GTX 965M with 4GB GDDR5 with HDMI output Mini display port to HDMI video adaptor converter	$300 Visor, $15 dongle, $10 adaptor Cost of computer varies.	Standalone thanks to Adaptor and dongle.	Accurate and programmable controls.	Good all-around system. Can be used in most indoor spaces, responsive

	Bluetooth 4.0 LE + EDR Dongle				interaction controls.

Discussion

Both Oculus Rift and HTC Vive were not chosen due to the high cost resulting from needed laptop/additional hardware requirements. In addition, Oculus VR head set was not chosen because it does not provide positional tracking. HTC Vive was not chosen because of large space required to use the system. Oculus was the first system used and allowed a better understanding of the desired characteristics needed for users to have an enjoyable VR experience with the simulation. It was found that this system requires tremendous set up time and learning curve for inexperienced users to use the VR simulation. Use minimal to no extra hardware/software to both keep the cost of the system as low as possible but to also keep the set up as simple as possible for users. And lastly that the system could still provide an immersive experience with proper control responses while keeping hardware requirements from becoming overly expensive or difficult to attain.

The Samsung Odyssey was also not chosen due to the need to buy an additional smartphone with a plan, as this cost could possibly keep incurring after the project ends and is much easier to lose/damage smartphones than the large headsets. While the GCBH is the least costly of the options, it did not offer the same level of interaction the other systems could due to their advanced controllers and could not provide the motions of picking up objects and movement/teleportation in the virtual scene desired for users.

The system chosen was the Dell Visor: as it offered the best combination of software support (Unity and SteamVR package), is a standalone system, affordable, and has hardware and software requirements that could be met relatively easily. While both Oculus and HTC require 1 HDMI port and 3 USB ports for head set and controller tracking, Dell Visor only requires 1 HDMI port and 1 USB 3.0 port to connect the VR head set. Dell Visor uses Bluetooth to connect two hand controllers. Dell Visor provides easy set up and increased flexibility of movement, by reducing the number of ports and connecting wires required for the head set. Dell Visor is Unity compatible, aside from the needed adaptor and dongle, it was a standalone system that could work with both laptop and desktop, was considerably cheaper than the Oculus/HTC.

Conclusion

The new system chosen for the project was successful in running the simulation and allowing users to interact with the simulation in the desired manner. When the simulation was shown at the MANEUVER training event, industry users with vary levels of experience with VR were able to successfully use and interact with the simulation as intended.

The need to provide more efficient training for workers is a need that will only continue to increase as time moves forward. The use of VR will continue to evolve as hardware and software become more affordable and widespread as both companies and consumers become more familiar with the technology. While not all available VR hardware and software can solve the instructional needs required for the workplace, different product options assist to help users determine what system will be the most beneficial for them. With time these systems will only become more accessible due to evolving technology and increasing demand of the workforce for faster and more efficient training.

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References

Attridge, A., Williams, M., & Tennant, C. (2005). Achieving craftsmanship targets across the UK automotive supply base, through the use of quality maturation tools and processes (No. 2005-01-1566). SAE Technical Paper.

Chandramouli, M., Takahashi, G., & Bertoline, G. R. (2014). Desktop VR centered project based learning in ET courses using a low-cost portable VR system. In *Proceedings of the American Society of Engineering Education*.

Chandramouli, M., Zahraee, M., & Winer, C. (2014, June). A fun-learning approach to programming: An adaptive Virtual Reality (VR) platform to teach programming to engineering students. In Electro/Information Technology (EIT), 2014 IEEE International Conference on (pp. 581-586). IEEE.

Delorme, S., Laroche, D., DiRaddo, R., & Maestro, R. (2012).NeuroTouch: A Physics-Based Virtual Simulator for Cranial Microneurosurgery Training. *Operative Neurosurgery, 71,* 32-42

Elbadawi, I., & Chandramouli, M. (2014). 3D Design Process for Manufacturing and Assembly Table Top Tools for Incremental Continuous Improvement (Kaizen). Technology Interface international Journal, 15(1), 28-34.

Ergürel, D. (2016, October 14). *How virtual reality transforms engineering*. Retrieved from https://haptic.al/virtual-reality-engineering-bd366c892583

Gallagher, A., Ritter, E., Champion, H., Higgins, G., Fried, M., Moses, G., Smith, C., & Satava, R. (2005). Virtual Reality Simulation for the Operating Room: Proficiency-Based Training as a Paradigm Shift in Surgical Skills Training. *Annals of Surgery*, *241*(2), 364–372

Grantcharov, T., Kristiansen, V., Bendix, J., Bardram, L., Rosenberg, J., & Funch-Jensen, P. (2004). Randomized clinical trial of virtual reality simulation for laparoscopic skills training. *British Journal of Surgery, 91,* 146–150

Holmstrom, J., Liotta, G., & Chaudhuri, A. (2017). Sustainability outcomes through direct digital manufacturing-based operational practices: A design theory approach. *Journal of Cleaner Production, 167*, 951 – 961.

Leinonen, J., & Kähkönen, K. (2000). New construction management practice based on the virtual reality technology. In Construction Congress VI: Building Together for a Better Tomorrow in an Increasingly Complex World (pp. 1014-1022).

Steed, A. (2017, March). *How virtual reality is changing engineering.* Retrieved from https://www.ingenia.org.uk/Ingenia/Articles/46eb0338-dee8-4322-adae-97f339e0118a

Toth, E. E., Ludvico, L. R., & Morrow, B. L. (2014). Blended inquiry with hands-on and virtual laboratories: the role of perceptual features during knowledge construction. Interactive Learning Environments, 22(5), 614-630.

Wiet, G., Stredney, D., Sessanna, D., Bryan, J., Welling, D., & Schmalbrock, P. (2002).Virtual temporal bone dissection: An interactive surgical simulator. *Otolaryngology–Head and Neck Surgery, 127*, 79-83