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Utilizing VR for Manufacturing Learning and Training

Jetrin Wichienwidhtaya
Western Washington University

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Abstract

This paper looks into the world of virtual reality as seen from the manufacturing point of view, specifically inside manufacturing education. Virtual reality is growing within many industries including manufacturing and is a key piece in Industry 4.0. Every year, the capabilities of virtual reality grow as the resolution of screens progresses to the point where it can simulate near-perfect depictions of reality as processing power continues to grow. This opens a massive amount of potential into things like training. Especially in the current environment where learning virtually has become the norm, being able to have hands-on experience can help education by a large margin. In this project a virtual reality environment was created in which those unable to or are simply interested can experience and learn how to utilize CNC machines. Working, visually appealing models of the laboratory machines were being constructed with machining models that can be implemented within them. Step-by-step instructions were created for the use of these models.

Introduction

It does not take much experience or imagination to know how expensive large manufacturing machines can be, especially ones that are precise to thousandths of an inch. Every part can be worth hundreds of dollars and every piece of the machine could be worth thousands. Training on these machines is a necessity to the industry as manufacturing will never stop but the possibility of damaging them during this process is very real. Each new part or operator introduces an increased chance of errors that can cause thousands of dollars of damage. That is why the advancement into non-risk methods of learning and training is so important. One of the newest advancements of non-risk methods is virtual reality. Virtual reality is commonly perceived to be a tool for gaming, but it is an integral part of industry 4.0, the next step into the future of manufacturing.

Analyzing the state of virtual reality learning starts with the hardware and the increasing accessibility. Without the hardware, it is impossible to use any form of virtual reality. Companies like HTC and Oculus have been dominant in the market for virtual reality with original prices for high-end setups costing around 800 dollars. In more recent years, prices have fallen to as low as 200 to 300 dollars. The rise in accessibility makes virtual reality a more reliable option to use as a teaching tool. The possible training benefits are numerous and are especially useful in a reality where direct contact with others needs to be limited.

To show the applicability of virtual reality for manufacturing training specifically, there are several aspects of the current state that need to be analyzed. Key aspects of applying virtual reality to learning require studies of learning speed and enjoyment. If learning in a virtual environment is significantly slower, it may not be worth the investment. The same can be said if it is significantly less enjoyable. At the same time efficiency and enjoyability are pointless if it is found that training done in virtual reality does not provide results in improved learning. If seeing things from different perspectives and generating mock runs of tasks someone may be doing does not allow for actual learning to occur, all the investments of time and money become pointless.

Given the speed at which technology is advancing, this paper aims to answer what aspects of virtual reality make it advantageous for the future and if it is applicable for use in manufacturing training.

Literature Review

For virtual reality to be an integral part of the future, it must be affordable and accessible. The accessible aspect of this is a prerequisite that has been met for a while with companies like Oculus having products available to the public and big brand names like Samsung cashing in on the virtual reality craze in more recent years. For under $100, a headset that utilizes their phone as the screen to experience virtual reality can be purchased. A standard PC tethered headset such as the Oculus Rift would cost around $300 and a higher-end complete virtual reality setup such as the Vive Cosmos Elite would be around $800. To highlight the affordability, a MacBook Air, one of the most purchased college laptops, is around 1000 dollars. As a recreational technology, virtual reality has shown incredible growth in recent years. The world market for virtual and augmented reality is projected to grow 7.7 times between 2018 and 2022 with consumer hardware accounting for the largest percentage of virtual and augmented reality spending (Statista). A large group of people are enjoying the virtual interface for recreational use.

The rise in accessibility has led many companies to begin to utilize virtual and augmented reality setups as part of the advancement into industry 4.0, a revolution of changing technology that will be utilized in industry. As much as one-third of U.S. manufacturers have stated that they would adopt augmented and virtual reality technologies by the end of 2018 and only another third stating that they had no plans of adopting the technologies [1]. The trends are pointing towards virtual reality as an important tool of the future as more companies adopt it and younger engineers and technicians join the workforce. At machine exhibitions, virtual reality has been utilized to showcase new pieces of equipment. It was shown that younger engineers were impressed by these displays from EMO in Germany and at IMTS in the U.S. but older engineers struggled to adapt easily because of eyesight issues [2]. As time passes, the new age of industry will attract the most outside-the-box thinkers to bring virtual reality to its greatest potential.

The abilities of virtual reality are what make it a strong investment for the future. The possibilities in a virtual world are only limited by the imagination and when used in combination with augmented reality, the virtual and real worlds can coexist to create anything any engineer could want. The focus of virtual reality as it stands is in training. Training can apply to many different manufacturing processes including operating a machine, observing a workspace, general fabrication, and many other practices. Assembly is one place that virtual reality has seen a lot of success with the training. It has been shown that those who have been trained to assemble in virtual reality make fewer errors and are quicker to complete the tasks given to them than traditionally trained employees [3]. The ability to give people the chance to move through the motions of a task allows them to build memory more easily for when they must complete this task repetitively in production. Learning by doing has been shown to be more successful than simply learning by seeing, listening, or observing. Virtual reality provides that platform to "learn by doing" which is what makes it great for training. When working on things like CNC offset analysis, it has been shown that using virtual reality training instead of theoretical training allows students to make decisions quicker and more accurately [4]. In a test done in the medical field, it was shown that those taught using virtual reality scored higher on identical tests compared to those trained traditionally. The participants of this study completed two hours of teaching where the non-VR group was shown a one-hour video lecture and reviewed an accompanying article for another hour. The virtual reality group was exposed to objects and visuals in virtual reality. The study was on a fetal brain and what malformations can happen. An interesting aspect of this study was that the subjects were tested after both one and four months after learning. After one month the group that was exposed to virtual reality still performed more impressively on tests than the control group but even more telling is that after four months, the gap between the virtual reality trained group and traditionally trained group increased [5]. So, the effects of virtual reality in training are not a short-term improvement that puts trainees at a competent level more quickly. It also has lasting effects on their abilities in the long-term cementing itself as an optimal choice to add to training in any field, manufacturing included. In another study in the medical field, virtual reality training has been shown to improve operating room performance. Those who used virtual reality to train were able to perform gall bladder dissections 29% faster as well as being 9 times more likely to succeed and 5 times less likely to injure or burn the gall bladder [6]. It has also been shown in a study that virtual reality groups respond more positively than video or textbook groups in regular learning environments. In remembering content, those training in virtual reality were able to score a significantly higher percentage compared to use of videos or textbooks. In understanding content, virtual reality was able to match textbook learners and significantly outperform video learners. As a simple training tool, virtual reality performs optimally [7].

Another improvement virtual reality gives to learning and training is the increased safety for everyone involved in the process. According to the CDC, there were a total of 900,380 nonfatal work injuries that resulted in days away from work, with 235,740 of those coming from contact with objects and equipment in 2019. A huge appeal of virtual reality is that it allows those being trained to be taught in a much more controlled environment increasing the safety of everyone involved in the process. It provides a space that can be used flexibly and leads to great interdisciplinary learning environments. A trainee can be put directly in front of a running milling machine with a tool spinning thousands of times a minute without having to worry about their arm being torn from their body. Operating room residents can see the procedures and recognize mistakes at a higher rate ensuring the safety of those being worked on [5]. The clear visual engagement has proven to support the recognition of mistakes and errors. This can be seen during machining processes when recognizing tool zone safety. In virtual reality, learners can be brought extremely close to the rotating tool to see and hear what should and should not be happening. Not only does this improve the training experience, but it also ensures the safety of the trainees [4].

For any new technique to be widely accepted, the potential end user must be willing to use it. Something common for virtual reality is an aversion from older generations unaccustomed to using new technology. Not enjoying or avoiding virtual reality is a hurdle that must be overcome for virtual reality. For many, virtual reality is synonymous with the video game industry and easily excites much of the younger generation who grew up playing these games. Much the same can be said for those using virtual reality for training. In simple learning environments, students have responded to virtual reality content very positively and much less negatively compared to textbook and video learning [7]. In scientific environments, given similar scenarios, those trained in virtual environments enjoyed their experience significantly more than those who trained through video instruction [8]. In the specific study, virtual reality was compared to video learning, so the enjoyment applies more specifically to students. Students are going to be the future of the workforce and the ones who will most soon be trained making virtual reality a phenomenal tool for the future.

Virtual reality can train motion, but the question is often raised of how much motion can virtual reality support. Most versions of virtual reality utilize a headset and hand controllers that do not replicate the motion of hands directly, rather they simulate hands through other means such as using a trigger to grip items or drag them to a different location. This can be a problem for using virtual reality for manufacturing training because many of the motions that would be desired would require minute movement of fingers. Hand tracking has improved but has a long way to go. Newer virtual reality devices can calibrate hands and fingers into the virtual environment by using the headset to track the specific position of the extremities. Where this is still developing is the latency and speed of tracking where faster hand movements are difficult to follow with the headset. This requires the headset to recalibrate hand positions leading to delays of several seconds which is reported to cause a large loss in the feeling of immersion within the virtual reality environment [9]. Locomotion within virtual reality is another type of movement that is limited. Current systems of virtual reality are often limited by space but also do not feel the same as motion in real life due to the large headset sitting on you. Experiments about moving linearly in virtual reality versus in real life show that there is little difference in the movement of people with them having similar velocities and accelerations. When asked to perform non-linear movements, deviations, of course, occurred at multiple angles with less smooth turning. During object avoidance tests, subjects were able to move much closer to the objects in real life than in virtual reality. The final results show people in virtual reality take more steps and reduce their speed, showcasing one of the weak points of using it for training [10]. While all the tasks are still possible and can be done, there is not a perfect replica of real-life actions in virtual reality due to the latency of any headset.

There have also been forays into using virtual reality to teach alternative perspectives. The concept of perspective-taking or perceiving an experience or understanding of a concept from a different point of view is not something that is taught traditionally to many as safety and time are large concerns when training new employees. Being able to see a shop floor from the perspective of a technician or simulating the experience of someone else can be extremely productive as it allows for learners to become dynamic perspective takers. While learning these skills in person has proven to outperform utilizing virtual reality, using virtual reality to support the teaching of perspective is much less time intensive [11].

The many different aspects that virtual reality can improve are important but the one thing that encompasses it all is whether it brings results. Mentioned earlier was that virtual reality training reduces mistakes in assembly by a significant margin [3]. In Edgar Dale's model of Immersive VR education, people can remember 90% of what they do two weeks after doing or simulating an action (Hitch). It has been shown that the skills used to function within the virtual world are the same skills that we have been practicing in the physical world since our birth. In addition, it adds many unique capabilities such as being able to physically see from different perspectives as well as to provide a flexible learning environment.

Process Design

To utilize the virtual reality setup in 3DExperience, proper models, kinematics, and machining instructions were put together in various workbenches. Three aspects of design are required to have a function setup in the virtual machining environment. The first is your workpiece. The workpiece needs a starting piece of stock that will be machined and the final form that it will have after machining. Examples of these used in training tutorials for a class on Computer-Aided Manufacturing and Computer Numerical Control can be seen in Figure 1 and 2.

Figure 1: Starting Stock

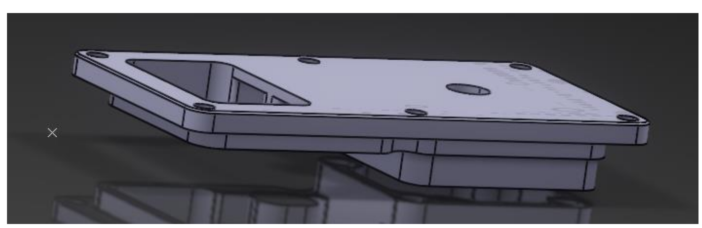

Figure 2: Final Form

It also needs to have a fixture, whether this is a vise or some other work holding device. These pieces need to be properly constrained in positions they would be in during machining. In this project, the piece modeled is a part used in a Western Washington University machining class held inside a vise. Pictured in figure 3 is an example picture with a piece of stock already mounted.

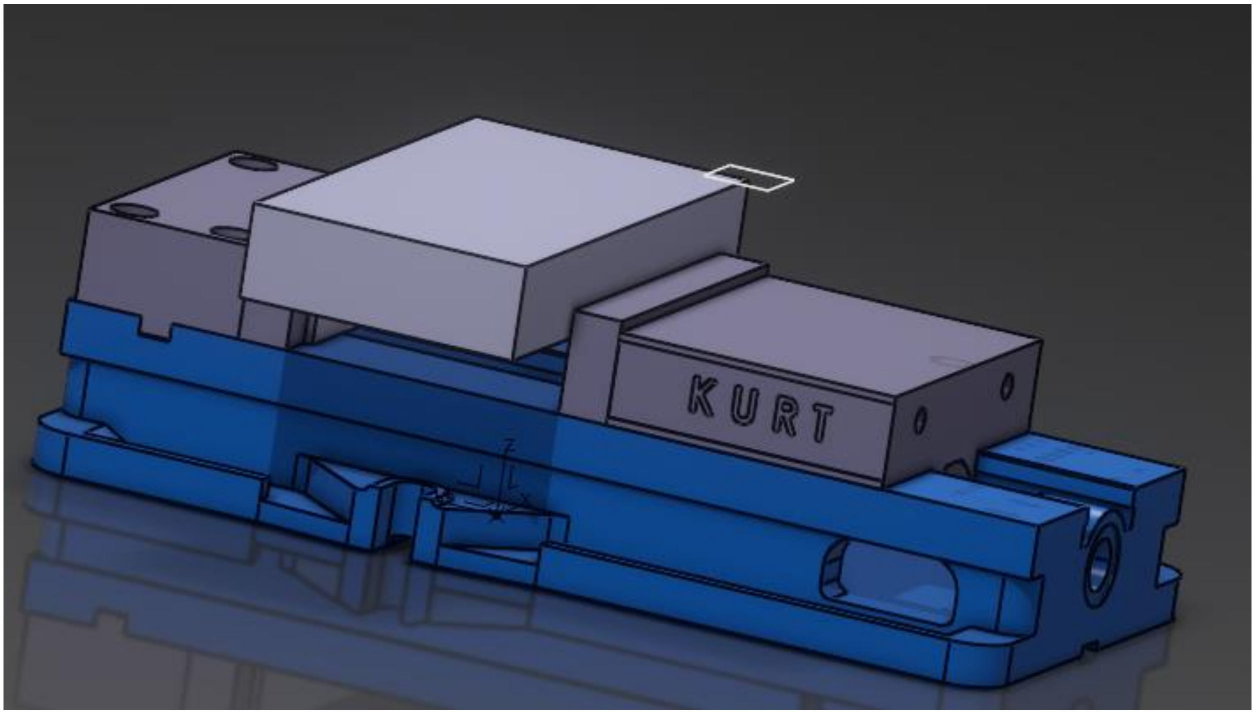

Figure 3: Stock in Kurt Vise

The next aspect is the machine. The machine will require proper kinematics so that it moves properly during simulation. The directionality of each of the pieces and what they move about is important. For this project, the model is of the Haas VF-2 mill. The 3 main moving pieces of the VF-2 are the tool turret, saddle, and table which move the z, y, and x-axes, respectively. Figure 4 shows a model of a Haas VF-2 made in 3DExperience.

Figure 4: Haas VF-2 Model

The final aspect is the machining process that will be observed. Using the prismatic workbench on the workpiece setup, machining operations can be added in 3DExperience to the piece. Adding machining operations requires models of the cutting tools that will appear in the model of the mill if the mounting point is properly defined.

Virtual Reality Integration

Integrating the model and processes into the virtual reality is a simple process in the 3DExperience prismatic workbench once all the files are correctly loaded. Built into 3D experience is an AR-VR feature tab that allows for the utilization of several different virtual reality setups including CAVE and augmented reality. The one utilized for a properly set up HTC Vive Cosmos headset and station is labeled VR for Manufacturing.

The physical setup of the system requires a high-end PC, headset, hand controllers, and sensors. The sensors are placed around ten feet away, facing each other and onto the desired work area. The headset must be able to "see" the sensor so the sensors cannot be blocked in any way. (See Appendix B for complete setup instructions)

User Test Cases

Three main user cases were prepared for the utilization of the virtual reality setup.

Observing the Model

1. The participant will be able to walk around and into the machine which also sees the location of the part that is to be machined. Figure 5 shows a view of the Haas VF-2 from the in-screen view of virtual reality.

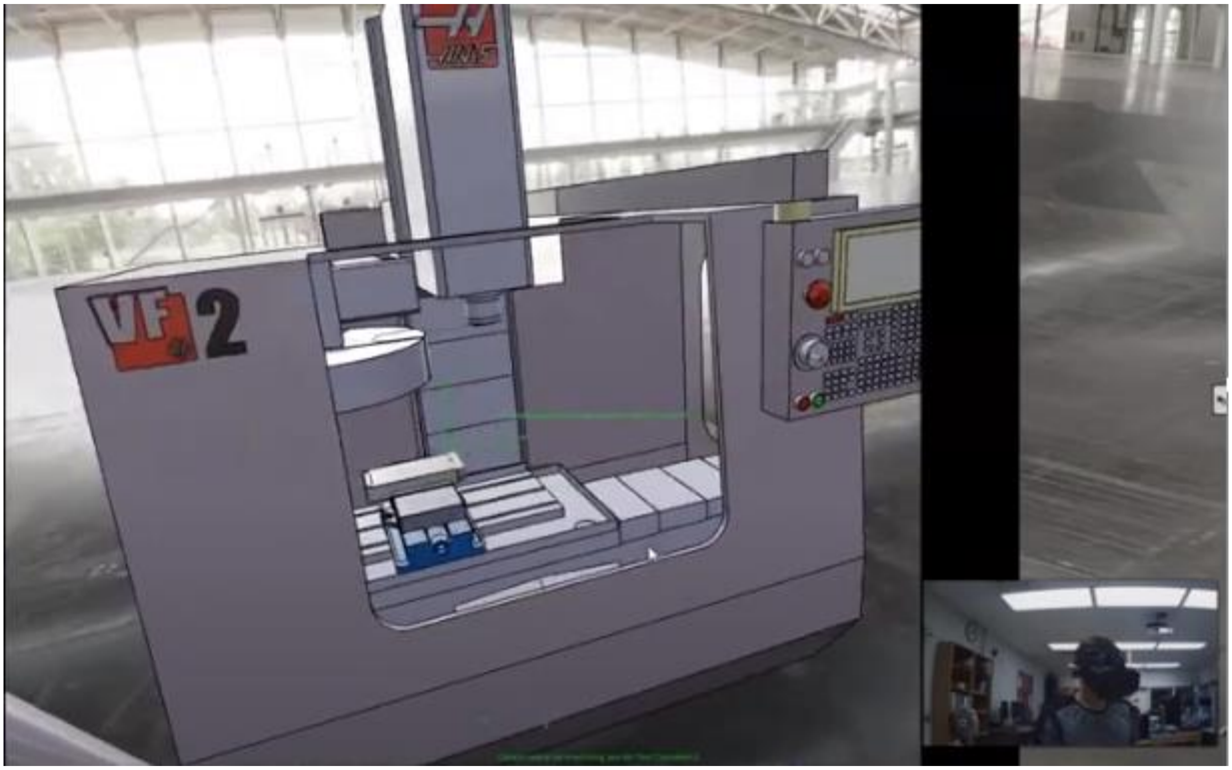

Figure 5: Viewing the Machine

2. The second case was an in-process machining task. A preloaded program would be launched in 3DExperience that could then be observed in virtual reality as the machine cut away material and changes tools. Figure 6 is a picture of the Haas VF-2 in the middle of a milling operation viewed from the inside of the machine.

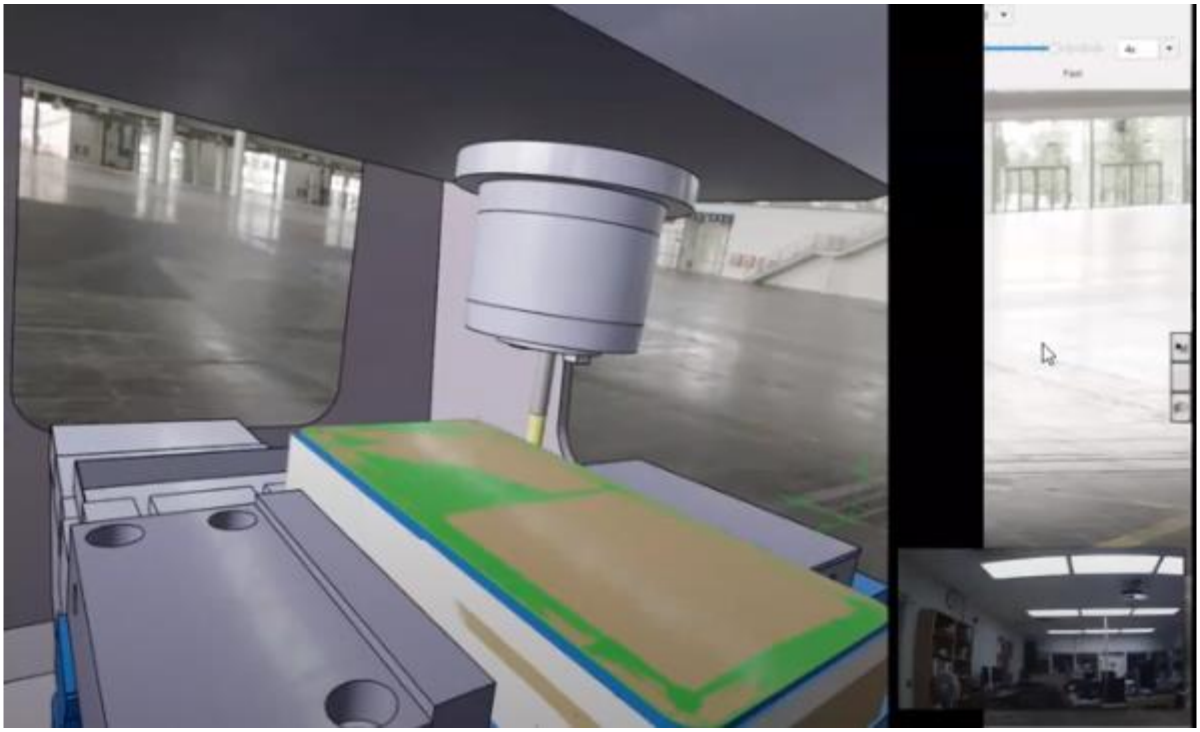

Figure 6: Viewing the Process

3. The final case was part design comparison where the participant can utilize the comparison tool within 3DExperience so that the cut part would show visually using different colors how the machining program performed compared to the ideal part. Figure 7 depicts a view of the comparison tool after one half of the example part has been machined.

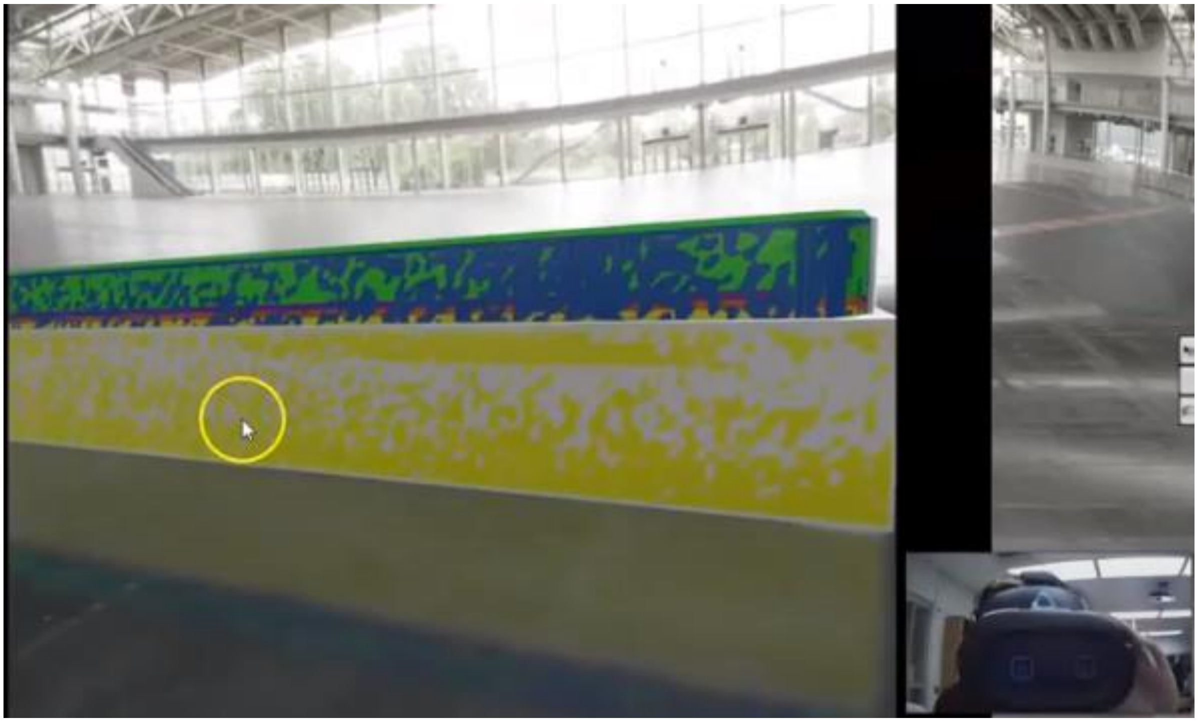

Figure 7: Viewing the Results

Future Work

Due to the limitations of accessibility, many aspects of the virtual reality models were skipped but are necessary to move forward with research on the topic. An aspect that is critical for the continuation of this project is the evaluation of the created model. Due to the Covid-19 Pandemic and the strict visitation rules implemented due to it, surveys and assessments using the created model were not completed. These surveys are critical to see the effectiveness and applicability of the model that was created as information about what the people who would be using it matter the most. The plan in the future would be to ask students at WWU to come into the lab and to try using the virtual reality setup. These students would be engineering students with some knowledge of 3DExperience so the survey and tests can focus on the application in virtual reality. The students will be walked through the instructions to successfully run the developed model in virtual reality and then asked to complete a questionnaire afterward. The questionnaire would include the following questions:

- Before today, what has your experience with virtual reality been?
- Did you find using virtual reality for the model a useful experience?
- Do you think virtual reality has a place in the future of manufacturing learning?
- What aspects of virtual reality do you think are advantageous to use as a learning tool?

These questions are designed to focus on the future of virtual reality as a teaching tool in manufacturing. The first question establishes how familiar the participants are with virtual reality. The next questions are to find what the participants thought of using virtual reality for learning. It would also be advantageous in the future to try to test the model against traditional teaching to see if the same information can be gained in the virtual world compared to the real one.

In another vein of model validation, tests versus a control group would be necessary to see if the virtual reality process can compare to videos, or in person learning. This could be conducted in multiple ways. Because the models are from an already use in class activity, it would be easy to have some students go into the real lab to machine the parts, some use video instruction, and some use the virtual reality interface. Time studies of the students in the lab versus the ones in virtual reality could show how virtual reality performs against real life. Quiz questions could be used to test how virtual reality teaching measures against video instruction. Like many other case studies, testing the results of virtual reality use would be important

The models can also be continuously improved. Latency changes and updates to modeling software will make updating the models necessary to look as realistic as possible to increase the feeling of immersion when used inside the virtual environment. It would also be ideal to continue looking for ways to manipulate the model in virtual reality so that more focus could be placed on working in the virtual world rather than jumping in and out to change modes. The software that is utilized for virtual reality is also still prone to crashing as well from various actions (Appendix A) so finding more of these actions and reporting them to the parties responsible for the software would be recommended.

Discussion

The bottom line of the research is that virtual reality, while it is still a developmental strategy, is a technology with a lot of potential to add to many aspects of manufacturing training. Unfortunately, due to the extenuating circumstances of the world, research using the model was impossible so there is no way to draw any firm conclusions at this time. If engineering students were to react positively to the use of virtual reality technology, that would infer that there would be a definite market for the advancement of the technology.

The research that would occur in this study would build more directly on many of the studies that have been done before with a higher focus on education. While there are a couple of studies in manufacturing jobs and academia, there are few to none that specifically target learning done for manufacturing and how beneficial it can be if utilized.

Conclusion

The purpose of this research was to investigate the applicability of virtual reality as a tool for the future of manufacturing teaching and learning. A new age of industry is on the horizon with the rapid progression of technology and virtual reality is on the leading edge. It is important that those pursuing the advancement of manufacturing comprehend the impact that fully implementing virtual reality into teaching and learning will have. The intent behind this report is to express the capabilities of virtual reality to the next generation of engineers and to highlight the advances it could bring to training. Every new technology must be researched and optimally implemented so that the industry can continue to thrive.

This paper peers into the world of virtual reality as seen from the manufacturing point of view, specifically inside manufacturing education. Virtual reality is growing within many industries including manufacturing and is a key piece in Industry 4.0. Every year, the capabilities of virtual reality grow as the resolution of screens progresses to the point where it can simulate near perfect depictions of reality as processing power continues to grow. This opens a massive amount of potential into things like training. Especially in the current environment where learning virtually has become the norm, being able to have hands on experience can help education by a large margin. In this project a virtual reality environment was created in which those unable to or are simply interested can experience and learn how to utilize CNC machines. Working, visually appealing models of the laboratory machines were constructed with machining models that can be implemented within them. Step-by-step instructions were created for the use of these models.

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Appendix A:

3DExperience Bug List

- When running a machining process, trying to use the hand controllers in anyway will cause the program to crash
- Changing the view on the computer while having the virtual reality window open will often cause the virtual reality window to crash
- The “change mode” button will change the mode on the controllers but most of the actions from the changed modes will cause virtual reality to crash
- Virtual reality screen will flash to white at random times which may go away but also may persist and force you to reset the virtual reality window
- When using the comparison tool, the colors on the part will flash like static

Appendix B:

List of Parts

- 2x Leg Base
- 2x Ball Screw
- 2x Sensor Block
- 2x Long Power Cords
- 1x Computer Adapter Block
- 1x Short Power Cord
- 1x HTC Vive Cosmos Elite Headset
- 2x VIVE Hand Controllers
- 2x MicroUSB Chargers with Adapter Blocks

Sensor Setup

1. Attach ball screw to the base
2. Attach sensor block to the ball screw
3. Extend legs of the base to maximum wideness
4. Place sensors ~10ft away from each other facing towards each other with the desired work area between them
5. Plug long power cords into the sensors
6. Extend necks of base to maximum height

Headset Setup

1. Plug display port and usb cables of adapter block into the computer
2. Plug headset into the adapter box
3. Plug short power cord into the adapter box
4. Ensure the computer has the headset and the sensors registered

Controller Setup

1. Click menu button to sync and turn on the controllers
2. Check for a green light. If there is no light or the light is red, ensure the controllers are charged with microUSB chargers

Software Setup

1. Launch the program VIVEPORT
2. Open Room Setup
3. Follow instructions to setup work area

Appendix C

Manufacturing Process Walkthrough – 3D Experience

1. Open machining file in Prismatic Machining
2. Ensure all components of the file are there (machining processes, models, kinematics, etc.). You may have to close and relaunch it.
3. Hide components of the model that may get in the way of viewing the process (guard panels, panels, etc.)
4. Open the activities process view panel
5. Click the AR-VR tab
6. On the far right side of the AR-VR tab there should be a VR for Manufacture button, click it
7. Now put on the head set to see if the model space is visible. Make sure to adjust the headset to the correct size using the dial on the back and to the correct resolution using the small dial on the right of the eyepiece
8. Position yourself close to the operation in VR
9. Raise the headset
10. Click on the desired manufacturing process
11. Click on the play button on the 3DX compass to launch the viewer
12. <u>NOTICE</u>: Once you start the operation, do not move in VR using the controllers, only through your actual movement. Currently, there is a bug that will reset the simulation if you do so
13. Once the simulation has started, freely move to get the desired perspective
14. Make any visual changes to the model that you would like to inspect in VR on the computer including but not limited to hiding the machine, applying material removal analysis, and changing the colors

Part Design Comparison

1. At any point during the machining simulation, material removal analysis can be applied
2. This will stop the simulation and launch a material removal analysis of the current cut stock against the design of the finished part
3. In virtual reality, you can look closely at the part at all angles easily
4. Note: Do not use the air grab feature of the hand controllers as it will reset your simulation

Project Supervisor

Derek Yip-Hoi

Project Member

Jetrin Wichienwidhtaya