Application of Virtual Reality Simulation in Photolithography Laboratory Experiments

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Marty Clayton entered the 3D animation and video game industries through the "back door" when those industries were in their infancy. He received his Bachelor’s Degree from The Ohio State University in a rigorous design program in which he learned how to design indoor and outdoor spaces. He graduated with the Senior Award for his program and his senior design for the Baltimore Inner Harbor was featured in a national publication. Even back in the early 1980’s his interests in computers and graphics was strong. Quickly in his career, he turned his focus on CAD production drawings on the computer and built a computer division and set standards at the Myers/Schmollenberger Design firm in Columbus, Ohio.

In the Early 1990’s, Marty started up his own consulting company doing visualizations and animation for companies in the design industry. Some of his clients included: Rubbermaid, Christian Broadcasting Network, Frigidaire, Hobart Ware-washing Division, Character Builders, and American Greetings. The highlight to his consultant career was working on the 1996 movie "Space Jam" and had 10 seconds of animation featured in the movie. While running his own consulting company, Marty also taught 3D design and animation full-time at the Columbus College of Art and Design and realized that his true passion was teaching. He would spend the next 15 years preparing himself for that goal.

Marty entered the video game industry in 1997, and has worked as everything from an Environmental Artist to a Development Manager to an Associate Art Director. He has worked with outsourcing partners both nationally and internationally in environmental design, modeling/texturing, character development and animation. Marty took a short 2-year sabbatical to get his MFA from Savannah College of Art and Design in Animation and used those talents to continue his 15 year career in the video game industry. In recent years, Marty has taught adjunct in the game programs for the Art Institute and the University of Utah. In 2012 realized his goal and joined the Digital Media Department at Utah Valley University using his skills in the design, pre-production, and production phases of the video game and animation industries, his hope is to work closely with the other faculty to help the UVU students grow and stand above students from other schools and programs, ultimately making a difference in the highly competitive entertainment industry.

Notable Projects: Top Gear Rally 2, Tiger Woods Golf, Nerf N Strike and N-Strike Elite, Monopoly Streets, Sims 3 Pets for the 3DS. Currently working on Virtual Reality and Augmented Reality projects with students and faculty.

Cody Anderson
Creating a Virtual Reality Simulation for Use in Teaching the Photolithography Process

Abstract

Photolithography is an expensive and time-consuming process that involves the use of high-cost machines and materials. Students learning this process run the risk of damaging these components, and any mistakes the students make could cost a lot of time and money. This paper details a virtual reality simulation that is being developed to help mitigate these potential losses and lower the chance of equipment damage. This simulation could also be used for training purposes. The goal of this paper is to outline the history of virtual reality (VR), the use of VR in education and training, the reasons why VR is the best option for this project, and the creative process behind the photolithography simulation that has been created. This paper will also use data gathered from user testing to showcase the benefits and disadvantages of using a VR simulation for photolithography training purposes.

Introduction

Nanotechnology is the science, engineering, and application of submicron matters that tie together unique biological, physical, chemical properties of nanoscale materials in essentially new and useful ways. [1] Nanoscience involves the ability to see and control individual atoms and molecules.

It is not exactly known when humans first started using nanosized materials. However, Romans in the fourth-century A.D. used metal nanoparticles to make glass cups which change color from green to a deep red when a light source is placed inside of it. Italians used nanoparticles to make 16th century renaissance pottery. The presence of metal nanoparticles in the glass is responsible for the beautiful colors of the windows of medieval cathedrals. [2]

Nanotechnology is expected to have a large impact on many sectors of the world’s economy. A strong nanotechnology economy can lead to new products, new businesses, new jobs, and even new industries for many countries. The United States is committed to becoming a world leader in nanoscale science and engineering research, as the applications of nanotechnology could have numerous implications for the economy. [3] The National Nanotechnology Initiative (NNI) is a U.S. Government research and development (R&D) initiative involving the nanotechnology-related activities of 20 Federal department and independent agencies. The United States set the pace for nanotechnology innovation worldwide with the advent of the NNI in 2000. The NNI was officially created in 2003 when the 21st Century Nanotechnology Research and Development Act was passed by Congress and signed by President Bush into law. Since the inception of the NNI, Federal nanotechnology R&D funding has grown from $464 million per year to almost $1.5 billion requested in FY 2015. The U.S. is not the only country to recognize the remarkable potential of nanotechnology. Other countries are also investing in nanotechnology research. In 2008, it was estimated that the governments of the European Union (EU) and Japan invested approximately $1.7 billion and $950 million, respectively, in nanotechnology research and development. The governments of China, Korea, and Taiwan invested approximately $430 million, $310 million, and $110 million, respectively. [4] This
compares to 2008 U.S. Government spending $1.55 billion. Approximately 60 countries have adapted nanotechnology research programs, making nanotechnology one of the largest and most competitive research fields globally [1].

The following are four goals of the NNI to achieve its vision:

1. “Advance a world-class nanotechnology research and development program.
2. Foster the transfer of new technologies into products for commercial and public benefit.
3. Develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology.

Advances in nanotechnology are helping to considerably improve, even revolutionize, many technology and industry sectors: information technology, energy, environmental science, medicine, homeland security, food safety, and transportation, among many others. [1]

Virtual reality has permeated the entertainment market in recent years. “Serious games,” like simulators, have also been developed. Simulators have long been used for training purposes in the military [6, 7] and the airline industry [8], but with the advent of relatively inexpensive VR systems, more people now have access to VR. With more people interested in VR, the interest in VR development has increased, and so has the demand. Non-entertainment-based VR simulators are beginning to crop up in many industries. VR simulations are used for rehabilitation [9, 10, 11], surgical training [12, 13], machine training [14], learning how to improve public speaking skills [15], and for teaching children with ASD [16, 17].

For example, in their review of some VR rehabilitation tests, Keshner and Fung saw great success in the progress of patients who had trouble recovering their motor skills after trauma. They saw evidence that “incorporating the cognitive and perceptual functions of motor performance with the performance of the actual motor skill will enhance motor learning and task transfer.” [8]. These results are promising for the photolithography simulation as a training tool; users of the simulation can practice their motor skills in virtual spaces just like they would be able to in the physical world. The motor skills they gain can then be used in real-world experiments.

In addition to its uses in entertainment, training, and rehabilitation, VR simulations are being used as educational tools. A 3D laboratory developed in 2015 with the goal of enticing high school students into STEM careers saw success in increasing interest and skills in engineering. Their results, though formed from a relatively small sample size of testing data, showed that the experiments they performed in the virtual lab were on par with the physical laboratory for teaching engineering procedures [18]. In 2016, a VR simulation was created to teach Concentrating Solar Power technology to high school students. In addition to reporting that the simulation was entertaining and engaging, the users showed substantial improvement in performance [19].
The project detailed in this paper is a virtual reality simulation of the photolithography process (Figure 1). The simulation will take the user from the start of the process to the finished result, measuring the user’s performance data as they move from step to step.

Using an HTC Vive headset and controllers (Figure 2), alongside a VR capable computer, each user will handle simulated photolithography equipment and materials in a 3D environment. By reading the data gathered from each use, the user will be able to pinpoint weaknesses in their experiments and learn which steps they performed well.

To create the simulation, the team used Autodesk Maya (Maya), Unity 3D (Unity), the Virtual Reality Toolkit (VRTK), and Substance Painter 2X (Substance).
Maya is industry-standard 3D modeling software used by Pixar and Disney. All models were created in Maya and then exported to Unity, which is a piece of game-development software also a game engine (Figure 3). Unity Technologies SF provides the full version of the software for free. VRTK is a third-party plugin for Unity, and this plugin contains a library of premade assets (scripts and tools) for VR development. The plugin also allows for a large amount of customization. The team used C# in Unity to develop and adapt preexisting Unity and VRTK scripts for the simulation.

Currently, the facilities at the university where the simulation is being developed has relatively small class sizes, so there is not a huge backlog of students vying for the lab. The program and university are growing, however, and space will become very limited. In addition, the school is trying to make computer engineering a general education course, but there is not nearly enough space in the physical lab for that many students. Moving forward, it is expected that the course will be taught using VR.

In addition to the university developing the simulation, there are many universities that do not have access to photolithography equipment because they can’t afford it. The purpose of this project is to teach fundamentals to as many people as possible.

**Justification**

A standard photolithography experiment takes up to two hours, while the same experiment in VR takes only ten minutes maximum. The user’s speed increases significantly as he or she becomes familiar with VR controls. This speed allows the user to perform numerous experiments in the
same time it would take to perform a single experiment in the physical world. As a result, students can master the photolithography process much more quickly than they typically could.

Costs for a typical photolithography lab range from several thousand dollars to hundreds of thousands of dollars. Each lab requires an expensive mask aligner and spin-coater, as well as several smaller components, such as silicon wafers and chemicals like photoresist and developer. Due to the prohibitive costs of these items, only one set of machines is available at the university and only one student can perform an experiment at a time. Additionally, inexperienced and experienced users alike run the risk of damaging these costly materials.

In comparison, the equipment needed to perform a VR experiment is significantly less expensive. The current cost of an HTC Vive bundle is $599, which includes a headset, two motion controllers, two base stations, a cable adapter, and all necessary input and power cables. The only other cost required for a VR setup is a computer; a prebuilt desktop computer that can run an HTC Vive costs $1000 or more, though this price can be reduced if the computer is custom built.

Using our VR simulation and relatively inexpensive headsets and computers, the cost can be reduced to under $2600 per setup, and the risk of photolithography machine damage is eliminated. Additionally, the executable file containing the simulation as well as the simulation’s data folder are easily transferable. As a result, any organization or individual with a VR setup can use the simulation. The following table outlines the costs of photolithography equipment versus VR equipment (Table 1).

<table>
<thead>
<tr>
<th>Physical Lab Costs</th>
<th>Virtual Lab Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual Mask Aligner</td>
<td>HTC Vive Bundle</td>
</tr>
<tr>
<td>$50,000-$200,000</td>
<td>$599</td>
</tr>
<tr>
<td>Manual Spin Coater</td>
<td>VR Capable PC</td>
</tr>
<tr>
<td>$3000-$7000</td>
<td>$700-$2000</td>
</tr>
<tr>
<td>Hot Plate</td>
<td>Total Cost</td>
</tr>
<tr>
<td>$1000</td>
<td>$1299-$2599</td>
</tr>
<tr>
<td>Photoresist</td>
<td></td>
</tr>
<tr>
<td>$400-$1000/liter</td>
<td></td>
</tr>
<tr>
<td>Developer</td>
<td></td>
</tr>
<tr>
<td>$100/gallon</td>
<td></td>
</tr>
<tr>
<td>Commercial Wafers</td>
<td></td>
</tr>
<tr>
<td>$10-$60 each</td>
<td></td>
</tr>
<tr>
<td>Total Cost</td>
<td></td>
</tr>
<tr>
<td>$54,510-$209,160</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Physical lab costs compared against the virtual lab.

The greatest investment in development time is spent in two areas; modeling and scripting for functionality, which includes testing and fixing bugs in the code. There are great strides being made in 3D imaging software programs, with the aim of shortening the time it takes to create 3D
models for simulation game environment [20]. These imaging software programs use cameras to create a 3D scan of a person or object, and that data is then converted into a 3D model. This greatly cuts down on time spent in development.

**Experiment Design**

The first things created were simple, low-polygon, boxy shapes of a clean room to get an idea of what the final room should look like (Figure 4). This room shape was refined into a more practical space with a door leading to a locker room area where the user starts.

![Figure 4. A very early prototype of the room layout made in Maya.](image)

In the early asset creation phase, it is standard practice to make very simple models as placeholders. This is so the scale of the environment and placement of objects can be tested before anything more complicated, such as VR functionality, is added.

To recreate the machines as faithfully as possible, pictures of each machine were taken from multiple angles, both in the physical lab and using pictures from the manufacturer’s website. Figure 5 shows the mask aligner in the lab at the university.

![Figure 5. The physical mask aligner in the lab.](image)
Next, a very simple box model of the aligner was created (Figure 6). It lacked buttons, knobs, or anything interactive, but served as a useful placeholder. This kind of simple model takes a very short time to create in 3D.

Early in development, only the most basic VR functionality was in place. The user could pick up and drop items, but neither the machines nor the tools in the environment had interactivity. To add this interactivity, the mask aligner model had to be updated with buttons and knobs to match the real machine in the lab (Figure 7). A microscope and CRT monitor were added in addition to the more detailed mask aligner model.
Once the buttons and knobs were added to the 3D model (Figure 8), it was imported into the Unity scene. The power supply box for the aligner was added alongside it, so the proper scripts could be applied to both power supply and mask aligner to make them work in tandem.

![Figure 8. Model placed in Unity VR environment (power supply on left).](image)

Using Unity C# and VRTK, the buttons became interactable and made the machine move and function like the real mask aligner (Figure 9).

![Figure 9. Mask aligner being used in VR environment.](image)
All objects exported from Maya to Unity were positioned within the simulation environment (Figure 10) and then made interactive by adding various VRTK elements such as highlighting, grabbing, and events (actions that happen on trigger presses, etc.).

![Figure 10. Objects placed in unity (results whiteboard on the right).](image)

Textures were mostly created as single-color materials in Maya (Figure 11), and these textures were exported to Unity alongside their models (apart from a few textures that were created in Substance, a 3D-texturing software developed by Allegorithmic).

![Figure 11. Hot plate and eyedropper materials in Maya (material is on the right).](image)
To provide a more immersive experience, animated custom hand models were created to replace the standard HTC Vive controller models (Figure 12).

The hands were animated to look like they are pointing when coming close to a button. Unity has an OnTriggerEnter function that is used to start an event when an object nears another object. In addition to looking like pointing, the VRTK script on the controller was tweaked to allow the area of VR influence to be moved to just the tip of the finger. As a result, the user can press small buttons and flip switches on the machines (Figure 13). These buttons and switches were previously unusable because the VR area of influence was too large for the small buttons.

Figure 12. Custom hand model being animated.

Figure 13. Custom hand model with a point animation, which enables the user to press small buttons easily.
To further help the user, they were provided with a whiteboard detailing how to use the VR controls (Figure 14). These instructions are visible to the user as soon as the simulation loads, and they exist in the locker room area outside the photolithography lab door.

Additionally, a script called the event manager was developed. This script runs in the background and tracks the user’s actions. These actions are sent to various displays within the simulation such as a whiteboard and the tablet that the user should carry with them. There is also a tablet that the user can carry that contains instructions on how to perform each step. This tablet contains information like spin-coater RPMs and UV-exposure time. The users can look at the tablet and whiteboard to see their progress and results.

Once the final step of the simulation is over or the time runs out, the whiteboard fills with results. Expected actions are written on it as well as actions that the user performed, and the user is awarded with a letter grade depending on their individual performance.
At the start of development, the Steam VR plugin for Unity was used. This plugin enabled the developers to add basic VR functionality to objects in the simulation, such as the ability to pick up and drop items, open doors, and highlight important objects. Three months into development, it was discovered that Steam VR has a few limitations and requires much more custom code, so the simulation plugin was switched over to VRTK. This switch better enabled the customization of existing VR functionality and allowed access to more built-in tools for interaction (Figure 15).

Results

Preliminary testing for this project was performed with 14 students, 12 of whom were majoring in Computer Engineering, and two who were in Animation and Game Development. Testing data was gathered by having the students run through the simulation and fill out a questionnaire once they were done. The questionnaire consisted of 16 questions on a Likert scale from 1-5. In addition, there were two short-answer questions at the end of the questionnaire.
Many of the questions were written for development and bug-testing purposes, but the questions that dealt directly with photolithography showed a trend of promising results. Table 2 shows the list of questions on the questionnaire.

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. How much did you know about the photolithography process before testing?</td>
<td>8 (57.1%)</td>
</tr>
<tr>
<td>2. How much video game experience do you have?</td>
<td>3 (21.4%)</td>
</tr>
<tr>
<td>3. How much VR experience do you have?</td>
<td>2 (14.3%)</td>
</tr>
<tr>
<td>4. Did you have any difficulty with controls?</td>
<td>1 (7.1%)</td>
</tr>
<tr>
<td>5. I was able to easily move within the environment</td>
<td></td>
</tr>
<tr>
<td>6. The environment seemed realistic</td>
<td></td>
</tr>
<tr>
<td>7. I was able to clearly read and understand the tutorial (whiteboard instructions) provided</td>
<td></td>
</tr>
<tr>
<td>8. I was able to clearly read and understand the text on the buttons</td>
<td></td>
</tr>
<tr>
<td>9. I was easily able to operate the machines</td>
<td></td>
</tr>
<tr>
<td>10. The system operated as expected</td>
<td></td>
</tr>
<tr>
<td>11. This simulation would help me learn the real photolithography process</td>
<td></td>
</tr>
<tr>
<td>12. The machines in the simulation are similar in shape and function to their real lab equivalent</td>
<td></td>
</tr>
<tr>
<td>13. This simulation would help me learn how to use the real machines in the photolithography lab</td>
<td></td>
</tr>
<tr>
<td>14. This simulation would help me improve my performance in a real photolithography lab</td>
<td></td>
</tr>
<tr>
<td>15. I needed more instruction to use this simulation</td>
<td></td>
</tr>
<tr>
<td>16. How satisfied were you with the simulator?</td>
<td></td>
</tr>
<tr>
<td>17. Any recommendations for improvement?</td>
<td></td>
</tr>
<tr>
<td>18. Any overall feedback?</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Questions asked of testers.

57% of tested students said they had a novice level of familiarity with the photolithography process. This question of familiarity was on a scale of 1-5, from “novice” to “expert” (Figure 16). Only one student answered that their knowledge was above at a 3 on the scale.

![Figure 16. Photolithography familiarity of testers.](image)
Observations of each student’s run through the simulation showed that they each gained an amount of comfort with the machines in the room as they spent time interacting with the machines, and their own feedback supports this (Figure 17).

![Graph showing 85.7% strongly agree and 14.3% agree](image)

**Figure 17.** 85.7% “strongly agree” and 14.3% “agree”.

92.9% stated that they agreed very strongly that the simulation would help them learn the photolithography process, while one tester answered a 4 toward the “agree” side of the scale (Figure 18).

![Graph showing 92.9% strongly agree and 14.3% agree](image)

**Figure 18.** 92.9% “strongly agree” and 14.3% “agree”.
100% of students agreed that working in the simulation would help improve their performance in a real lab, with 10 students answering a 5 toward “Strongly agree” on the scale (Figure 19).

Overall feedback of the simulation was positive (Table 3), with major complaints being the small size of text on the machines and initial difficulty with controls. Efforts are being made to mitigate some of these concerns, and further testing will be completed once the project is fully finished.

<table>
<thead>
<tr>
<th>Any Overall Feedback?</th>
</tr>
</thead>
<tbody>
<tr>
<td>The virtual reality photolithography room is phenomenal! So much like the real lab procedure.</td>
</tr>
<tr>
<td>It looked great. My only real issue was how small the timer on the machine was. I couldn’t change it at all with the controls</td>
</tr>
<tr>
<td>Fun Vr and maybe put fun things in the lockers. Possibly something outside when someone goes through the walls.</td>
</tr>
<tr>
<td>It works good.</td>
</tr>
<tr>
<td>Very cool process. I can see this being used in a lot of places.</td>
</tr>
<tr>
<td>I think this was an awesome idea! Very fun to try out and I think it would be a great learning tool</td>
</tr>
<tr>
<td>It was good.</td>
</tr>
<tr>
<td>Great! Love it!</td>
</tr>
<tr>
<td>Very impressive, tons of potential and applicability</td>
</tr>
</tbody>
</table>

Table 3. General tester feedback.

More testing will need to be done to compare a student’s performance in the simulation to their performance in the real lab. Familiarity with machines will be tested along with overall competency in photolithography procedures.

Conclusion

A VR simulation is the best option for photolithography training outside of a physical lab. Using a VR simulation is much less expensive than other training options, and experiments take much less time to complete. Additionally, VR could improve users’ performance in real-world labs.
Also, motor skills can be gained just as well in a virtual world as they can in the physical world, and using VR greatly decreases the risk of damage to expensive equipment.

Preliminary testing shows an increase of student confidence in their ability to learn the photolithography process and machine functionality.

Disseminating the simulation is simple; the executable file and data folder are easily transferable. Any university or individual with access to VR hardware and a VR-ready computer can run the simulation at no additional cost. Due to the low price of development and usage, this project has the potential to help students learn photolithography at a greatly reduced cost to their universities while improving their ability to perform experiments.

References