

Augmented and Mixed Reality-based Modules for Scientific Instrumentation Training

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ABSTRACT

Virtual, Augmented, and Mixed Realities (VR, AR, and MR) have the unique ability to create immersive mediated/extended learning environments and enhance the user's sensory perception of reality in real-time, from simply overlaying virtual information onto the real world to interactive and immersive training experiences. However, creating the right degree of augmenting, that is, how much digital information one can incorporate in the real environment, is one of the challenges. The degree and focus of augmenting should be carefully weighed to reduce the mistake rate and make learning experiences more interactive, attractive, and motivating. This project aims to develop a series of AR-based training modules on using scientific instruments housed in the NSU Nanofabrication Cleanroom, a state-of-the-art facility for electronic material growth and characterization. The initially targeted areas are photolithography, thermal evaporator, plasma etching, and corresponding safety procedures. During Augmentation Stage-I, the actual training process inside the Cleanroom is first recorded in real-time with 360o cameras and then augmented during post-production using Unity toolkit by adding computer-generated labels and objects. Next, during Augmentation Stage-II, the training module will be advanced to the Mixed Reality (MR) environment to provide a more interactive and immersive training experience. Students will benefit significantly from experiencing the virtual Cleanroom before stepping their feet to the high-quality laboratory for the actual training process. These AR-based training modules will also be available and accessible to remote users as a mobile application on smartphones, tablets, smart glasses, and headsets.

ABOUT THE AUTHOR

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INTRODUCTION

Incorporating the latest technologies such as Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) into a three-dimensional (3D) learning environment has been shown to improve learning efficiency and be more effective than conventional learning systems. Unlike VR, AR does not isolate the users from the real-world environment and provides enough flexibility. AR has the unique ability to create immersive enhanced learning environments by overlaying virtual information (like virtual objects, texts, avatars, etc.) onto the real world. Due to technology evolution, it is broadly accessible today and is already becoming one of the most exciting and creative approaches to learning and professional training (Cai et al., 2013). AR is currently in the developing phase and, by creating apps and interfaces, will dramatically change the way we interact with the data, how we learn, how we work, and arguably how we think. We believe that soon AR will be available through smart glasses and contact lenses and will create amazing things for improvements in various industries and fields of education.

It is essential in engineering education and professional training to have a practical field of experience apart from classroom theories. Also, higher education students desire to be prepared well for their professional life and expect more practical training. Norfolk State University's Micron Nanofabrication Cleanroom can be considered one of the leading Cleanrooms among HBCU's and other universities in the United States. The Cleanroom offers state-of-the-art equipment to conduct research in the field of science and engineering. Although having the experience of being and working in an actual cleanroom can be very rewarding, especially for current and future work and research, access the cleanroom equipment is not straightforward because it requires substantial cleanroom certification and training. The general and equipment-specific certifications confirm that the person entering, working in, and exiting the Cleanroom is familiar with Cleanroom protocols and operating procedures. The interest in cleanroom use could be improved by providing more information to students on the Cleanroom purpose and use, encouraging them to become more familiar, along with novel training and certification practices.

The purpose of this research is to develop a series of augmented reality training modules on the use of scientific instruments housed in the NSU Nanofabrication Cleanroom, a state-of-the-art facility for electronic material growth and characterization. Specifically, the first AR-based module focuses on the thermal evaporation process training. The actual training process inside the Cleanroom is first recorded in real-time with 360-degree cameras and then augmented during post-production by adding computer-generated labels and objects. Table 1 details general Cleanroom issues to address.

Table 1. General Cleanroom Issues to Address

General Cleanroom Issue	Proposed AR-based training modules
Need a high level of cleanliness and follow the safety procedure strictly	Provide self-oriented space for exploration
Limited time and resources for the individual user	Easy to access for a longer duration
Risk of accident and damaging equipment and machinery	No risk of accident or equipment damages and saves cost
Time schedules must comply with the University Cleanroom rules	Pre-recorded modules are available for asynchronous training

This application will provide a life-like experience within a laboratory cleanroom before physically entering the Cleanroom and will allow the users to view the Cleanroom layout, become familiar with the equipment, and even interact with the augmented environment by pressing buttons to read specific specifications. This AR-based training method will allow for disseminating rules, regulations, and protocols that involve the Cleanroom, from general safety procedures and preparing a person before arriving at a cleanroom to the moment that person enters and exits the Cleanroom. This method could also be used to certify new Cleanroom users without or before taking up actual cleanroom schedule time. A further iteration of this project will allow for augmented reality training to be held inside the Cleanroom, improving the quality of the training provided. Allowing additional information to be presented in a digital format, layered over the user's visual interface, lets the instructors use additional teaching techniques and materials which might not normally be available.

BACKGROUND

The term "Augmented Reality" appeared for the first time in the 1950s, and it became a field of study at the beginning of the 1990s (Alkhamisi & Monowar, 2013). AR turns the environment around users into a digital interface by placing a virtual object into the real world in real-time. It is a form of VR that allows the user to see the Reality superimposed or contrasted with virtual objects (Lin et al., 2012). In the early years, AR systems used two types of Head-Mounted Displays (HMDs), namely optical HMD and image-based HMD, that users can use to blend the real world and the virtual environment. Today, AR is available in several forms, ranging from glasses to headsets, from large tablets to mobile phones to projectors and heads-up displays (Mealy, 2018). Unlike VR HMD, AR HMD has a pair of small cameras, either built-in or attached to it.

In the fall of 2017, the introduction of software development packages like ARKits by Apple and ARCore by Google made it much easier for developers to write AR applications for iOS and Android platforms (Mealy, 2018). Currently, mobile devices already cover the largest market segment for AR. For the mobile AR, a user must continually hold a device and capture the images of the physical world, onto which the digital objects are superimposed. Also, on the limitations side, the current smartphones provide only a relatively narrow field of view which is far smaller than the user's field of view (Mealy, 2018). Therefore, a headset is used for AR's better experience, and some examples of AR headsets include the HoloLens, the Glass Enterprise Edition 2, and the Epson Moverio BT-300. These headsets bring a more immersive AR experience for the users. The AR makes the user's life easier by providing virtual information complementing the user's adjacent real environment and developing the user's insight into communications with the real world (Alkhamisi & Monowar, 2013). It has already become one of the most exciting and creative approaches to learning in education (Cai et al., 2013). In engineering education, it is essential to have a practical field of experience apart from classroom theories. Also, higher education students desire to be prepared well for their professional life and expect more practical training.

AR Displays

The three major types of AR displays are HMD, handheld, and spatial displays (Carmigniani & Furht, 2011). AR HMD is the device worn by the user on the head that places both the digital information and the real-world environment over the user's view of the world. The AR HMD can be of two types. Namely, they can be either video see-through AR HMD or optical see-through AR HMD. The video see-through system requires two cameras to record the real scene. Then, recorded video is sent to the video compositor (computer), where the graphic images are combined to create an AR scene displayed to the users through HMD. In contrast, the optical see-through employs an optical combiner that is a partially reflective and partially transmissive view of the physical world to pass through the lens and graphically overlay information to be reflected in the user's eye (Yadav, 2019).

In addition to AR HMDs, other mobile devices with displays such as smartphones and tablet PCs that the user can hold in their hands could also be utilized for AR experience. They use video see-through techniques to overlaying graphics onto a real environment (Carmigniani & Furht, 2011). Handheld devices are highly portable and widespread, and today they have powerful CPUs, cameras, accelerometers, GPS, and solid-state compass, making them a very promising AR platform.

Software Components

Some of the VR development tools used in VR and AR content creation are virtual world modeling/authoring tools, VR toolkits/software development kits (SDK), and application program interfaces (APIs) (Bamodu & Ye, 2013). VR toolkit is a collection of tools and software for designing, developing, and maintaining the virtual environment and the database where the information is stored. Several modeling engines are available in the VR designing market, e.g., Unity3D, 3DS Max, Maya, Blender, etc. It is very important to choose the VR development tools based on the flexibility provided by different software packages such as model input available, interface compatibility, file format, animation ease, collision detection, supported I/O devices, and support community available to the users (Bamodu & Ye, 2013).

Unity3D is often described as the best option in terms of the license, ease of use, and compatibility with VR hardware such as various HMDs, haptic interaction devices, etc. (Polcar et al., 2016). It is also used by a higher number of communities. Unity3D highlights are detailed below (Parisi, 2015):

- **Powerful:** Unity engine offers excellent graphic features with physically based rendering, real-time lighting, physics simulations, and scripting, including a high-quality material framework.
- **Extensible:** Unity provides a versatile, expandable, and configurable framework through user scripts. The scripts can be overwritten, and a custom tool can also be developed.
- **Portable:** The player runtime supports all types of device operating systems (Windows, Linus, Mac) and both iOS and Android mobile platforms.
- **Affordable:** The Unity engine is completely featured and cost-free. However, fees for the commercial use of licensing terms are fair and affordable.
- **Useful Resources:** Unity has a wide variety of online asset shops, including 3D models, animations, bundles of code, and utilities. It has very clear documentation as well.
- **Ready for VR:** Oculus SDK needs to install Unity3D to build for the Oculus Rift, which comes with a Unity integration kit that offers support to get started with VR.

While PlayStation VR is focused on the entertainment market, other HMDs developers like Oculus and HTC have released their SDKs. Oculus updates SDK constantly to create prototypes and involve communities for the application development process. The software and the specifications of the DK1 are available under GitHub (Anthes et al., 2016). Most HMD device developers come with their SDKs for their hardware, and it calls for standardization to guarantee cross-device development.

DESIGN

This section describes the design approaches and workflow of the research. As stated in the introduction, the project aims to develop an AR-based Cleanroom training module with augmenting 360-degree videos (pre-recorded and real-time) to provide a better learning environment than other instruction methods. The overview of the project layout is shown below in Figure 2. First, the video can be either pre-recorded or real-time recorded using 360-cameras. Then those videos are imported into Unity Engine to provide an enhanced environment for immersive and interactive experience by adding 3D text, 3D avatars, and other virtual objects and/or schematics.

Similarly, developing the core AR content for the Cleanroom tour and equipment-specific training process during Augmentation Stage-I will follow the same process as the project prototype. The general implementation process of AR development is shown as four layers in Figure 1. Finally, during Augmentation Stage-II, the users can experience this AR-based training in real-time via AR HMDs and remotely via VR HMDs.

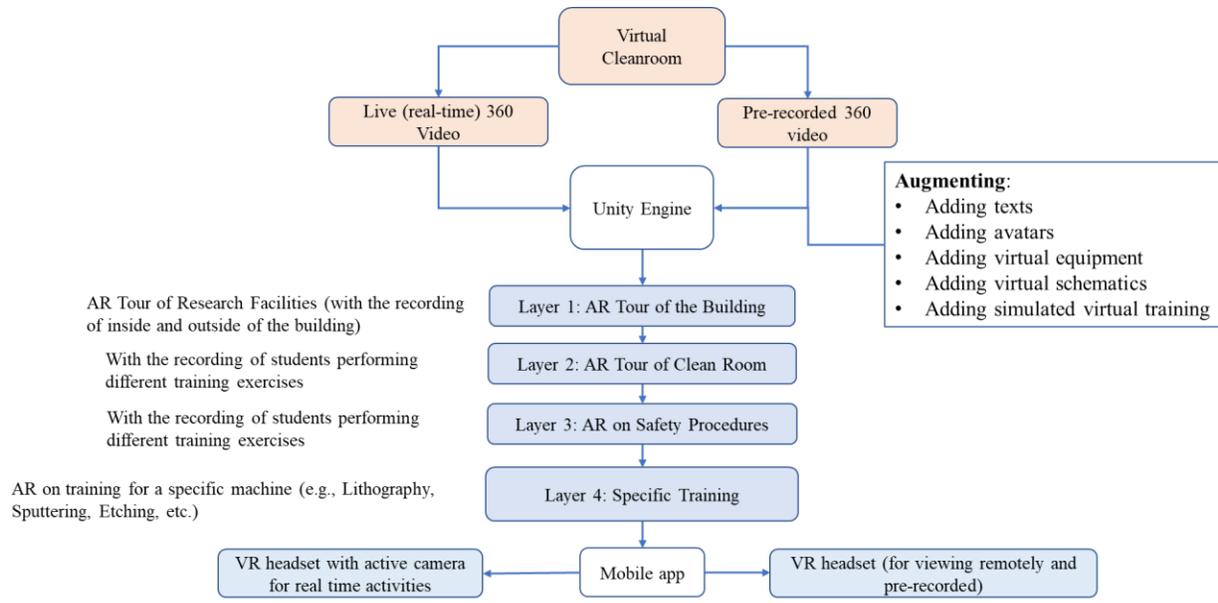


Figure 1. Overview of project layout

Issues Addressed

Specific Cleanroom protocols and procedures must be followed when using the Cleanroom. Certain people have limited time and, in some cases, limited resources to physically attend cleanroom training. First-time users risk accidental damage to equipment and/or machinery. These are the challenges of actual in-person training. The promise of how AR technology could change the training process is profound. However, there is a number of barriers, both technical and conceptual, that we have to overcome, as detailed below.

Technical

Creating a Virtual Environment

Several 3D modeling software and software development kit (SDK) tools have been used to develop AR environments. Therefore, understanding 3D modeling software and the proper framework selection to create a virtual environment and choose proper hardware is very important. Understanding the authoring tool's initial landscape to design and prototype AR experiences is one of the challenges.

Incorporating 360-degree movies into 3D software

The augmenting of 360-degree movies (that is, incorporating the 360 videos into a modeling software kit and superimposing the virtual digital information) is another issue to overcome, along with the challenges like object selection, conditional actions, scene flows, and movement between scenes.

Development of a mobile application

Developing a mobile AR application must go through many hardware and software compatibility-related and legal issues. Creating a good app needs to go through several processes and overcome all the challenges.

Conceptual

Degree of augmenting

The significance of AR in education is that it will provide a self-oriented space for exploration for the learners in more interactive ways close to real-life experiments. Creating the right degree of augmenting, that is, how much digital information one can incorporate in the real environment, is one of the challenges. It should be carefully weighed to provide a better learning environment and make learning experiences more interactive, attractive, and motivating.

Media of augmenting

AR is a technological system that allows inserting virtual content into the real world to create a mediated environment and enhance the user's sensory perception of reality in real-time. Using the proper augmenting media such as text,

virtual object, animation, and virtual schematic can create a better virtual Cleanroom with a better training experience for the users. However, choosing the right type of media for augmenting is one of the challenges. Adding appropriate digital/virtual content to the real environment is essential to facilitate the correct training process and reduce mistakes.

Different Modes of Training Flow

The implementation process of AR development is divided into two sections: inside Cleanroom and outside Cleanroom, as schematically shown in Figure 2.

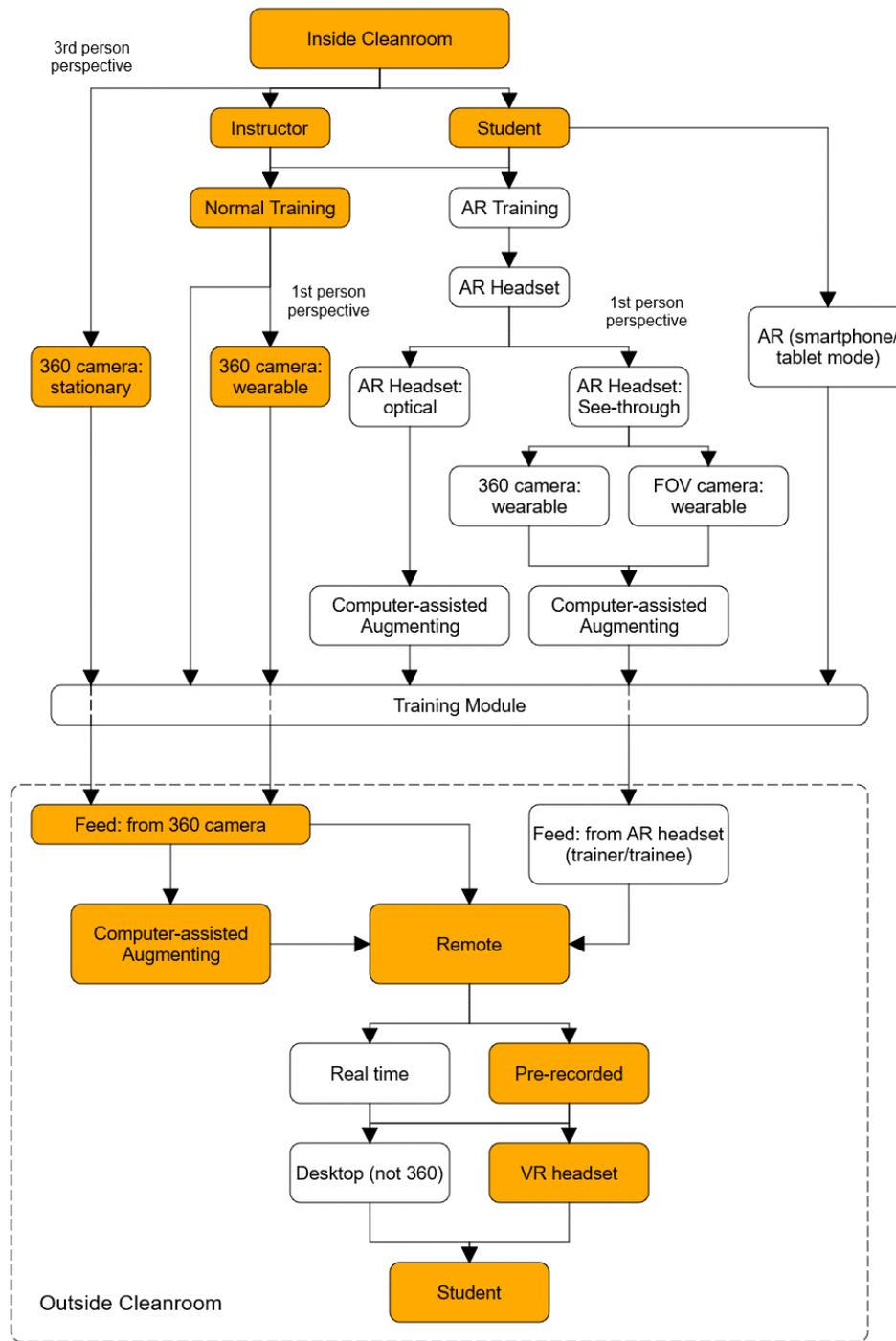


Figure 2. General training flow schematic.

There are about six modes of possible training flow:

- Instructor (inside) + trainee (inside) [live]
- Instructor (inside) + trainee (inside) + trainee (remote) [live/recorded]
- Instructor (inside) + trainee (remote) [live/recorded]
- Instructor (remote) + trainee (inside) [live]
- Instructor (remote) + trainee (inside) + trainee (remote) [live/recorded]
- Tour mode : Instructor (remote) + trainee (remote) [recorded]

The training flow for Augmentation Stage-I [Instructor (inside) + trainee (remote)] is highlighted in Figure 2.

The simplest method is the third-person perspective, where a stationary 360 camera (e.g., Samsung Gear 360 or Go Pro) is placed inside the Cleanroom to record the 360 videos /images of the training process. It captures every direction simultaneously, allowing the user to see all 360 degrees of footage in the sphere. 360-degree video/image files are saved just like any video/image files such as mp4 and .jpg. Initially, the simplest method will be adopted and then extended to the real-time interactive training modes.

METHODOLOGY AND RESULTS

360-Recording Procedure in the Cleanroom

Before creating the equipment-specific AR-based training modules, an augmented video tour of the Cleanroom was developed as a proof of concept. The tour consisted of entering the Cleanroom (chase area or the gowning area), recording 360 movies and pictures in the different bays of the Cleanroom, and exiting the Cleanroom. In order to make this AR experience realistic and immersive (a sense of being inside the Cleanroom), we used a 360 camera. The 360 camera could be stationary or wearable. A stationary 360 camera is usually fixed on the tripod or placed on a stable surface for recording. A stationary 360 camera is easier to record with and augment than a wearable 360 camera. On the other hand, wearable cameras are normally mounted on the user's head, providing a first person's view (egocentric perspective) experience. Two different cameras were used, a Gear360 and a GoPro Max. While Gear360 was acceptable for recordings and photography, it turned out that the GoPro had a better resolution, so most of the footage used in the project was from the GoPro camera. As the name implies, a 360-degree camera captures the entire environment around the user (so that the field of view is the entire sphere). 360 spherical video plays through like any other online video but allows the user to control the viewing direction like a panorama. A 360 camera basically captures two images or video files from dual lenses with a semi-spherical field of view each. Figure 3A depicts the images of the 360-movie shots of the Cleanroom Bay 2 area. The videos are recorded by Samsung Gear 360 camera with a 4K (4096 x 1920 pixels) resolution or Ultra HD resolution. For the preliminary test, the monoscopic 360-videos are used in this project, where both eyes see the same video in the virtual reality experience (no built-in sense of depth). Outside the Cleanroom, the raw 360 videos/images are then stitched together and converted into equirectangular projection with the help of 360-stitch software (Action Director Gear 360 and GoPro Player), as shown in Figure 3B. Equirectangular projection is a way to represent information of a sphere in a rectangle by transforming the latitude into horizontal lines and longitude into vertical lines with the aspect ratio 2:1. Once the videos/images are converted into equirectangular projections, they are imported into Unity for computer-assisted augmenting (see Figure 3C). Finally, the user can view the pre-recorded training module through a VR headset remotely as well as in Movies & TV Windows or VLC media players (capable of playing 360 recordings).

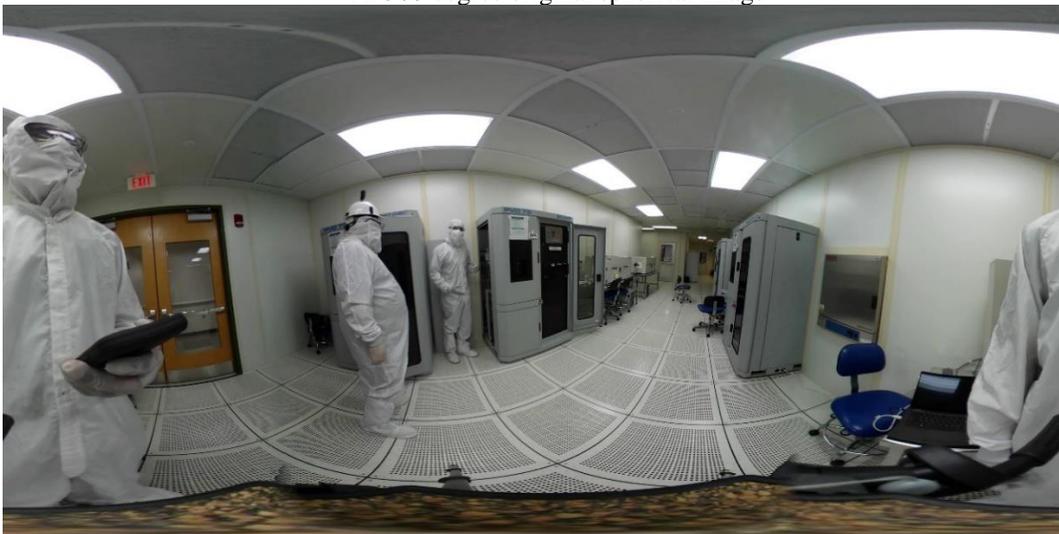
360-Movie Augmenting in Unity

The Unity Engine software tool is utilized to build custom AR/VR environments in this project. The 360 videos/images are imported into Unity Editor to build scenes and develop the project's structure. The Unity editor comprises several different windows shown in Figure 4 and detailed below:

- Hierarchy – which contains a list of all the objects in the project scene
- Scene – provides a 3D view of the project
- Inspector – contains the project's file structure with folders and assets such as 3D models, scripts, audio, 360 images, video, etc.



A. 360-degree original spherical image



B. Equirectangular image (converted)



C. As seen inside Unity

Figure 3. 360 Video recording and preparation for Unity

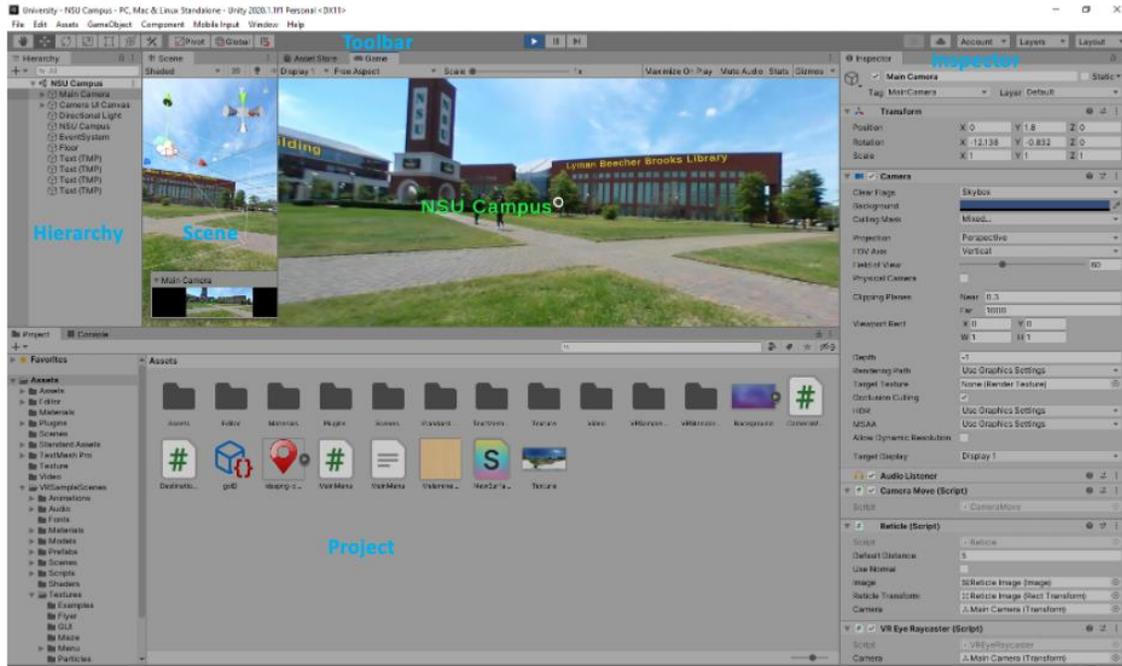


Figure 4. Unity editor interface

The most significant steps involved were learning the interface and setting up the project, creating scripts to achieve the desired results, and the actual augmenting process itself.

The screen capture in Unity3D includes a few steps. First, a sphere was created around the main camera, onto which the 360 footage could be projected. Then, the 360 footage was added to the assets and placed onto the sphere. One can then see the 360 footage being projected on the outside of the sphere. While this method of inserting objects into the scene will not work if the camera moves, a stationary camera allows for the perception of objects being included in the scene as part of the environment. The next task involved was to include text in the scenes to augment specific objects or locations with information. Depending on the design, AR labels could be

- Displayed permanently or could be displayed temporarily for a required duration of time (or added/removed by clicking the remote controller).
- Overlaying or semi-transparent
- Clickable (selectable) vs. non-clickable

At this stage, augmentation is mostly an overlaid text such as displaying safety procedures, equipment components, and operating procedures for instruments in the system. Two types of augmenting text have been used: the object-related text (inside the scene) - the gold color, and the text fixed to screen space - the green color. The object-related text is used to label the machines and instruments in the Cleanroom and Engineering laboratories. The text fixed to the screen can be used to display the safety and operating procedures for instruments in the system. More levels and other menus are added post-production to make the training process more informative and enhance learning.

Once the video is imported to Unity, as per the previous discussion, the video can be modified with text or animations and then re-recorded as a new 360 video, which includes the augmentations on top of the original video. The tool used to accomplish this is the Unity recorder, which is free for download in the Unity store. After the developer presses the 'record' button in the recorder window, the recorder application outputs a video file from the perspective of the camera used in the settings. The resolution of the video can be adjusted in the recorder application. It should be set to match the resolution of the video that is being recorded to allow for the greatest clarity in the output video in comparison to the original video.

After determining how to upload, augment, and export 360 videos, the last actions required were cleanup and additional functions. The project was then converted to a standalone application instead of just a movie recording. Scripts were added to perform a few different quality-of-life functions, including adding a pause menu, adding a button to close the application, and adding the ability to press the escape key to bring up the pause menu as well, as shown in Figure 5. Two more scripts were included to allow for the camera's rotation within the game mode and the ability to zoom in and out using the scroll wheel.

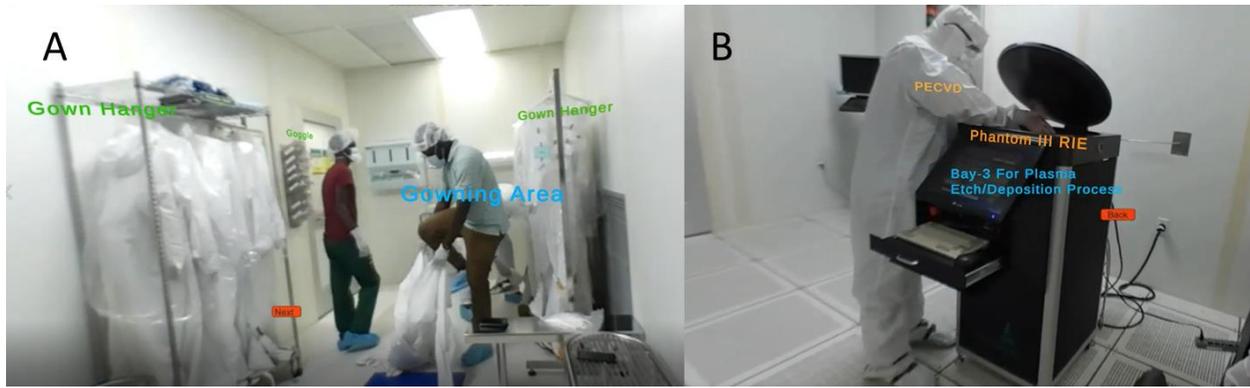


Figure 5. Developed AR Examples: A -Gowning Area, B - Plasma Etching Process.

CONCLUSIONS

The framework for a training method has been established, and the prototypes of the actual training program have been created. The delivered project outcomes show proof of concept and the project's potential in Cleanroom training. The next steps moving forward in the project would be:

- Determine how to transfer a completed Unity project into a mobile application
- How to add VR objects to 360 movies and control their location and motion
- Application of AR/VR module development process to photolithography, plasma etching, and thermal evaporation training
- Create an actual training session, and then use that session to train a group of students and evaluate the performance difference between the AR/VR training session vs. traditional training.
- After evaluation, the developed training modules will be uploaded to the NSU Cleanroom website

The developed training modules will be available online for remote training using a laptop, a web browser, a mobile phone, or a VR headset. On a desktop PC (locally and online), the viewer can use the mouse to pan and look around. On a mobile device, the viewer can either use a finger to pan and look around or directly point the device to where the viewer wants to look. When using a VR headset, the remote viewers will be virtually immersed in the video and can simply look around as it is in real life by moving their heads.

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