Additive Manufacturing Virtual Reality Lab for Training Industry Employees and Engineering Students

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Abstract: Virtual Reality (VR) is becoming popular in multiple applications like gaming, driving, aviation and medical training, fashion and tourism. This study is focused on the promising and encouraging role of Virtual Reality (VR) in engineering programmes. Robust development and innovations have been accelerated in several manufacturing technologies, especially in laser processing, additive manufacturing, and printed electronics. These developments demonstrate the use of Industry 4.0 technologies in creating fully automated and smart manufacturing of products controlled and monitored by computers and robotics. To understand and develop such systems, engineering students need to be trained and prepared for the next generation of computerised machinery, which might not be available in every educational enterprise. Due to its unique ability to produce parts with complex geometry, additive manufacturing (AM) is suitable for manufacturing customised individual products in the biomedical and Aerospace industries. Flexible designs can be adopted, and reduced mass and materials savings can be achieved in addition to processing materials difficult to machines, such as titanium, nitinol and magnesium alloys. Nevertheless, AM is not a standard manufacturing technology in the training of engineering students due to the high initial cost, high running skills and access difficulty due to health and safety regulations. This study reports the employment of a VR lab, tackling this problem and providing the students with a VR-based AM lab in which they can experience the entire build process and carry out assignments efficiently and, most importantly, safely.

Keywords; *Virtual Reality, engineering education, Additive Manufacturing*

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1. INTRODUCTION

Even though Virtual Reality (VR) and Augmented Reality (AR) have been known for over 50 years, the recent development in computing power, motion sensors, lightweight materials, and fast processors have allowed for the VR and AR technology to become employed in more applications (Hall and Miller, 1963). Several companies and manufacturers provide VR headsets nowadays, like Oculus (which was recently owned by Facebook, HoloLens (owned by Microsoft), HTC, Google, and LG.

The employment of the Virtual Reality (VR) labs in academia is increasing for many reasons, like the rapid development in VR technology and the ability to update the software according to the physical labs' updates. Moreover, there is increasing demand for remote teaching of AM courses for several reasons, especially the limited or prohibited travel due to expense or pandemics. Among several VR labs available in academia nowadays like chemistry, physics, and robotics (Ferrero and Piuri, 1999; Candelas *et al.*, 2003; Oidov, Tortogtokh and Purevdagva, 2012; Herga, Cagran and Dinevski, 2016; Soliman *et al.*, 2021), there is still a clear gap in adopting Additive Manufacturing (AM) processes in VR. For the rapidly progressing manufacturing technology being employed in a wide range of applications like Aerospace, biomedical (Rasheed *et al.*, 2021), and automotive, AM must be taught to engineering students to meet the predicted development in industry and to prepare skilled graduate engineers. Currently, advanced VR technology software could be easily updated to mimic the fast advances in the AM technology, adding any new feature in the AM industry.

2. ADDITIVE MANUFACTURING IN ACADEMIA

As a novel technology, AM has proven to offer a positive impact with noticeable interaction inside the classroom. It is a multi-stage process which can be represented by the part design and the CAD file preparation, loading the metal powder into the machine build chamber, purging the chamber with the inert gas, setting the processing parameters, running the print, and part removal and cleaning (Obeidi *et al.*, 2019; Ahmed Obeidi *et al.*, 2020; Fitzsimons *et al.*, 2020; Mussatto *et al.*, 2021; McCann *et al.*, 2021, Obeidi *et al.*, 2022). Each stage comprises sub-activities and more details in which group projects can be arranged and encouraged in the classroom (Gatto *et al.*, 2015)(Minetola *et al.*, 2015). Additive manufacturing is being delivered as a graduate program in both Penn Sylvania and Maryland universities. All the different stages of AM technologies are explored in these courses.

Similarly, other universities like Texas EI Paso, Georgia Tech, NC State, and MIT offer certificate courses in AM, including process overview, applications, design, software and hardware. Therefore, only some universities might be able to afford the cost of AM teaching preparing labs accessible to all students for hands-on learning. This is due to the fast evolving AM technologies and their machines, cost of owning and maintaining the lab, consumables and training/labour/time cost, in addition to the H&S concerns (Schelly *et al.*, 2015).

Despite the broad published work on the different AM technologies, there is still a significant lack in the availability of textbooks and tutorial which details these technologies in pedagogy and disciplinary matter (Gibson, Rosen and Stucker, 2015). Most of the published work is focused on a singular AM technology, a process optimisation, or a research topic aiming to explore the effect of the input parameters on the output measured property. Moreover, small and desktop-sized AM machines can be found in universities and technical institutions' labs. Nevertheless, larger and high-technology printers are too expensive and difficult to find at the educational level, besides the health and safety H&S restrictions.

3. ADDITIVE MANUFACTURING IN VR
(Case study)

Figure 1 shows the AM lab at Dublin City University (DCU), Ireland. The metal printer is manufactured and supplied by Aconity, Aachen, Germany, which uses the Laser-Powder Bed Fusion (L-PBF) technology. As previously mentioned, the build process comprises multiple stages and requires high skills and special training involving software and hardware. For the health and safety regulations, entering the lab in most cases must be sponsored by qualified and trained persons and is prohibited during loading the metal powder and/or removing the AM parts. Also, the metal powder handling must be carried out with the full personnel protective equipment PPE. This includes the anti-static coverall, HEPA standard powered respirator, anti-static gloves and safety boots.

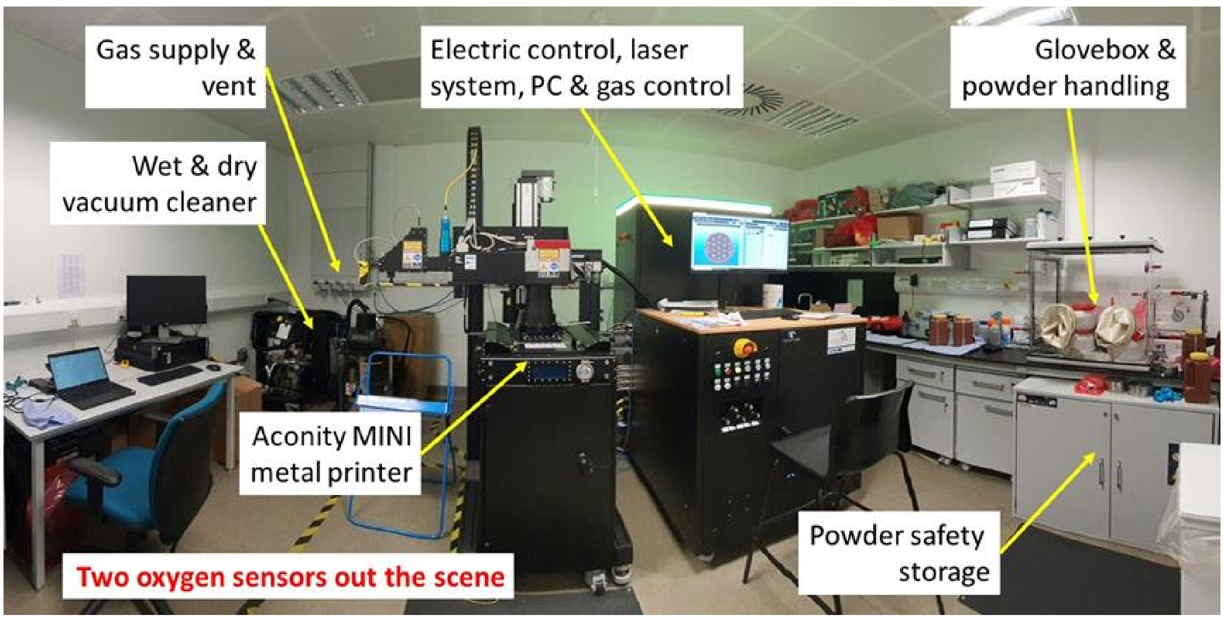

Figure 1 The AM lab in DCU showing the Aconity MINI 3D metal printer (Obeidi, 2022)

To avoid all the restrictions, difficulties, and limitations mentioned above and to offer more students the opportunity to experience this technology safely and reduce cost, it has been decided to establish the VR lab. The number of software designers and suppliers is interestingly increasing with competitive costs.

Figure 2 shows the most recent version of the VR lab software installed on Oculus headsets. The lab was designed based on videos captured during the research on the Aconity MINI. All the stages were recorded, and screenshots showed the Aconity Studio software features and interface running the build process.

Figure 2 The AM VR lab in DCU showing (a) the Aconity MINI 3D metal printer corresponds to Figure 1, (b) the PPE set that the user must wear to proceed to the lab and use the AM metal printer, (c) the glovebox used during the metal powder handling, (d) the virtual software on the machine CNC, and (e) the gas control valves on the control panel.

During the use of the VR headset, the user will be asked to go through the consecutive stages in chronological order starting from the compulsory use of the H&S PPE set to the finished AM part removal, cleaning and metal powder handling. The software was designed to mimic the captured videos and the actual process with instructions and explanation figures guiding the user to virtually experience the real lab with all the AM stages.

32 PhD students from two universities who piloted the use of the lab thought that "VR is a good teaching tool" with mixed feedback (positive like "Pretty cool, impressive" and "Impressive recreation of the lab in VR" and negative related to VR sickness "Felt very sick and had to stop early"). It was noted that all trainees showed clear interaction with improved types of questions after using the VR and a better understanding of the AM process after using the VR headset. It was also pointed out that they were encouraged to initiate debates and ask and answer questions compared to the time in the class and the traditional lecture.

One of the limitations or challenges that was observed in the VR lab is the motion sickness experienced by one of the students. This can be related to multiple reasons but mainly the person's health conditions and sight or the number of frames per second (fps) used in the application. Another reason, especially for the new users, is that their brain needs time to adjust with what it is experiencing in contrast with what their body is experiencing. The most effective way to avoid the motion sickness is by reducing the length of the VR sessions. A significant correlation between the VR exposure time and this sickness was found. A good practice is to play video games for short time in order to familiarise the brain to ignore some of the signals when the user is in the VR application. Another suggested solution is to adjust the headset properly to allow the sufficient distance from the eyes and inserting the recommended spacer necessary for the users with glasses.

4. CONCLUSION

Virtual Reality is a fast-growing technology expanding in a vast range of applications. It offers a complete advantage in training students and new staff (train staff before being trained in the real lab) on new instruments and machines, especially when the training involves possible physical equipment damage, users' injury, additional cost and time. For advanced additive manufacturing technologies like L-PBF, Direct Energy Deposition (DED), and Electron-Beam Powder Bed Fusion (EB-PBF)), the high cost of their labs is the prohibiting barrier to their existence in universities. In most cases, this kind of training is not necessary to give a full license to use some instruments. However, for example, in academic education, the students can gain respectful skills by learning about technology like additive manufacturing that would otherwise be unavailable due to space, safety, or cost considerations. Similar to the successful applications of Computer Integrated Manufacturing (CIM), VR is expected to be an effective teaching tool in both educational and industrial applications due to its interactivity, realism, and immersiveness.

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