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AFFORDABLE VIRTUAL AND AUGMENTED REALITY TRAINING MODULES FOR WORKFORCE DEVELOPMENT AND SMART MANUFACTURING

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Abstract

In the face of rapid technological advances, including digital, additive, and smart manufacturing, it is essential to continually update manufacturing competency to facilitate skilled workforce development. This study explains a user-friendly Virtual Reality/Augmented Reality/ (VR/AR) training framework for training manufacturing processes. Process equipment and operational protocols are complex and demand for highly skilled and trained operators. Operators trained using the current methods, including in-class and computer-based training, continue to need help with some of the key process equipment operations, causing batch failures resulting in significant loss of time and money. Conventional avenues and traditional computer-based training have been routinely employed to educate operators. However, VR/AR-based process training will remedy the exposed inadequacies of smart manufacturing training processes that are causing continued operator errors. The virtual simulation offers coordinated visual and proprioceptive (spatial perception) feedback cues to develop motor skills for procedural knowledge and memory. The interactive training explores the relationships between actions and outcomes to promote schema building and strengthen trainees' mental models in manufacturing operations. This project has a significant commercial impact within the manufacturing industry owing to increased operational efficiency, reduced product delivery time, and increased accuracy. Optimal training aids affordable, precise, and quality product delivery for generic and personalized medicines to needy patients, thus resulting in a significant societal impact. It will positively impact the professional development of trainees and operators through training in cutting-edge research, innovation and entrepreneurship.

Keywords: *Virtual training, VR, AR, Smart manufacturing, Operator training*

1. Introduction

During the past several decades, despite a notable decline in jobs in some manufacturing sectors worldwide, employment in specialized manufacturing continued to grow. On the other hand, current trends also point towards millions of manufacturing positions that will go unfilled worldwide and caution specifically about the ‘impending shortfalls’ in the specialized manufacturing labour force. The skills gap [1-3]and recurring failure in manufacturing facilities continue to cause considerable losses to the company in terms of money, time, and resources. Some of the significant characteristics of these inadequacies are:

i. Training practices cannot simulate and match the sophistication required in manufacturing scenarios.
ii. Training procedures cannot engage the trainee in accomplishing optimal participation.
iii. Limited availability of expensive and sophisticated manufacturing equipment that can be spared for training purposes.
iv. Operators need enormous time commitment to rectify any failure and accident-related malfunctions, adversely impacting the production process and causing delays.

2. Background

Customizable VR/AR applications developed with intuitive interfaces reduce cognitive load and optimise the integration of visual, auditory, and haptic stimuli for training transfer and retention. Such virtual modules allow users to turn guidance/query features, captions, and audio on or off. Let us briefly discuss subtractive and additive manufacturing practices to get an idea of the background and the importance of developing non-traditional approaches such as virtual modules for training. Subtractive manufacturing

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comprises building real-world and 3D objects by subtracting (deducting) the building material (e.g. metal – iron, copper, etc.) from a solid chunk of the original material (like a cylindrical one or other forms).). Characteristically, equipment and apparatuses such as gears and manufacturing parts developed with CNC machines used to belong to this class of manufacturing. In Computer Numerical Control (CNC) [4], wherein such subtractive processes are employed, the final product or component is generated by eliminating or removing the raw material using various tools and procedures. Material removal is performed within a 3D coordinate framework (e.g. a cartesian coordinate space). Over time, several advances in this technology have led to subsequent significant enhancements to the overall processes and their efficiency.

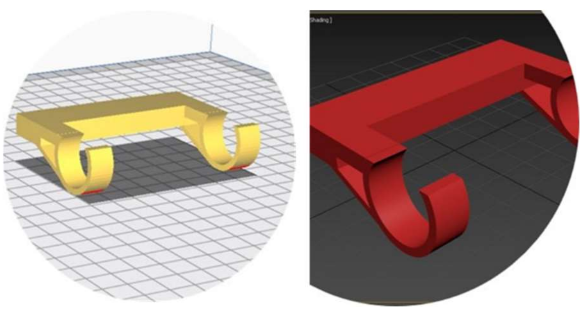

Fig. 1 3D model generation

Conversely, with additive manufacturing, the final products are generated by successively placing or depositing the raw material (metal, PLA, etc.) in the form of layers that are piled (systematically and precisely) one on top of the other to generate an exact 3D object (Fig 1). These are built in 3d modelling software, then converted into STL files (Stereolithography) to enable printing a 3D printer to create 3D objects that can be used for real-world purposes (Fig.2). Insufficient and inappropriate procedures and operation executions are significant causes of workflow interruptions and inordinate delays in supply chains. By facilitating optimal training, the resulting VR/AR training framework will, directly and indirectly, help avoid and minimize shop-floor mistakes and mitigate supply chain and manufacturing delays.

Summarily, stated below are some of the major factors responsible for the manufacturing crisis [2] [3] [5]:

i. Insufficient exploitation of the advances in VR/AR in manufacturing
ii. Lack of virtual interactive training practices in areas like specialized manufacturing
iii. Lack of virtual operator training exercises that can offer real-time feedback to trainees
iv. Loss of productivity due to over-reliance on human trainers
v. Compromised safety and higher risk to operators due to outdated training
vi. Resultant extended production times causing delay in delivery schedules
vii. Hampered product throughput due to operational failures and insufficient operator availability

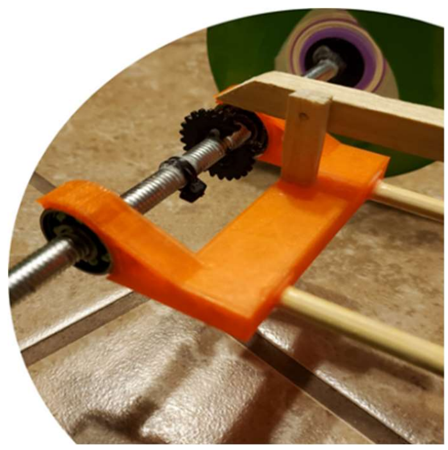

Fig. 2 Use of 3D printed model

Bossard et al. [6] state: "Transfer of training is defined as the extent of retention and application of knowledge, skills and attitudes from the training to the workplace environment." While actual training on physical equipment is undoubtedly required, VR/AR training saves considerable money and time while increasing trainee engagement & confidence. By not using actual physical equipment throughout the training process, industries with limited equipment face fewer interruptions concerning using their machinery for actual production. The virtual training equips the trainees with the knowledge and spatial cognition/perception skills to handle physical equipment confidently. The following section briefly discusses VR and AR training practices in industry and manufacturing.

3. VR training practices

According to Sherman and Craig [7], VR can be described as "... a medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being

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mentally immersed or present in the simulation." Several notable studies have successfully demonstrated the use of VR in learning and its effectiveness in instruction [8-10]. The features of VR, such as interaction and navigation, facilitate actively engaging with the learning materials. The multimodal content delivery will include an immersive

VR, augmented VR, mixed VR and desktop VR, thus facilitating accessibility and affordability as required by budgetary, infrastructure, and space constraints. However, given the increasing budgetary restrictions in workplaces and educational institutions, Modules can be accessed using desktop computers or laptops and low-cost head-mounted displays. The module development is targeted towards multiple modes: notebooks or desktop computers (for easy access), head-mounted displays (where preferred or affordable), and web-based delivery will allow access on Chromebooks and iPads. In addition to the physical characteristics of the task, the cognitive aspects must be modelled. While high levels of physical fidelity can be achieved with AR/ VR technology, which helps the trainee feel immersed in the environment, to be effective, the training must also simulate the necessary job tasks (specialized manufacturing) and allow one to practice the knowledge, skills, and abilities required to perform those tasks. The primary focus of the technical approach is the design and implementation of the content overlay on an actual asset (or a physical mock-up of an actual tangible asset) to facilitate training/operations.

4. Methodology

Characteristically, for ideal outcomes, pipelines for areas such as graphics and VR/AR projects entail meticulous pre-production procedures, and in this step, storyboarding is carried out to generate the three-dimensional scene suitably and execute the well-planned processes.

Preproduction also saves considerable time and resources as it helps to avoid potential pitfalls. Storyboards are a common vehicle used in many 3D design projects. They are designed after meticulous ideation and brainstorming sessions to describe the VR/AR narrative, including embedded training and operational content, as well as the challenge and malfunction scenarios that could be experienced on the field. Although the storyboarding of the manufacturing scenarios can be detailed, it may only be possible to include every possible scenario of equipment training thoroughly. The basic required processes/steps are necessary for the planning and successful deployment of a framework for the virtual training modules and virtual software applications may generally include three chief steps:

i. 3D models for the manufacturing procedures and apparatus are designed and finalized using 3D software and programming languages
ii. Export to an appropriate three-dimensional format such as Filmbox (. FBX) or Object format (.OBJ) to be well-suited with the 3D virtual reality software;
iii. Program objects and customize them for different modes/interfaces, including
    a. Desktop PCs and Laptops
    b. Head Mounted Displays (HMD)
    c. Tablet Devices

The virtual reality software modules will be developed using 3D modelling tools like Autodesk 3ds Max©/Maya© and then importing these models as assets in a VR platform like Unity©. Subsequently, these will be programmed (scripting) for user interaction.

With utmost importance to affordability and accessibility, the design of the virtual reality modules was carried out for access by standard desktop PCs and laptops that are readily available and accessible by small and medium-scale manufacturers to train their operators. These can also be accessed by low-cost head-mounted displays (HMD). Besides, the web-based version will also allow trainers and operators to access it at their convenience. For instance, pilot plant equipment is expensive, and only a few students can receive hands-on training. These often further restrict the utility of pilot scale equipment for operator training. On the other hand, adequately designed virtual reality modules can help train students in best laboratory practices. Prospects to try out multiple states and situations that could occur in various production scenarios warrant that the project members be well-trained to deal with the challenges.

Virtual reality laboratories can be helpful tools for introducing flip classroom teaching concepts into pilot plant laboratories. A virtual reality laboratory can help the students understand complex concepts before being introduced to the pilot plant lab. They can help the student pay attention to intricate details about the machinery or its components, which can be overlooked in a physical pilot plant laboratory due to practical constraints. This, in turn, can help the operators to be more engaged and better prepared with their curriculum, improving their knowledge retention.

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The inherent characteristics of virtual reality, such as functionalities to navigate and interact with scene objects, enable dynamic engagement with the training concepts. The several means by which materials can be presented via virtual reality consist of immersive virtual reality, augmented virtual reality, and mixed virtual and desktop virtual reality, which permit the capability to choose the most suitable mode of delivery as entailed by financial, organizational, and physical space requirements and limitations. In this specific research effort, various modalities of VR are employed (multimodal) to facilitate accessibility and affordability, thus overcoming cost and (physical) space constraints. Physical laboratories cannot always meet today's advanced manufacturing demands, especially in COVID-like situations, when training people under a strict time schedule becomes imminent. Virtual training laboratories can be planned and executed for access and delivery across many operating systems and open-source frameworks so undergraduates can easily access them using standard desktop computers in PC labs. Fig.4 shows a screen capture of a desktop computer's interactive virtual training module. The objects (3D) in these virtual reality worlds can be easily interacted with via standard, regularly used input and output) devices including keyboard, mouse, touchpad etc. Such user engagement and interactions can be planned to be completed with an inexpensive computer input apparatus to engage with the material actively and understand various manufacturing processes.

5. Results and Discussion

The advances in virtual and augmented reality must be exploited to benefit medium and small-scale industries that cannot afford customized VR training for their employees. Moreover, more than the availability of virtual training practices, the affordability of such advanced procedures for medium and small-scale manufacturing companies is of utmost importance. This study demonstrates the immense impact of VR within the manufacturing industry, which can be accomplished owing to increased operational efficiency, reduced product delivery time, and increased accuracy. There is an imminent need for more tools to offer affordable, state-of-the-art training to match the rapid pace of advancements in the manufacturing industry.

The following are the specific advantages to the manufacturing domain through the use of virtual training practices:

i. Ease of access through affordable head-mounted displays (HMD) and tablet devices
ii. Enacting what-if scenarios (including equipment malfunction and troubleshooting) with response mechanisms as applicable to real-world manufacturing
iii. Reducing costs of obtaining & fitting multiple training equipment
iv. Heightened safety of the operators/trainees resulting from the virtual nature of training (virtual training is not intended to replace physical/ actual, but to reduce wastage and increase access to training materials)
v. Shortened delivery times for product delivery
vi. Flexibility in accessing training modules, especially in COVID-like situations

The technological innovation of this kind of work, when further continued, can potentially lead to key advances in precision & high-resolution graphics component modelling with distinct training advantages in advanced Manufacturing, including the following benefits:

i. Multimodal Access: Seamless access to training modules via VR/AR devices
ii. Cross Platform Access: Access via desktop PCs, laptops, tablet devices, head-mounted displays
iii. External/Internal Access: Equipment exterior and interior can be accessed without loss of resolution
iv. Component Model: Virtual product assembled from high precision 3D models for virtual dissection
v. Diverse Learning Styles: Suitable for diverse operator learning styles and preferences
vi. I/O Options: access via usual Input/output devices & advanced handheld controllers & joysticks

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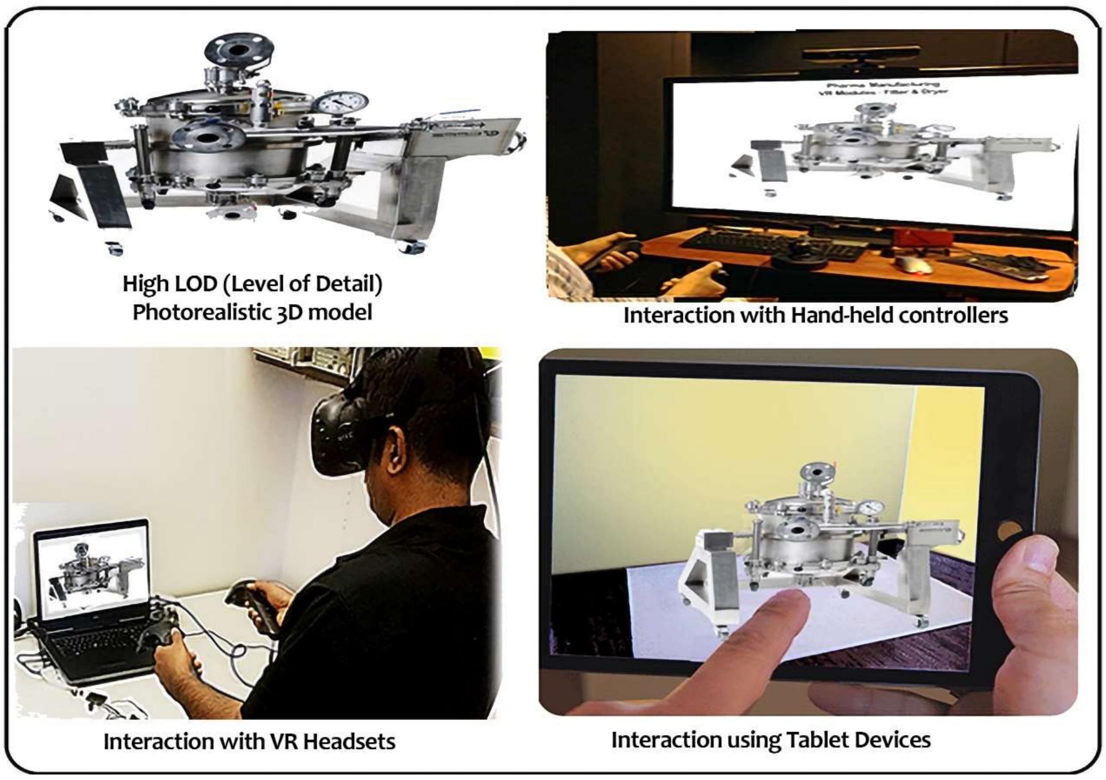

Fig. 3 Accessing virtual training modules using multiple modes and devices.

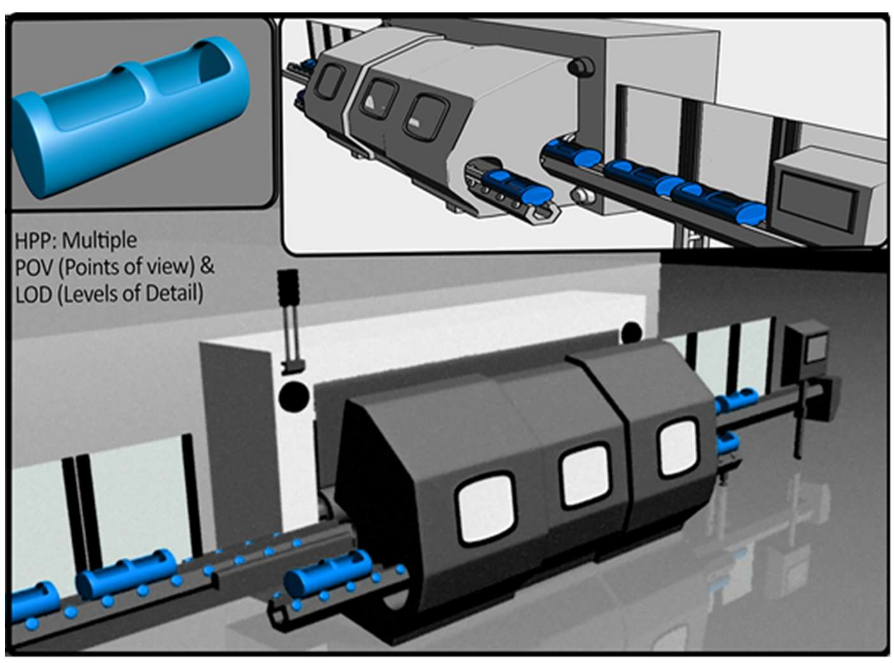

Fig. 4 Illustration of a virtual 3D model representation of a High-Pressure Processor (HPP) VR environment allows multiple points of view (POV) & levels of detail (LOD)

6. Conclusion

In the face of recent advances in manufacturing, including digital, additive, and smart manufacturing, as well as bio and pharma manufacturing, it is essential to continually update manufacturing competency worldwide. This study explained a user-friendly Virtual Reality/Augmented Reality/ (VR/AR) training framework for specialized manufacturing processes (Fig. 3). Process equipment and operational protocols can be complex and demand for highly skilled and trained operators. Operators trained using the current methods, including in-class and computer-based training, continue to need help with some of the key process equipment operations, causing batch failures resulting in significant loss of time and money. Conventional in-class and computer-based training avenues have been routinely employed to educate operators. However, VR/AR-based process training will remedy the inadequacies of smart manufacturing training processes, causing continued operator errors and delaying product availability, as witnessed during COVID-19. The key goals of this framework were to facilitate:

i. Efficient personnel training in AAV maintenance and operation to include routine maintenance (extended from existing IETMs) and training to anticipate and handle equipment malfunction scenarios that may be encountered in the field;
ii. Enhanced safety through accurate AR simulations & AR simulated training to improve situation awareness and prepare for quick decision-making under a variety of stressful scenarios encountered in the field; Development of an AR training approach that improves task engagement and transfer of training to field operations;
iii. Reduced cognitive load through careful photorealistic design founded on sound UI/HCI (User Interaction/Human-Computer Interaction) principles such as clutter avoidance, pictorial realism, and minimized information access cost (Aukstakalnis, 2016; Lee, Wickens, Liu & Boyle, 2017; Yuviler-Gavish, Yechiam, Kallai, 2011).

7. Limitations and Future Work

Some significant constraints had to be faced during this prototype study. Further detailed studies must be conducted to design, plan, implement, and evaluate applications in assorted manufacturing areas. Nevertheless, as part of further research, the authors intend to perform detailed tests and obtain data to assess operator learning gains and skills transfer.

Future work in this direction should involve adding the capability for supervisors to enter customizable details to the parts and processes. Since supervisors know about the trainee's experience, strengths, and weaknesses, allowing customization can enable supervisors to direct trainees' focus more on the specific areas that need greater attention. Furthermore, such customization will be designed to deliver effective photorealistic 3D digital representations of manufacturing concepts, processes, and simulations. Virtual environments also allow catering to different learning styles and formats: verbal (textual description), audio (voice annotation), visual (graphic representation), and tactile (Interactive virtual representation).

References

1. *A. Skevi, H. Szigeti, S. Perini, M. Oliveira, M. Taisch, and D. Kiritsis, "Current skills gap in manufacturing: Towards a new skills framework for future factories," in Advances in Production Management Systems. Innovative and Knowledge-Based Production Management in a Global-Local World: IFIP WG 5.7 International Conference, APMS 2014, Ajaccio, France, September 20-24, 2014, Proceedings, Part I, Berlin, Heidelberg: Springer, 2014, pp. 175-183.*

2. *P. Osterman and A. Weaver, "Skills and skill gaps in manufacturing," 2014.*

3. *F. Azmat, B. Ahmed, W. Colombo, and R. Harrison, "Closing the skills gap in the era of industrial digitalisation," in 2020 IEEE Conference on Industrial Cyber-Physical Systems (ICPS), vol. 1, June 2020, pp. 365-370.*

4. S. Y. Liang, "Subtractive processes—traditional operations: cutting, grinding, and machine tools," in Handbook of Manufacturing, 2019, p. 17.

5. M. Chandramouli, G. Jin, J. Heffron, M. Cossette, I. Fidan, W. Merrell, and C. Welsch, "Virtual reality education modules for digital manufacturing instruction," in ASEE Annual Conference Proceedings, 2018.

6. M. Chandramouli, 3D Modeling & Animation: A Primer. CRC Press, 2021.

7. W. R. Sherman and A. B. Craig, Understanding Virtual Reality: Interface, Application, and Design. Morgan Kaufmann, 2018.

8. E. E. Toth, L. R. Ludvico, and B. L. Morrow, "Blended inquiry with hands-on and virtual laboratories: The role of perceptual features during knowledge construction," Interactive Learning Environments, vol. 22, no. 5, pp. 614-630, 2014.

9. Y. H. Jen, Z. Taha, and L. J. Vui, "VR-based robot programming and simulation system for an industrial robot," International Journal of Industrial Engineering, vol. 15, no. 3, pp. 314-322, 2008.

10. P. A. Oskarsson, L. Eriksson, P. Lif, B. Lindahl, and J. Hedström, "Multimodal threat cueing in simulated combat vehicle," in Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 52, no. 18, Sept. 2008, pp. 1287-1291.

11. V. Puri, M. Chandramouli, C. Van Le, and T. H. Hoa, "Internet of Things and fuzzy logic-based hybrid approach for the prediction of smart farming system," in 2020 International Conference on Computer Science, Engineering and Applications (ICCSEA), Mar. 2020, pp. 1-5.

12. M. Chandramouli, G. Jin, and D. Cubillos, "MOOC videos in project MANEUVER," in 2019 IEEE Learning With MOOCs (LWMOOCS), Oct. 2019, pp. 84-89.

