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Paper ID #36044

Effectiveness of Utilizing Immersive Virtual Reality for Weekly Design Review Team Meetings in Capstone Mechanical Engineering Courses

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Closely Related Publications • Emad Tanbour and Suleiman Ashur, Gap Analysis of Engineering Course Learning Outcomes using NCEES FE Exam, Abstract submitted and accepted to ASME 2015 International Mechanical Engineering Congress and Exposition, Huston, Texas Nov.13-19, 2015 • Butler, P. B., Tanbour, E., Rahman, S., and Smith, T. F., "Virtual International Design Teams," Proceedings of 2002 ASEE Midwest Section Meeting, Madison, WI, September 2002 Significant Other Publications • M. F. Alzoubi, E. Y. Tanbour and R. Al-Waked (2011), Compression and Hysteresis Curves of Nonlinear Polyurethane Foams under Different Densities, Strain Rates and Different Environmental Conditions, IMECE11 2011, Denver, Colorado, USA • E. Y. Tanbour (2011), Institutional Effectiveness, the Point Of View of Southern Association of Colleges and Schools (SACS), King Saud University, Feb 2011 • Emad Y. Tanbour, Rafat Al-Waked and Mohamed F. Alzoubi, Experimental Study of a Waste Heat Recovery System for Supplemental Heater, Energy and Sustainability, April 2011, Spain • Ramin K. Rahmani, Anahita Ayasoufi, Emad Y. Tanbour and Hosein Molavi, Enhancement of Temperature Blending in Convective Heat Transfer by Motionless Inserts With Variable Segment Length, Journal of Thermal Science and Engineering Applications, September 2010, Vol. 2 • Ramin K. Rahmani, Emad Y. Tanbour, Anahita Ayasoufi and Hosein Molavi (2009), Enhancement of Convective Heat Transfer in Internal Compressible Flows by Stationary Inserts, Journal of Thermal Science and Engineering Applications MARCH 2010, Vol. 2 • Emad Y. Tanbour, Ramin K. Rahmani and Anahita Ayasoufi (2009), Large-Eddy Simulation of Turbulent Flow Through Small Gage Gas Appliance Orifice, Proceedings of IMECE 2009, Lake Buena Vista, Florida, USA • Emad Y. Tanbour and Ramin K. Rahmani, (2009), Enhancement of Temperature Blending in Convective Heat Transfer by Motionless Inserts with Variable Segment Length, IMECE 2009, Lake Buena Vista, Florida, USA • Emad Y. Tanbour and Ramin K. Rahmani, (2009), A Numerical Study of the Thermal Performance of Two Stationary Insert Design in Internal Compressible Flow, ASME Summer HT2009, San Francisco, CA, USA

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Synergistic Activities • Introduced Computer Aided Design for elementary and middle school children (2005-2009) • Supervised 30+ design/research projects involving 83+ undergraduate students • Hosted numerous outreach programs for 2000+ pre-college students • Combustion Institute KSA Country Chapter founding member • Supervised three annual teams of international design exchange students from France conducting research/design at U of Iowa and Industry • Served as industry liaison between U. of Iowa and HNI Corporation for nine years • Served as a member of industry advisory board for College of Engineering at the U. of Iowa representing HNI • Reviewer for Energy and Sustainability Journal since 2010 • Developed and implemented three strategic plans to earn KSA national, ABET and SACS

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accreditation for PMU, KSA (2009-2013) • Conducted Specialized ME training on numerous industrial applications for major oil/gas corporations worldwide (2009-2013) • Serving on the advisory board of Center for Computer Aided Design, U of Iowa (2003-present) • Tens of industry consulting services in the areas of product design, development over the past 25 yrs.

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Utilizing Immersive Virtual Reality for Weekly Design Review Team Meetings in Capstone Mechanical Engineering Courses and a Future Effectiveness Study Plan.

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Emad Y. Tanbour is Associate Professor in Mechanical Engineering. He is also the Interim Associate Dean of GameAbove College of Engineering and Technology at Eastern Michigan University. He currently teaches junior Mechanical Engineering courses in Dynamics, Machine Design and the Senior Capstone course sequence. He is the founder and supervisor of the Virtual Reality Lab at Eastern Michigan University.

Utilizing Immersive Virtual Reality for Weekly Design Review Team Meetings in Capstone Mechanical Engineering Courses and a Future Effectiveness Study Plan.

Abstract

This paper provides an account of the system integration of the VR lab with Mechanical Engineering Senior Capstone Course. The paper discusses the layout of the VR lab, its CAD software and hardware integration components that facilitated the immersive experience of virtual prototyping of capstone designs of the teams of senior students, and the overall effectiveness assessment of utilizing virtual prototyping of students designs compared to rapid prototyping methodologies such as 3D printing. The paper also provides benefits and challenges of using VR technology for weekly design review meetings of students' teams. The Mechanical Engineering Program at this university houses a 1500 sq. ft. active and immersive virtual reality (VR) lab. The VR lab consists of three rear projection walls providing an interaction environment of 14ft by 14ft area. The VR environment provides optical tracking integrated with three-dimensional digital stereoscopic projection to facilitate immersive VR experience.

Introduction

The use of virtual reality (VR) in engineering education is expanding due to the widespread utilization of VR in industry. There is evidence that constituents of engineering programs across the globe are demanding VR literacy in engineering curriculum. VR has been extensively used in product development visualization as a fast substitute to rapid prototyping [1]. More emphasis has been observed in the past 20 years in utilizing VR in product marketing and voice of customer surveying.

The utilization of VR spans over a wide spectrum of sophistication. From head-mounted low-cost VR systems to more upscale head mounted displays with advanced on-board computing and wider field of view, to passive rear projection VR walls, to active VR rear projection walls and enclosures. The VR labs utilized in academic and industrial settings are also varying in user experience sophistications. From completely non-tracked user VR to fully optically tracked immersive VR experience. In early 2000's, basic graphic curriculum was reported to be using VR as reported in [2]

Schools of engineering around the nation and globally are integrating VR into curriculum enhancement and delivery methods. Architectural Engineering Design Education has shown a dramatic shift in utilizing VR. Due to the abundance of massive architectural content that is CAD driven, VR simulations of architectural content has proliferated into design studios and architectural design schools [3]. Other disciplines of engineering, such as chemical engineering, are catching u and showing promising practical benefits of utilizing VR in education as reported in [4].

The VR is also seeing expansion of its utilization in the field of consumer products development and voice of customer and consumer usage and experience data collection [5]. As it has been a very feasible simulation platform for aviation applications, VR has also penetrated the flight simulation market and training[6]. Consumer behavior and perception of digital consumer products was also benefiting for the VR technology [7]. The VR has gone as far as probing virtual store emotional state and store attractiveness as recently reported in [8].

The most challenging aspects of adopting VR in industry and in engineering design education, is

the fidelity (visual quality) of the VR content as displayed in VR environment. The higher the fidelity, the higher the end-user satisfaction of the viability of VR as a design review and visualization tool [9]. In the following parts of this paper, the adoption of active and immersive VR system in design review meetings will be presents. The VR environment's construction and an account of utilization in Design Review meetings for Mechanical Engineering Capstone design is also demonstrated.

Background on Mechanical Engineering Capstone

The Program in Mechanical Engineering is Part of the newly introduced engineering programs and GameAbove College of Engineering and Technology at EMU. The college has five major priorities among them increasing the college research and teaching profile in emerging fields of autonomous systems, robotics and mobility cybersecurity, sustainability, virtual reality applications in manufacturing and smart living. Mechanical Engineering senior capstone course at EMU is a sequence of two 3 credit hours courses delivered fall/winter in the senior year. The sequence is focused on applying design of mechanical, electromechanical, thermo-fluid and energy systems, and devices that introduce a new problem-solving approach or innovate a capability that improves people's life. Students are allowed to select from a set of department-proposed and industry-sponsored projects. Students work in teams of three to five members, depending on the expected scope of the capstone project. The establishment of the 1500 square feet VR Lab in the College enhances the access to research tools in VR field for both teaching and research, hence fulfilling one part of the priorities of the College. The VR Lab attracted external equipment funding that facilitated expanding the three-wall system into 4-wall system. The Mechanical Engineering program is a fairly new program and is growing very rapidly. It is expected to offer the capstone sequence in multiple sections of 25 to 30 students in the next couple of years. Currently, the capstone sequence is being delivered with six capstone projects in the current cohort.

The capstone sequence provides a holistic umbrella to emphasize and apply advanced engineering design knowledge gained during junior year and continued to be learned during senior year. Initially, for the first three cohorts, the capstone sequence utilized the following methods for students to practice design prototyping:

1. Actual Physical Prototyping utilizing machine shop and fabrication shop in the College of Engineering
2. Rapid prototyping methods mainly utilizing additive manufacturing
3. Virtual Reality prototyping

The utilization of the VR has started during the second cohort of Mechanical Engineering senior capstone classes. Students start building conceptual designs, intermediate level of detailed designs and final detailed designs using CAD tools available in the curriculum. Students utilize the VR lab located in the College of Engineering to conduct weekly design review meetings. The VR visualization has proven to be feasible, fast and satisfactory according to the feedback from the two cohorts used VR so far.

Description of the VR lab at the College of Engineering:

The VR lab at the College of Engineering is a 1500 square feet facility that includes a three rear projection rigid screens of 14ft wide by 8.5 ft high. The three walls are arranged into a U-shape. A forth wall is a front project wall represented by the floor. The environment is equipped with four 3D active stereoscopic projectors and a set of nine high end optical tracking cameras to facilitate immersive experience. The environment is also equipped with sophisticated special pointing and user interaction hand-held device. The VR environment is supported by the following software enablers:

1- Complete solid modeling CAD packages commercially utilized by the School's constituents and employers of college's graduates. Currently they are CATIA, SolidWorks, NX and AutoCAD.
2- An embedded add ins to CAD packages to allow expert of CAD content into other non-native format adaptive to game engine software.
3- Game Engine Software
4- VR enabler software
5- Tracking software to control and configure

Figure 1 below shows a picture of the VR lab at the College of Engineering at Eastern Michigan University (EMU).

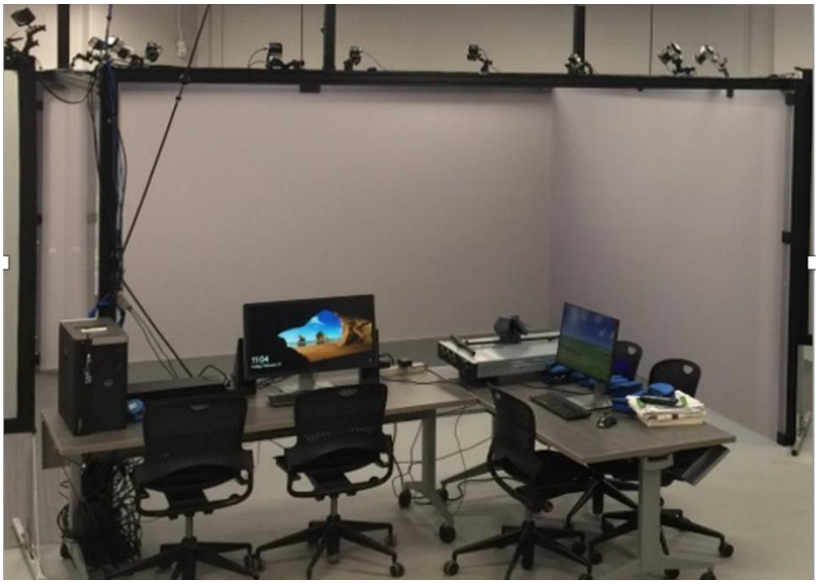

Figure 1: VR Lab at the GameAbove College of Engineering and Technology at EMU

Utilization of VR Lab by ME Seniors in Capstone Design Review Meetings

The VR Lab has become an integrated part of the ME capstone curriculum during the past two cohorts. Students use the VR Lab as a meeting place to conduct weekly design review sessions. The utilization of the VR lab is still in its experimental phase but have proven effectiveness and widely preferred by ME students over the flat screen design visualization.

Method of Making CAD as a VR ready Content:

The process to make the CAD content as VR-ready has been optimized by many years of VR system integration experience of faculty and graduate students. The process starts with exporting

CAD content into a game-engine compatible format. In our case, to be compatible with Unitiy3D game engine software. The CAD content is then configured in Unity3D and animation and rendering aspects can be added in the Game Engine software. Then it is exported into the VR-enabler software which transfer the content to the 3D digital stereoscopic rear projection hardware. Students wear LCD shutter glasses that are optically tracked by optical tracking system of nine cameras to produce VR content that is immersive. Students use hand-held interaction device to maneuver and walk through the VR content.

Current Use Examples: Figures 2 and 3 show students' interaction with the VR-ready content of their capstone design.

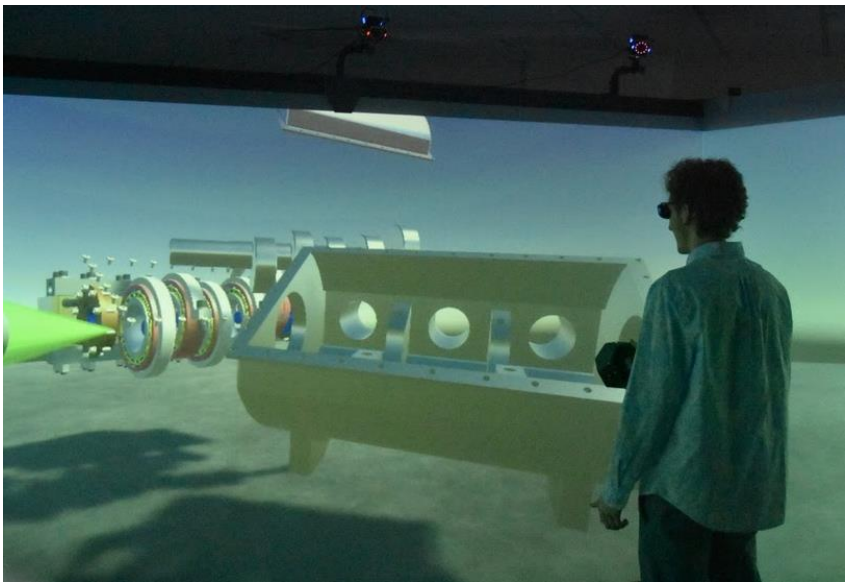

Figure 2: an ME Senior interacting with a VR model of a triplex piston pump

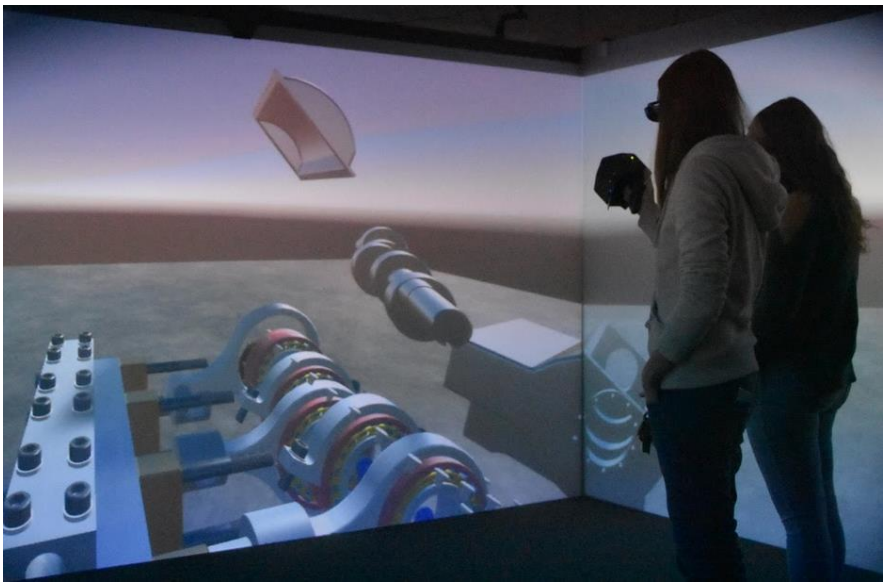

Figure 3: ME students practicing design review meeting using VR Lab

Figure 4: ME students practicing design review meeting using VR Lab

Discussion Future Effectiveness Study Plan:

Although unstructured feedback from the two ME cohorts that was given the experimental access to the VR Lab as a weekly design review tool, the overwhelming feedback is very positive on the VR Lab as effective. The study planned will probe more in-depth information related to tying the VR effectiveness to the attainment of the course learning outcomes of the Capstone class. The utilization of the VR Lab as a design review visualization tool for Capstone Seniors in ME is planned to be conducted during the upcoming 2022/2023 academic cycle. The student utilization will be surveyed and the outcome of the survey will be published. The following survey questions, statements will be used at the start of the semester and at the end of the semester to gage any change in the perception of the VR Lab as a design review tool. The survey will probe response of students on a scale of strongly disagree, disagree, neutral, agree and strongly disagree.

1- Did you enjoy your experience with the system?
2- Were you successful using the system?
3- Were you able to control the system?
4- Is the information provided by the system clear?
5- Did you feel discomfort during your experience with the system?
6- Do you think that this system will be helpful for your learning experience?
7- I believe using VR hardware would help me be more productive in developing my design prototype.
8- I believe using VR hardware would help me be more effective in developing my design prototype.
9- Using VR hardware would be useful in engineering design process.
10- Using VR hardware would improve my engineering design.
11- Using VR hardware would enhance my effectiveness in developing new engineering design
12- I believe using VR hardware would be easy for me in designing.
13- I believe it would be easy to get VR hardware to do what I want it to do to improve

my design.
14- I believe using VR hardware would be clear and understandable.
15- I would find VR hardware flexible to interact with
16- It would be easy for me to become skillful at using VR hardware
17- I believe I would find using VR hardware enjoyable.
18- I believe I would have fun using VR hardware.
19- Using VR hardware would be exciting.
20- Using VR hardware would be enjoyable.
21- There is a high likelihood that I will use VR hardware within the foreseeable future for engineering design projects
22- I intend to use VR hardware within the foreseeable future for engineering design projects
23- I will use VR hardware within the foreseeable future for engineering design projects
24- Using VR hardware in the foreseeable future is important to me for engineering design projects

What Metrics of Performance Would Be Used to Define Success:

The planned effectiveness study will utilize the following metrics to define success:

1- Ability to Transform CAD content of capstone projects into VR-ready content within a feasible time to allow a cohort of 50 students to utilize the VR lab as a weekly design review medium. This is expected to translate into 10 to 12 capstone project teams per week. With the VR lab operation hours of 50 hours per week, this is expected to necessitate that each team to have the VR lab for 4-5 hours per week including pre=processing of the CAD content to be VR-ready.
2- Ability to provide adequate fidelity of the visualized content using the framework of VR content fidelity developed by Al-Jundi and Tanbour[9]
3- Ability to simulate animated mechanist as applicable to capstone project that include moving parts
4- Ability to replace rapid prototyping and 3D printing needs for capstone until the last stages of design review process per semester.

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