Next-Generation Training with Advanced Visualization and Digital Twins

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ABSTRACT

In this paper we present the various ways in which digital twin technology is utilized for next-generation training for the Department of Energy. Traditionally, high consequence training utilizes classroom training with subject matter experts, case studies, paper based scenario response exercises, and expensive response drills. The Oak Ridge Enhanced Technology and Training Center has collaborated with the University of Central Florida to research how digital twins combined with advanced visualization including virtual and augmented reality can impact engagement, immersion, and efficacy of training. Leveraging the increasingly available digital engineering backbone allows training to be specific to the trainee rather than simulations on generic facilities against generic hazard scenarios. Examples and use cases discussed include a virtual glove box with haptic feedback, operational uses cases for digital twins of facilities, and virtual production processes used for training first responders and site teams how to respond to security events. ORETTC increased engagement with trainees through the deployment of AR tabletop exercises by sending the AR head mounted displays to trainee teams to train when they could not travel. Additionally, advanced video production using green screen technology personalized training by providing opportunities to train against a trainee's home facility. This research is targeting best practices, technology selection / recommendations, AI and scalability of solutions to meet the needs of the Department of Energy' workforce and customers.

ABOUT THE AUTHORS

Ashley C. Stowe is the Director of the Oak Ridge Enhanced Technology and Training Center (ORETTC). ORETTC provides a unique venue staffed with subject matter experts and equipped with state-of-the-art immersive technology to deliver training for domestic and international partners on challenging problem sets in nuclear security, nonproliferation, emergency management, and responsiveness to high-consequence events. Ashley previously served as CNS University Partnerships and Minority Serving Institutions Partnership Program (MSIPP) program manager, Y-12 Googin Fellow, and Director of the Nuclear Forensics and Detection Initiative. Dr. Stowe holds multiple adjunct faculty positions at universities across the Southeast in physics, nuclear engineering, game design, and business. He has received four Y-12 Special Recognition Awards; a Technology Use Award; and a Mentor Award for the Mentor-Protégé program, facilitating collaboration with Fisk University. Ashley is also founder and Vice-president of L.I.F.E. Consulting, a leadership development firm which grows leaders and their teams in schools, non-profits, and businesses. Dr. Stowe earned a Ph.D. in chemistry from the Florida State University. He also holds an MBA from the University of Tennessee. Dr. Stowe was recognized with a 2013 R&D 100 award, has twenty patents, has authored over 70 peer reviewed publications, and presented over 200 conference presentations. His successes have been recognized by the Knoxville Business Journal as a 2014 Top 40 Under 40 recipient.

David Metcalf has more than 25 years of experience designing and researching web-based and mobile technologies converging to enable learning and healthcare. Dr. Metcalf is Director of the Mixed Emerging Technology Integration Lab (METIL) at UCF's Institute for Simulation and Training. The team has built mHealth solutions, simulations, games, eLearning, mobile, enterprise IT systems for Google, J&J, VA, U.S. military, UCF's College of Medicine, and many others. Recent projects include Lake Nona's Intelligent Home and transmedia, adaptive learning projects using mobile, AR, and sims. Dr. Metcalf encourages spinoffs from the lab as part of the innovation process and has launched Merging Traffic and several other for-profits and non-profit ventures as examples. In addition to research and commercial investments, he supports social entrepreneurship in education and health. Dr. Metcalf continues to bridge the gap between corporate learning, simulation techniques, non-profit and social entrepreneurship. AI, blockchain, cybersecurity, IoT, simulation, mobilization, mobile patient records and medical decision support systems, visualization systems, scalability models, secure mobile data communications, gaming, innovation management and operational excellence are current research topics. Dr. Metcalf frequently presents at industry and research events shaping business strategy and technologies used to improve learning, health, and human performance. For more information, see http://metil.org. He is the co-editor/author of HIMSS Voice Technology in Healthcare (2020), HIMSS Blockchain in Healthcare (2019), Blockchain Enabled Applications (2018), Connected Health (2017), HIMSS mHealth Innovation (2014), and the HIMSS best-seller mHealth: From Smartphones to Smart Systems (2012).

Michael Eakins is the Creative Lead of the Mixed Emerging Technology Integration Lab (METIL) at the Institute for Simulation & Training and has 15 years of experience in the field of 3D modeling and animation for simulation and gaming. He received his M.F.A. in Digital Media at the University of Central Florida in 2017. His development and production teams have skillsets that span most forms of digital media to support simulation and training applications. Over the years Michael has led research projects involving advanced visualization, VR/AR, AI, blockchain, medical and healthcare simulations, interactive decision-based simulations, interactive narrative, game design, instructional design, and other METIL research initiatives including STEM outreach. His work has been presented at MODSIM World, I/ITSEC, MedBiquitous, Training Magazine, Unity Simulation & Training Speaker Series, various local events, as well as local and international news outlets such as BBC Click.

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I. OVERVIEW

The Mixed Emerging Technology Integration Lab (METIL) at the University of Central Florida's Institute for Simulation & Training has partnered with Oak Ridge Enhanced Technology and Training Center (ORETTC) over the last several years researching next-generation training through the use of digital twins and advanced visualization modalities for the Department of Energy's (DoE) internal and external audience. Transitioning high consequence training from traditional classroom and expensive in person drills has been slow due to a reticence to use novel technologies. In addition to this research, METIL has also been evaluating ways in which the ever-expanding AI toolsets can enhance the production, scalability, and efficiency of project development[1,2]. Examples of key projects include a digital twin of a virtual glove box using virtual reality (VR) and gloves with haptic feedback technology, digital twins of buildings for use in logistics planning, security, and simulation including augmented reality (AR), and virtual production for training scenarios related to security at sites with radioactive materials. METIL and ORETTC have come together to collectively bring expertise in both the technology and subject matter to tackle real-world problems using digital twin solutions across multiple platforms, modalities, and for a range of audiences from first responders, chemists in the lab, and nuclear operations. Establishing a design strategy to build training on a digital twin ecosystem rather than bespoke training applications provides flexibility and scalability to training tools in this ever changing immersive technology landscape. Training scenarios can be designed generally and applied readily across a variety of specific buildings so that trainees and trainee teams can practice tactics, techniques, and procedures on their own buildings. ORETTC's facilities provide a unique opportunity for the DoE to conduct research and development without the more rigid requirements applicable to other DoE facilities. Due to the location and scope of work carried out at this facility, ORETTC has more flexibility in their operations with more cutting-edge technologies such as AR/VR.

II. VIRTUAL GLOVE BOX

The goal of the virtual glove box is to provide an immersive experience that mimics the conditions of working in an actual glove box, to include stress, restrictive movement, fatigue, limited dexterity, temperature, and multi-user interaction. Traditionally, an apprentice model of training is employed with limited hands-on physical training opportunities due to the high cost of glove boxes. In practicality, much of the training process involves abstract classroom training and watching someone else work without much actual hands-on practice. This reality is due to the high cost of fabricating sufficient training equipment and the pressures to continue production activities instead of training new staff. As a result, workers are often not confident as they begin independent work. The inclusion of virtual training using this technology stands to increase training access, authenticity, repeatability, and readiness for the DoE workforce using glove boxes for manufacturing operations. Currently this training is primarily conducted in physical glove boxes rather than virtual, limiting scale, logistical restrictions (quantity, location, and availability). Increasing the scale at which this training can be delivered while allowing for more standardization is a driving factor for this research which will help us better understand the feasibility, appropriate conditions, use cases, logistics, and best practices for integrating VR and haptic training for glove box manufacturing operations. Over the past year, METIL has worked with ORETTC to develop an VR-based glove box paired with HaptX gloves (Fig. 1) which provide haptic feedback when working in virtual spaces.

Figure 1. VR and HaptX glove

The haptic feedback allows for a more immersive and natural experience when interacting with the virtual objects in the glove box (Fig. 2). Users can feel the collision with digital objects including objects in the glove box or other users' hands working in the same virtual training session. METIL is assisting with the technical integration of the VR environment and assets paired with the haptic glove control to create a realistic setting that matches the real-world conditions of working in an actual glove box as closely as possible[3]. Virtual glove boxes provide a unique opportunity to deal with high-consequence training scenarios in a safe, immersive, physically-based environment. The nature of materials, processes, and high-stress situations that glove box production involves makes a virtual training simulation ideal at face value. Working in this simulated setting aims to promote long-term knowledge retention[4], safety knowledge retention[5], reduce costs from training accidents / incidents[6], reduce exposure to harmful radiation[7,8]. For the initial stages of this project, researchers at ORETTC are evaluating user experience under multiple conditions across three modes of a glove box scenario, VR with haptic gloves, VR with standard VR controllers, and a tradition glove box (non-VR) building upon similar approaches to evaluation within medical simulation[9,10].

Figure 2. Real-world (Left) and Virtual (Right) Glove Box Scenario Examples

Users will engage with objects such as a busy board (used for dexterity training) to complete a variety of tasks while smart sensor wearables such as the Oura Ring (Fig. 3) collect biometric data to evaluate metrics such as stress while engaging in the activity. This information along with user feedback on the experience will provide valuable insight in the next steps of this research as the team works to improve the software simulation to create a safe, repeatable simulation that can mimic the real-world activity with the added benefits of reduced cost, remote participation, and flexibility of 3D solutions for reconfiguration. While this research is still in an early stage, to date we have created the virtual environment and technical framework for both single and multiplayer activities and (at the time of this paper submission) are finalizing the study design. Initial qualitative feedback from experienced glove box workers suggests that the VR experience with haptic feedback represents the real life experience well. Participants experience the same sense of restricted motion and reduced dexterity of working in oversized protection gloves. Participants also indicated similar levels of exertion and fatigue working with a virtual haptic glove box as they did performing the same tasks in a physical glove box.

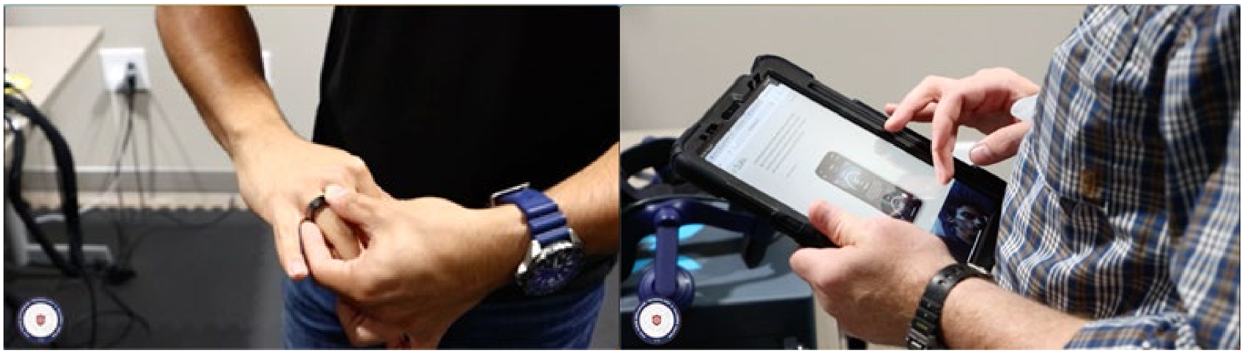

Figure 3. Oura Ring and Biometrics

III. DIGITAL TWINS FOR HIGH CONSEQUENCE TRAINING AND RESPONSE PLANNING

METIL collaborate with ORETTC in a variety of ways related to security, planning, and simulation using digital twins for a data-driven virtual representation of their physical facilities. One of the critical services provided by ORETTC is the training around security of facilities with radioactive materials. Y-12 trainers (prior to ORETTC's establishment) trained thousands of first responders over the past decade and customized solutions specific to their customers' needs to make it engaging, relatable, and memorable. METIL has worked to include additional layers of training content using advanced visualization of mobile technology such as tablet and phone-based applications (traditional touch-screen and AR). Examples of this include security planning training that shows conceptual configurations of various layered intrusion detection systems, response time, and other factors (Fig. 4) that would be customized to match a particular site for training purposes of security personnel or first responders. This figure showcases the virtual representation of some of the physical security systems for a specific location. For the purposes of training, this virtual environment provides a way to show first responder trainees how these systems work when responding to a location and are designed to represent relevant real-world locations with their specific technology such as sensors.

Figure 4. Layered Intrusion detection System visualization

The production of these game engine-based simulations has been impacted by the integration of AI tools supporting cross-skilled development tasks. While still early in the implementation of AI-supported development, METIL is in the process of conducting systems analysis work on the quantitative and qualitative effects on quality and efficiency. Preliminary results have been promising with early case studies around optimization of load times and responsiveness of interactions. In this case study a developer working in Unity was able to use GPT-4 to construct an initial framework for a navigation feature. Initially the inclusion of this feature resulted in a 45 second load time and a 30 millisecond to 10 second range of response time after a navigation input request. Upon revisiting this architecture, using GPT-4 at a later date, the feature was optimized down to an 8 second load time and a range of 1.2 to 1.8 millisecond response time. The significant optimization results are also meaningful considering the troubleshooting and optimization process which was estimated to have taken 2 to 3 days and require additional developer team members, only required a targeted ~20 mins by a single team member. These encouraging results are but a sample of the results METIL is experiencing. Integrating AI tools into the production pipeline of this particular application has yielded significant productivity boosts and efficiencies, with this particular example as one of the highlights. METIL looks forward to continuing this research and reporting which has already proven to be of great benefit to our ORETTC partners and expected to expand as additional tools, processes, and best practices are implemented across real-time systems for AR/VR as well as other training use cases.

Some of the devices that these real-time systems are developed for include tablets and AR/VR platforms (includes but not limited to HoloLens 2, Magic Leap 2, and Vive headsets) to create smart city simulations of events (generalized) to inform key stakeholders about the importance of containment procedures and protocols. These solution sets provide multi-user experiences that leverage data feeds and have user-friendly customization tools for authoring scenarios without the need for game engine experience. Through our data connections a subject matter expert is able to make changes through a web-portal and configure a simulated scenario for training which plays out on the edge device such as the tablet or head-mounted display. This data connection is a key feature that drives multiple applications such as a digital twin of facilities.

METIL worked with ORETTC to construct a digital twin of one of their buildings (Fig. 5) prior to its construction for the purposes of visualization and logistics planning. This figure shows both a final render and production process in one of the digital content creation (DCC) software that then integrates with various game engines to power real-time simulations and applications. Once completed this asset was used for several solutions/prototypes, such as an interactive map with room scheduling, layout, and navigation. Through this platform we have the ability to customize elements in the live simulation via back-end data feeds without the need to rebuild and redeploy the application. This also serves as a sandbox environment for future use cases for expanding training at external sites regarding security and containment scenarios.

Similarly, using digital twins of facilities with a cache of digital equipment assets improves engineering design and facility layout through an immersive and collaborative design tool. Through this partnership, ORETTC and UCF are working together to better understand how these advanced technologies of AR/VR, haptics, and some of the latest and greatest in holographic visualizations can be woven together for unique immersive experiences for evaluation of training, systems, and human performance. The digital twin of the ORETTC facility formed the foundation of a simulation environment which gives context to emergency consequence tabletop exercises as part of in-person training at our facility which culminate with live response drills as well as orient trainees within the facility to the haptic glove box trainer and provide a test bed to visualize process equipment performance for facility decision making. The AR tabletop application increased familiarization of the training facility for trainee's such that their performance improved during live response drills at the end of the training week.

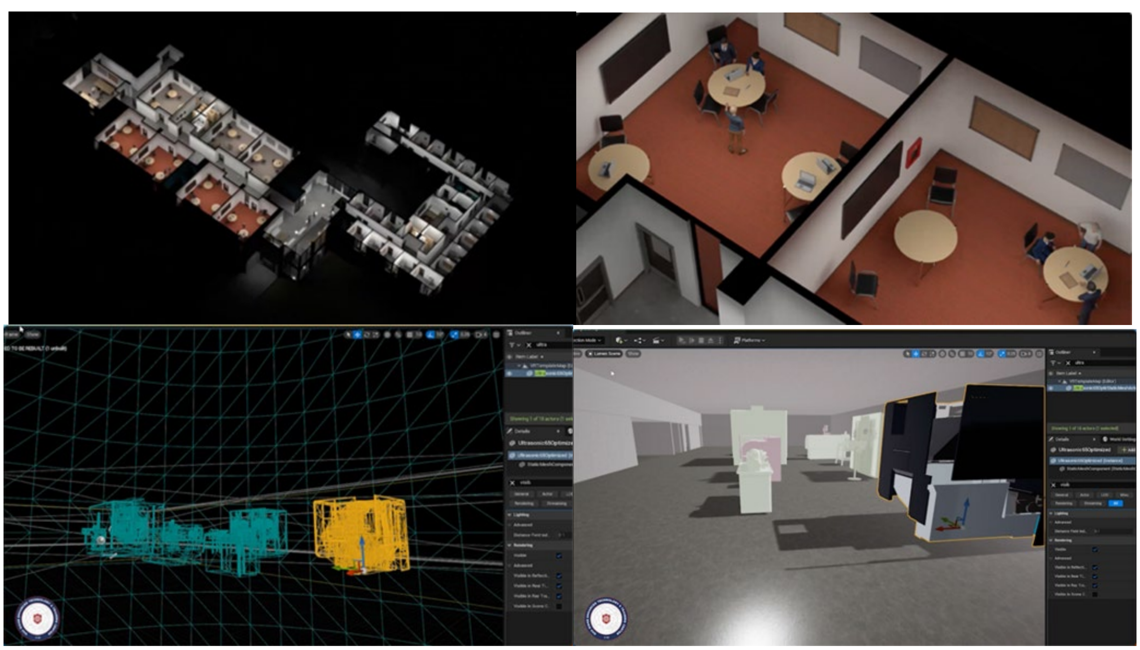

Figure 5. Digital Twin Production Examples of ORETTC Facility

IV. VIRTUAL PRODUCTION TRAINING

ORETTC began the transition to virtual production during the COVID pandemic due to curtailed travel. A trusted agent at a trainee's facility provided photos or a video of certain parts of the facility. Using green screen technology, ORETTC SME's created training scenarios for virtual training delivery. The recent installation of a LED volume moved training scenario development to large format video production, but still leverages video content created in the facility. LED wall technology allows for visualizing virtual environments at real-world scale and with more accurate lighting than standard green screen studio techniques (Fig 6). This approach has enabled their production teams to more accurately virtualize external site training materials that composite video and image reference material into a training video that now specifically matches their audiences' environment. Continuing the evolution to render engines on the LED wall combined with digital twin based simulations maximizes the flexibility and realism of training use cases.

The mimicked environment can provide a more authentic experience for training first responders regarding containment at a site in their area. METIL is assisting with research in this area regarding motion capture technology to allow for an even broader range of virtual production tools for ORETTC's training teams. Advanced motion capture systems using IR sensors or inertial motion capture suits give more flexibility to actors/trainers to puppeteer or collaborate in multiplayer simulations. Motion capture combined with leading edge LED wall technology provides ORETTC with a next-generation production suite and we are continuing to add to that process by researching ways in which AI can enhance the speed, subject matter accuracy, and efficiency of resource management for producing training material over a wide range of use cases. The resulting research is informing AI solution reporting, recommendation, selection, and integration opportunities in the form of reports (for sponsors, partners, leadership, publication, and eventually development/production pipelines.

Figure 6. Virtual Production with AR Visualization and Green Screen using an LED Volume

V. DISCUSSION AND FUTURE RESEARCH

The collaboration of ORETTC and METIL using digital twin representation has been fast-paced and working with some of the most industry leading tools for AR/VR and AI to meet the demands of ORETTC's training curriculum scope. Future research will target continued improvement on production pipelines, digital twin representation across multiple platforms to meet the scale and distribution of training audiences, and evaluation of the effectiveness of training solutions such as the virtual glove box and deployment. As part of this ongoing research ORETTC and METIL continue to share best practices and lessons learned to expand research related to these areas for DoE and its partners[11].

Case Study	Use case	Tools	Benefits
Haptic Glovebox	Manufacturing	Virtual Reality, Haptic glove, Digital Twin	Increased training repetitions compared to traditional methods, abnormal condition training, higher retention in operator roles
Digital Twins for High Consequence Training and Response Planning	Emergency Response	Augmented Reality, Digital Twin	Deployable for distance engagements, multiuser, specific (when leveraging digital twin), quick resets and changes for dynamic training, cheaper than live response drills

Virtual Production	Emergency Response, Manufacturing	Digital Twin	Tailored and specific training content, no AR/VR headsets needed, greater immersion

As training applications are deployed, multiple evaluative methods are being applied to understand the training value of such immersive techniques compared to traditional training protocols. Recent work showed that VR training reduced training time and allowed 83% of surgeons to perform surgery with minimal guidance or no guidance at all compared to the control group[12]. Emergency response training applications will be evaluated using Kirkpatrick's Four Levels of training Evaluation[13] which measures participants reaction to the training and how the training impacts learning, behavior, and ultimately results as the organizational level. While individual participant performance is not measured, an anonymous pre- and post-survey of participants perception of topics/skills/knowledge provided during emergency response AR tabletop exercises (TTX) will be measured. Statistical averages of perception and understanding of technical fundamentals will be compared prior to and post immersive training. Level 3 Kirkpatrick findings could include a survey months after the TTX to see if participants meet response expectations.

Additionally, for manufacturing training regimes such as the haptic glove box trainer, formal human trials are underway to measure the training value of using immersive training tools compared to traditional apprentice style glove box training. Participants will be split into two groups—experienced vs. novice glovebox worker—and will perform the same sample sorting and containerization task in three formats. The trial will require participants to perform the task in a physical glove box, virtual reality digital twin of the glove box with handheld controllers, and in VR with haptic sensory gloves. These environments are completed in a counter-balanced way to prevent a statistical ordering effect. A mixed-model analysis of variance will be conducted to determine if 1) there is a statistically significant difference for performance metrics among any of the three environments and 2) did either the glovebox or non-glovebox groups perform statistically different in any of the three environments. Initial results indicate that the virtual haptic glove box trainer simulates working in a physical glovebox realistically with participates indicating that they exert similar effort with similar fatigue during the training tasks.

ACKNOWLEDGEMENTS

The acknowledgements section is optional. If included, it appears after the main body of text and before the references. This section includes acknowledgements of help from associates, credits to sponsoring agencies, etc. Please try to limit acknowledgements to no more than a three or four sentence paragraph.

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