Immersive Content Creation Pipeline for Information Age Training

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ABSTRACT

Commercial Off the Shelf (COTS) Augmented Reality and Virtual Reality (AR/VR) technologies are increasingly finding their way into DoD maintenance training because of their ability to support hands-free, just-in-time (JIT) training and troubleshooting. In addition, these technologies reduce the need for physical training assets, thereby allowing learners to practice at their home station, rather than traveling to a dedicated training facility. A major impediment to the broad adoption of AR/VR training has been the advanced design and programming skills that are required to generate 3D content. Historically, the reuse and transformation of legacy maintenance training materials into immersive training content has been a time-consuming, manually-intensive process.

In this paper, we explore an automated content creation pipeline that uses open source tools to convert legacy training content into interactive and immersive 3D content. We lay down an approach to automate this pipeline, thereby minimizing the number of steps required to convert the source material into usable 3D content. The content creation pipeline does not require any specialized AR/VR design and programming skills, thereby providing instructors full control over the content generation process via an intuitive immersive scene editor. The resulting 3D objects can be managed in libraries and subsequently reused multiple times.

This paper will also aim to define the scope of legacy training content and prioritize which conversions to develop based on required effort and the prevalence of legacy content. Finally, we conclude with the results of a U.S. Marine Corps (USMC) training schoolhouse survey that identifies the most prevalent legacy content types that are candidates for conversion, as well as the required effort and efficiency of each conversion process. The paper concludes with best practices and lessons learned so that the reader can implement these content conversion practices in their own work.

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INTRODUCTION

With the increased digitization in defense operations, proliferation of smart sensors and IoT (Internet of Things) equipment, coupled with the inability of traditional manual-based and procedural approaches to adapt to the increasing complexities of Naval equipment, Maintenance Operations and Training finds itself at the crossroads with Model-driven Maintenance Training aided by Augmented Reality (AR) / Virtual Reality (VR). Future human-machine cooperation in DoD's missions will almost certainly feature AR interfaces. Integration of AR into Naval Maintenance training and Operations requires a holistic approach incorporating guided troubleshooting. AR with a dynamic intelligent reasoner holds the promise of reducing the technician's reliance on ground support and paper procedures. AR can support on the job training, virtual co-location, and just-in-time and just-in-place assistance approach to visualization.

Background and Current State of Maintenance Training

The USMC has taken an initiative towards advancing Maintenance Training from the Industrial age into the Information age. However, traditional classroom training techniques with student handouts and presentations, coupled with stove-piped legacy material, results in training being out-of-date with system operations. These learning techniques are inefficient and limit the capability to deliver and sustain improved readiness of DoD platforms. As more complex systems are fielded, not only will maintaining them be more challenging, but keeping training up to date will be even more difficult. Hence, there is a need for adaptive and immersive maintenance training techniques that provide up-to-date knowledge and expertise to successfully maintain systems. The Program Office Training Systems (PM TRASYS) stakeholders have stated that the main challenge in creating immersive content is lack of ready 3D models in the schoolhouses. This necessitates development of an immersive content creation pipeline that is able to generate 3D models from common sources such as available 2D pictures, or by taking new pictures using common cellphone cameras.

AR driven simulation training reduces physical hardware trainer footprint by minimizing the need for hardware-training devices and eliminating the need of contracted personnel required to set up the hardware training environment and their associated costs.

In this paper, we will demonstrate how an enterprise training platform can utilize photogrammetry, modern web-based AR/VR libraries, and learning sciences, to provide an immersive content authoring pipeline that provides just-in-time and just-in-place maintenance training with a varied set of immersive experiences.

THE IMMERSIVE CONTENT CREATION PIPELINE

Concept of Operations (CONOPS)

The content creation process aims to streamline the generation of immersive maintenance training experiences without any burden of 3D programming or graphical design on the instructors. The key steps of this process are shown as numbered steps in the Figure 1 below:

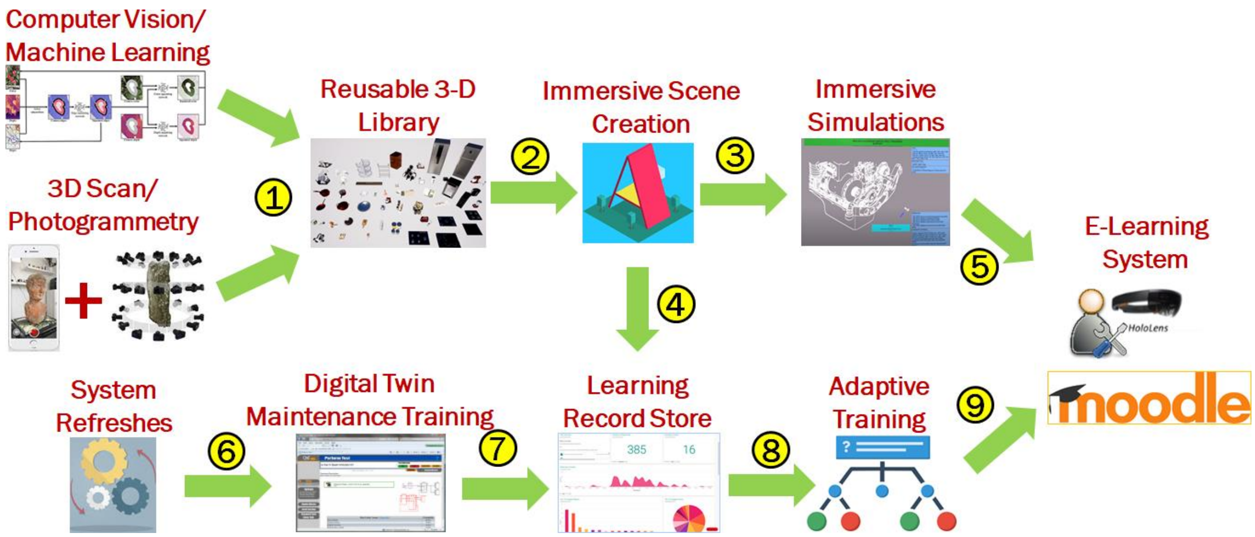

Figure 1: Immersive Content Creation Overview

1. The process begins by leveraging various source material such as 3D scans, 2D photos and CAD files for sourcing the 3D content. For 3D scans, we apply open-source Photogrammetry techniques to synthesize the 3D object. For 2D pictures, Computer Vision ML (Machine Learning) techniques can be used to extract 3D objects from images. The resulting 3D objects are cataloged in a reusable library that can be used for generating immersive content.
2. The next step is reusing the 3D objects from the 3D library to build immersive experiences using the WebXR framework (WebXR, 2022).
3. The web-based AR/VR Designer is accessible from anywhere in the network and will enable authoring of AR/VR scenes without the need for programming and graphics design skills. These scenes will be associated with relevant maintenance training steps. The AR/VR Designer also supports authoring of component identification tests in an immersive setting, and scores the students in Moodle or any other learning management system (LMS).
4. The AR/VR Designer can have a built-in capability to capture metrics of the amount of time taken to generate the immersive content. These recorded actions are transformed into xAPI (Rustici Software LLC, 2022) learner records and logged into a Learning Record Store (LRS). LRSs such as Learning Locker (Learning Locker Open Source, 2022) have built-in dashboards and analytics to display metrics related to the creation of immersive content. This will be useful in discovering variances in creation times for various types of source content. This will also provide insight into trends in content creation efficiencies over time as the content creation authors become familiar with the tool.
5. The training content is deployed in an E-learning platform such as Moodle (Moodle, 2022), which is adopted as the LMS of choice by the USMC. The embedded AR/VR scenes will be used as immersive training content.
6. Any tech refreshes to the system will “automatically” be reflected in the maintenance training content via a digital twin that uses an underlying model of the system to generate maintenance training content and activities.
7. The digital twin generates reference guided troubleshooting material and maintenance training activities that will test students on their maintenance troubleshooting skills by creating simulated failures that requires application of system knowledge to arrive at the root cause.
8. The student’s performance in the maintenance training exercise will be captured as xAPI learner records and logged in the LRS. Appropriate LRS dashboards will provide instructors with insights into common problem areas and learning gaps.
9. Instructors will assign training sessions within the Moodle E-learning environment. Analytics from LRS is also mined to assess the problem areas in the training regimens, and assess the training gaps. Based on the student KSAs (Knowledge, Skills and Abilities), competencies will be established through Moodle’s competency frameworks and appropriate maintenance training sessions focused on specific sub-systems will be assigned.

Immersive Content Creation Pipeline

The continually updateable immersive training pipeline enables source material to be fed through a tool chain which progressively refines it to be ultimately usable in immersive content. The steps are seamless and automated, combining open-source and commercial technologies. FreeCAD (FreeCAD, 2022) and Blender (Blender, 2022) open-source tools allow scripting of content manipulation steps for automating the refinement process. This process supports various formats for the source data, including 2D images. 2D CAD (Computer Aided Design) models and SVG (Scalable Vector Graphics) files can also be sourced from technical manuals. For instance, a 3D CAD file in STEP (Standard for the Exchange of Product Data) can be converted to a 3D Wavefront (.obj) for use in immersive scenes.

We investigated various photogrammetry software such as COLMAP, Meshroom, etc. to convert 2D photos taken at various angles, by 3D scanners or smartphones, into 3D models. Smartphones with LIDAR (Light Detection and Ranging) support Apps that automatically scan and 3D synthesize physical objects during walkarounds. For pre-existing static 2D photos, ML techniques such as CNN (Convolutional neural network)-based single depth estimation (Shih et al., 2020) and other computer vision techniques separate out various layers of a 2D photo. These layers can be extracted into individual 3D objects. Other methods include converting a 2D image into an open-source vector graphics editor such as Inkscape (Inkscape, 2022) and then converting into a 3D mesh using 3D computer graphics software such as Blender. CAD models can be converted to 3D Wavefront objects using tools such as FreeCAD.

After a 3D model is ready, the content creation pipeline is ready to ingest that material. The process includes manipulating and cataloging the 3D content for reuse in immersive scene generation. This process is automated and does not require any 3D programming and graphics skills. We used modern AR/VR immersive web-based frameworks that support network access and multi-device modalities (laptops, tablets, smartphones).

Web-based AR Scene Creation

The research team developed an immersive scene editor based on the WebXR technology, to enable rapid AR-scene generation over the web without requiring 3D programming and graphical design skills, or any specialized software such as Unity (Unity, 2022), or hardware. The editor has an interface to pull pictures, library of 3D objects and other re-usable content to sequence animations. This interface can be used from any web-browser. Using WebXR, modern browsers can display immersive scenes within their web-interface. The immersive training exercises and associated AR/VR content can also be viewed in Microsoft HoloLens, with the real world augmented to user's field of view.

The immersive content can be integrated with guided troubleshooting content for maintenance training. Chief considerations while integrating immersive content creation pipeline with maintenance training activities were:

- A toolchain that integrates the 3D-scan and photogrammetric process with the content creation pipeline
- A web interface to manipulate 3D objects online and apply effects to enhance their quality and appearance
- Web interface to catalog the 3D objects for reuse in an immersive scene creation
- Web interface accessible to anyone on the network to author immersive scenes
- Interface to deploy the immersive scene content to appropriate steps in the guided troubleshooting steps
- Web interface to incorporate feedback from instructors to update maintenance training related images and media

Legacy 3D data to immersive content

This step involve conversion of legacy SVG graphics file and CAD model into re-usable 3D content. For this purpose, we utilized the material from the USMC's PM AAA (Advanced Amphibious Assault) POI (Program Of Instruction) related to the NET (New Equipment Trainer) course for the ACV (Amphibious Combat Vehicle). The supplied Operator Manual for the NET course includes several schematics in SVG format. Additionally, a CAD model of the ACV was provided in the form of a STEP (Standard for the Exchange of Product Data) file. The STEP file provided only has the outer shell of the vehicle and not any inner vehicle details. In order to make this content useful for maintenance training, we imported these 3D models in our Immersive Scene generator through a series of conversions. Currently a manual conversion process imports the SVG into Blender application and then exports it as a Wavefront Object (.obj) file. Similarly, the STEP file was also converted into an .obj file in Blender. These conversion steps will be automated in the future by invoking open-source Blender libraries from within the web-based AR/VR Designer. Next, we utilized the converted object in AR/VR Scene Designer to create immersive scenes. Figure 2 below shows the utilization of the converted objects in an immersive scene that guides the maintainer in the removal of an Air Compressor from the Engine unit in the ACV.

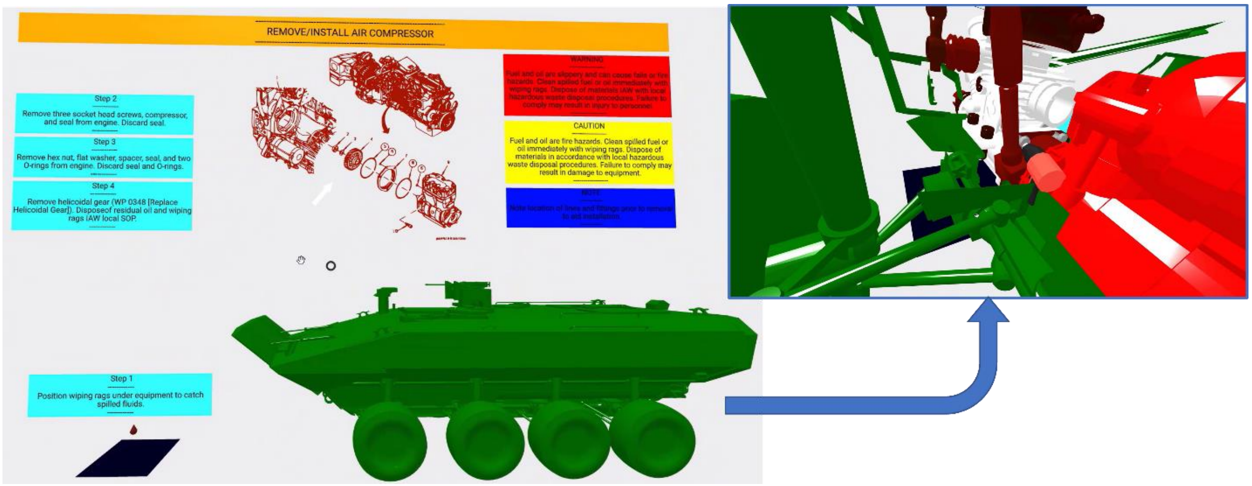

Figure 2: 3D STEP File Utilized in an Immersive Scene

The scene above shows 3D models of "Engine" and "Compressor" attached inside the empty shell of the ACV model.

Another immersive usage of a 3D-converted object is disassembly in an animated fashion. Figure 3 below shows an SVG object converted into a Wavefront object in Blender and then broken into parts that are then individually imported into the AR/VR Designer. The web-based interface uses modern WebXR technologies that enable 3D scenes to be rendered in any browser as well as 3D glasses such as HoloLens.

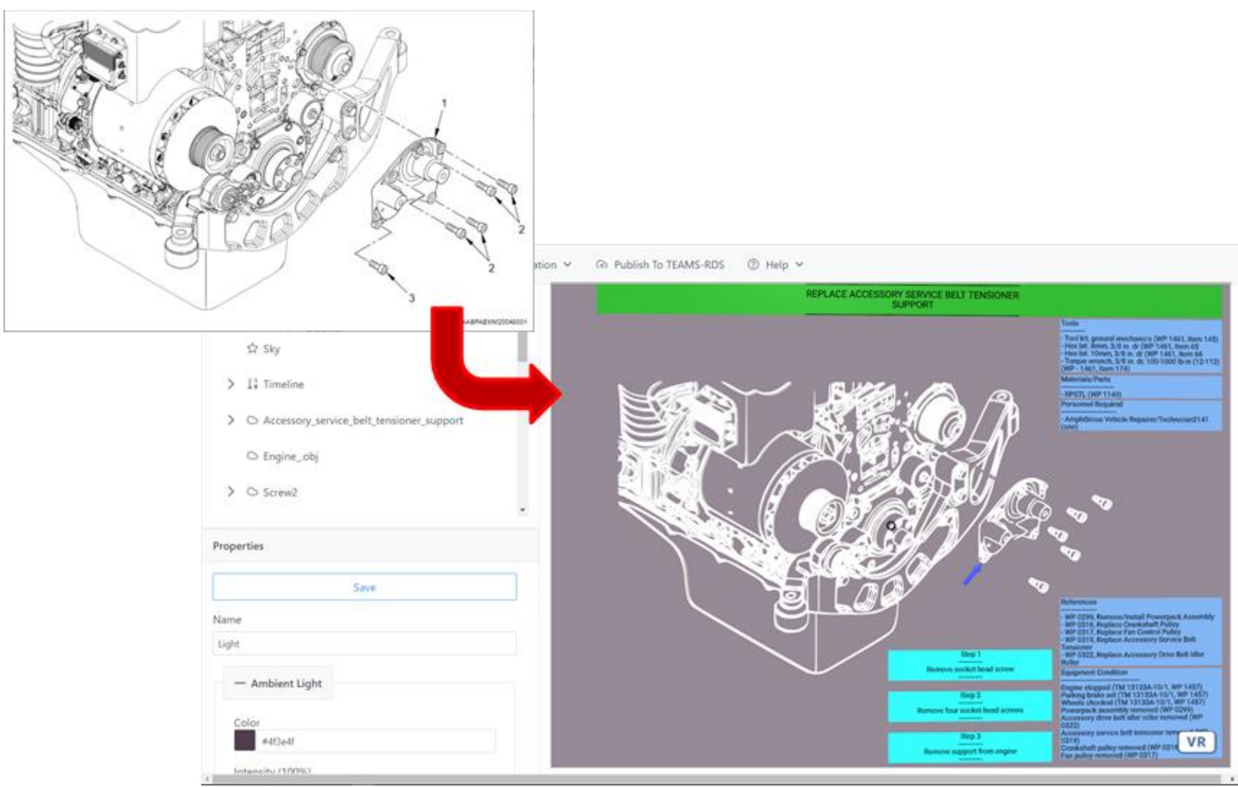

Figure 3: SVG Image Deconstructed in the AR/VR Designer

The immersive scene above is providing instructions to remove screws of the "Accessory Service Belt Tensioner Support" and then remove Support from the "Engine". This scene can be rendered in HoloLens or other 3D glasses.

3D scanned objects to immersive content

In order to demonstrate generation of immersive content when no source material exists, we utilized the training material from the MCES (Marine Corps Engineer School) POI of the Small Crafts Mechanics course for the Evinrude 55 HP Outboard marine motor. The POI teaches the fundamentals of the Evinrude engine using physical cutouts of the engine. This takes up a lot of engineering resources and physical training assets. This exercise sought to explore the extent of virtualization possible from existing POIs that use these physical assets. For this purpose, we first searched for a generic and equivalent marine craft engine since the Evinrude engine with the MCES was not available to us. We visited a marine engine repair shop and 3D-scanned a Mercury 50 HP marine engine. For this step, we used an open-source 3D Scanner App (Laan Labs, 2021). The results of the scanning exercise are shown in Figure 4.

Figure 4: 3D Scanning using Photogrammetry

Thus, it is feasible to get 3D models from physical training assets by Photogrammetry and other 3D capture techniques.

Immersive Content Creation in the Scene Designer

Once the 3D object is generated, we import it to our AR.VR Designer as a Wavefront object (.obj) format (Figure 5).

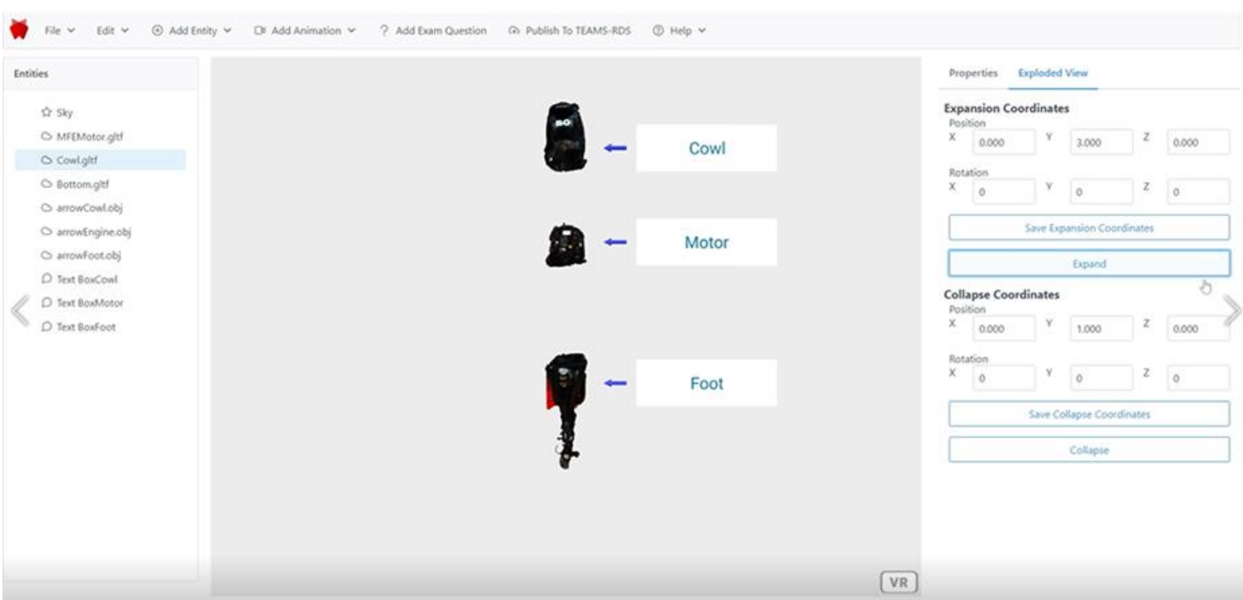

Figure 5: 3D Scanned Object Deconstructed in the AR/VR Designer

The AR/VR Designer above is entirely a web-based interface, accessible from any device. It has a library where 3D objects can be imported and reused for scene generation. The designer has simple form-based controls for creating "timeline" sequences of the animations. 3D objects can be manipulated within the canvas such as dragging, rotation, position changes, etc. Users can also add static images, textboxes/labels to annotate the scenes. The entire scene generation activity does not require any programming skills or any specialized hardware to create and visualize.

The Immersive content creation pipeline has the capability to disassemble and explode 3D scanned objects. Currently, we use Blender to extract parts of the 3D scanned model. We plan to automate this step using Blender library calls from the AR/VR Designer. Figure 6 below shows the Ignition Coils being "removed" from the core engine.

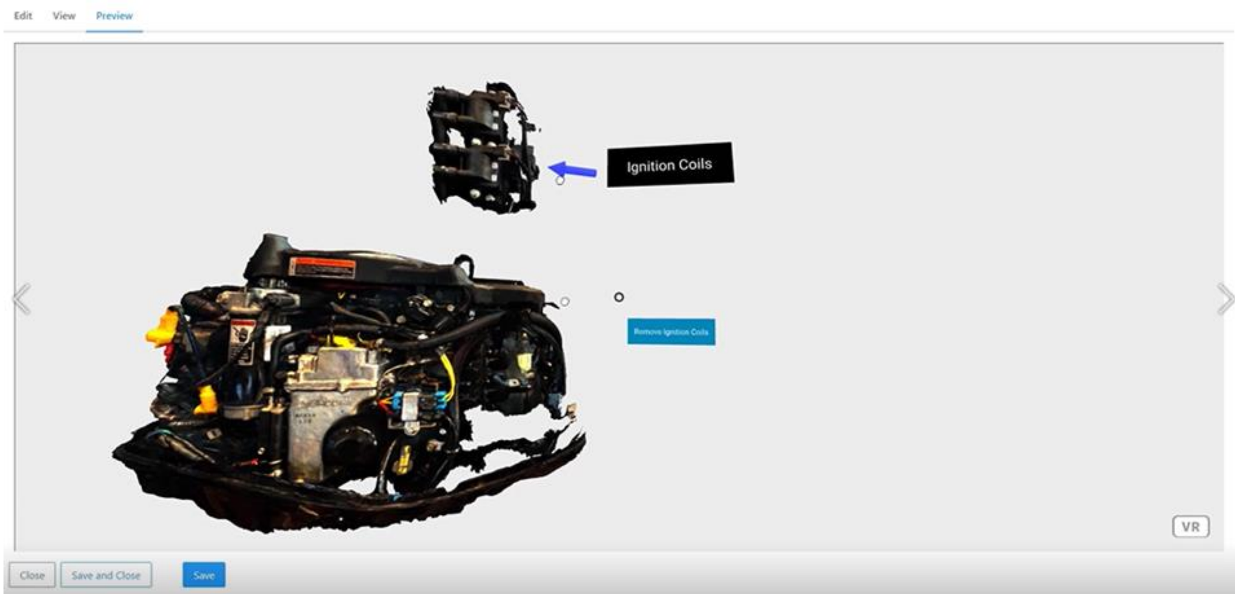

Figure 6: Disassembly and exploding of a 3D Scanned object in the AR/VR Designer

Once these scenes are authored, they can be associated with various maintenance steps during Guided Troubleshooting and Training exercises that simulate faults. In the Figure 7 below, an immersive scene is being used to guide the technician in the usage and setup of a Multimeter prior to checking the voltage in the Evinrude motor test.

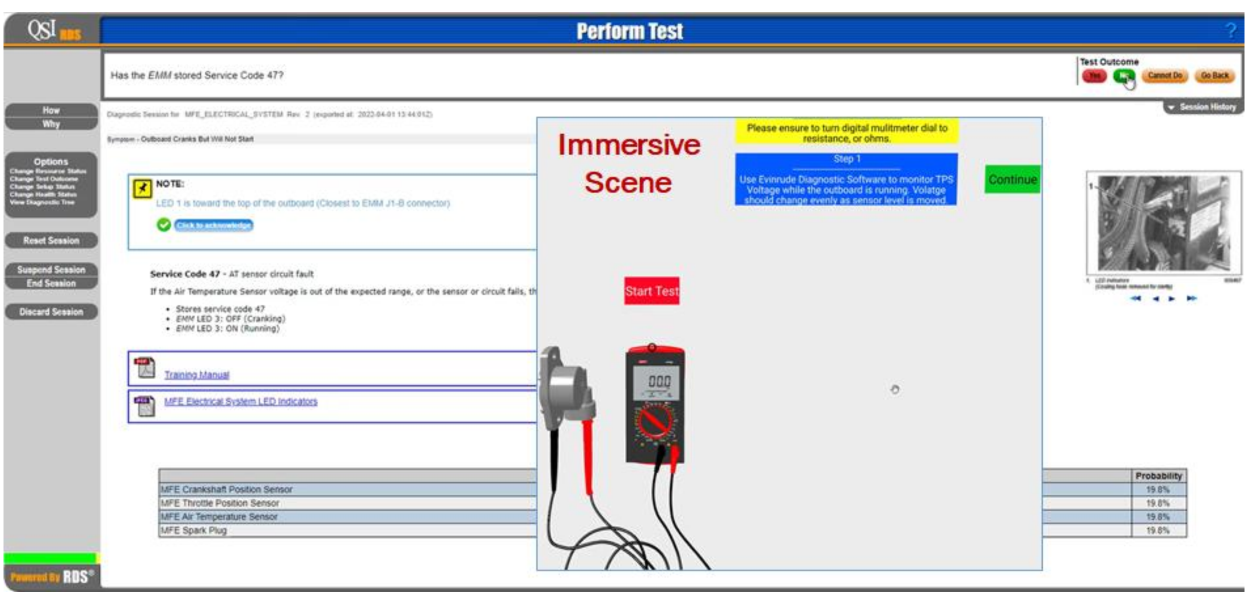

Figure 7: Immersive Scene in Maintenance Troubleshooting and Training

Immersive Practical Tests

Next, we focused on generation of component identification exercises in an immersive environment which test and grade the students in an E-learning framework such as Moodle. Figure 8 shows the approach, in numbered steps, for authoring and deploying such practical applications in Moodle.

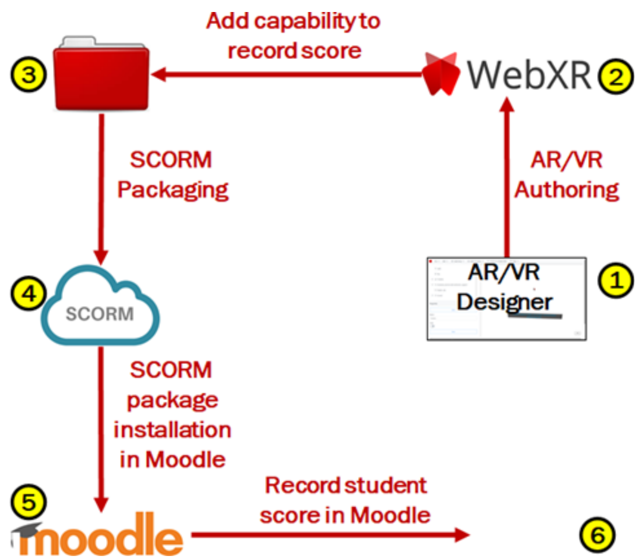

Figure 8: Content Creation Pipeline for the Immersive Component Identification Test in Moodle

1. The process begins with the instructor generating immersive practical applications in the AR/VR Designer.
2. The exercises and the scenes are packaged in a portable WebXR web-package that can be attached to immersive training and troubleshooting content.
3. The portable HTML archive is repackaged into a SCORM package utilizing free 3rd–party HTML to SCORM packagers. For this exercise we utilized Learning Cart's "HTML 2 SCORM" free converter: (Learning Cart Inc., 2021).
4. The SCORM package with AR/VR Practical Tests is uploaded and deployed to Moodle, which supports SCORM.
5. Students are assigned the AR/VR Practical Tests in Moodle as part of their course curricula.
6. Students then undergo the immersive exercise in Moodle and are scored based on their performance. These scores are recorded as part of the grading and competency framework.

Figure 9 below shows a Moodle immersive component identification test associated with the Central Tire Inflation System (CTIS) panel in the ACV that is used to control the tire pressure in various modes of operation. This test can be performed on a tablet, laptop or Microsoft HoloLens. The students are required to respond to the questions and then identify and click on the correct button in the scene. They are scored based on their responses, and at the end of the test their final tally is automatically uploaded into Moodle.

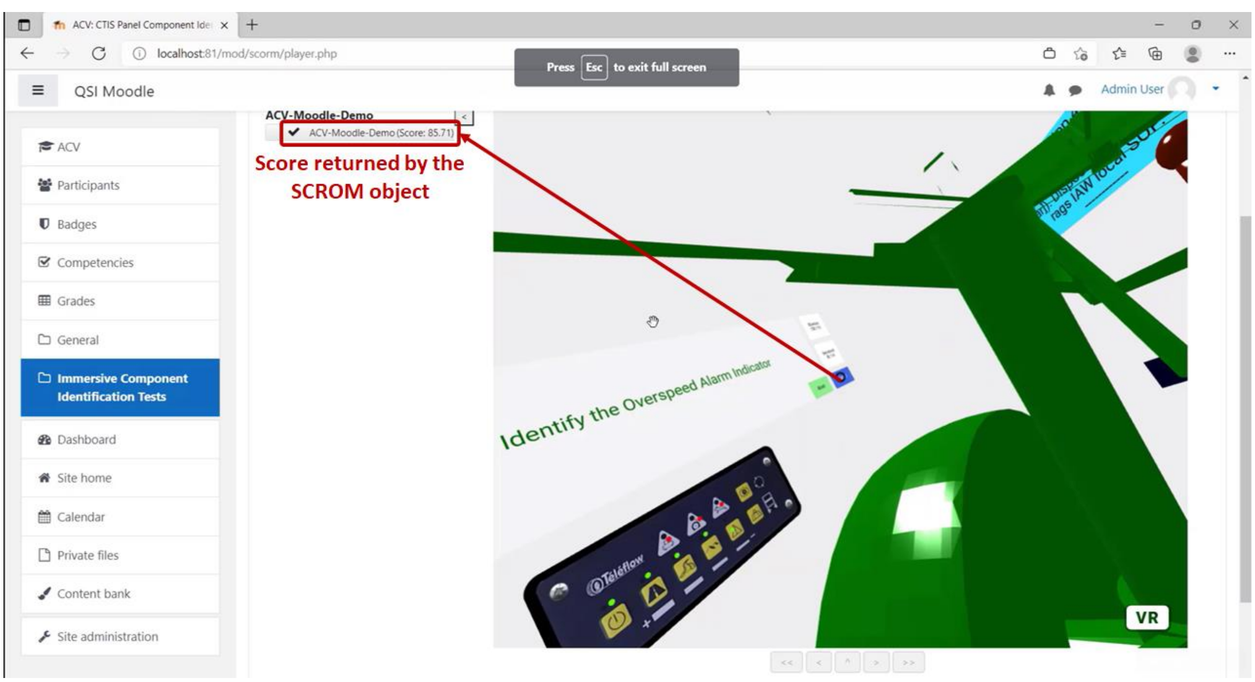

Figure 9: Immersive Component Identification Test for the CTIS Panel

Traditionally, these practical tests are performed using pen-and-paper with the physical ACV asset parked in the evaluation area, and students climb inside the vehicle and identify the buttons in the CTIS Panel for the instructor. The instructor then marks their answers and scores them accordingly. A virtualized component identification test would eliminate the need for physical assets as well as physical presence of the instructor and the students.

METHOD AND RESULTS (FRONT END ANALYSIS)

The Office of Naval Research (ONR) and MARCORSYSCOM (Marine Corps Systems Command) Manpower, Personnel, Training, and Education (MPTE) sponsored a Front-End Analysis (FEA) survey with various USMC schoolhouses to assess the availability of different kinds of legacy training data (e.g., quizzes, instructor handouts, checklists, animations, etc.) which could potentially be repurposed for use in immersive training environments. For example, some legacy data (e.g., maintenance checklists, technical flowcharts) could be potentially integrated into AR- or VR-based training scenarios. Prior to conducting the FEA, however, MARCORSYSCOM didn't have an accurate assessment of what types of legacy content currently exist, and which techniques would be required to convert this content into digital form.

The FEA survey – which was designed to identify the most common types of legacy training data at USMC schoolhouses – consisted of four parts. Part I identified courses and equipment in the schoolhouse. Part II surveyed their training requirements. Part III identified metrics of interest for student learning and successful maintenance activities. Part IV sought out legacy data types that can and should be converted to immersive maintenance training content. The FEA survey was sent out to 3 separate schools: (1) Assault Amphibian School (AAS) with the PM AAA (Advanced Amphibious Assault), (2) Marine Corps Combat Service Support School (MCCSSS) and (3) Marine Corps Engineering School (MCES). These schoolhouses identified a total of six courses as eligible for conversion into immersive maintenance training content.

According to the survey respondents, the most commonly available materials are common task lists, technical/OEM manuals, maintenance checklists, instructional videos, quizzes, lesson plans, and student handouts/outlines. The majority of these materials are saved in Microsoft Office or Adobe Acrobat formats. A host of student metrics are currently in widespread use; however, the most prevalent is learner/class throughput. The respondents indicated a desire to reuse these materials in various ways: learning exercises within Moodle; and as part of interactive AR/VR-based training scenarios.

METHOD AND RESULTS (FEASIBILITY TEST)

At the conclusion of the FEA survey, the research team developed an "immersive maintenance training content creation pipeline/process" to show MARCORSYSCOM personnel how digitized legacy training materials could be quickly and cost-effectively repurposed in Moodle and AR/VR environments. To this end, we designed and conducted a feasibility exercise for the interactive and immersive content creation process with the Program Of Instruction (POI) material supplied by (1) PM AAA on their NET course for the ACV and the (2) MCES on the Small Craft Mechanics course for the Evinrude 55 HP Outboard Engine.

The training material in the NET Course used for capturing immersive maintenance training content included:

- Training Presentation (TP) for each lesson in the form of PowerPoint slides;
- Lesson Plans (LP) in the form of Word documents which are instructor's aids for the Training Presentation;
- Student Handout (SH) in the form of Word documents which are Student lessons for the Training Presentation;
- Operator and Operator Maintenance Manuals;
- 3D model of the ACV (shell only) in .STP format.

The training material in the Small Craft Mechanics Course used for capturing immersive maintenance training content included:

- Field Technical Manual;
- Student Handouts (Word);

- Lecture Presentation (PowerPoint);
- Videos;
- Exams.

Finally, we demonstrated this immersive maintenance creation process using open-source and low-cost software tools such as Blender and 3D-scanning Apps during the course of a 2.5 day workshop. During the workshop, the USMC visitors logged in to a hosted Moodle instance and performed the following activities:

- Legacy 3D data to immersive content conversion
- 3D scanning of physical objects to be utilized as immersive content
- Web-based Immersive Content Creation utility
- Viewing an immersive scene with Exploded views
- Performing Component Identification and Practical Applications Test in Moodle (with Scoring)

At the end of the workshop, we conducted a brief usability test with a sample of USMC instructors and training program managers to solicit their feedback about the immersive content creation processes. In the following sections, we describe the usability test procedure, results, and findings.

Participants

The sample included six representatives from the USMC's AAS at Camp Pendleton, CA, three AAS training Program Managers (civilian contractors), and three ACV maintenance Subject Matter Experts (SMEs)/Instructors. Two SMEs were active-duty senior enlisted Marines and the third was a civilian contractor with recent active-duty USMC experience.

Measures

The primary criterion measure was the Post Study System Usability Questionnaire (PSSUQ; Lewis, 1992). The PSSUQ is a 16-item usability scale that measures perceived satisfaction with a process or system with anchors that range from "Strongly Agree" (1) to "Strongly Disagree" (7), with a high internal consistency reliability (.97) (Lewis, 1992). The scale is frequently used in Human-Computer Interaction (HCI) research. The PSSUQ has been translated into numerous languages, including European Portuguese (Rosa et al., 2015), Arabic (Al-Tahat, 2021), and Greek (Katsanos et al, 2021). The PSSUQ questions are organized into three categories. Questions 1-6 focus on the system/process quality (in our case, the content creation process). Example questions include "It was simple to use this system" and "I was able to complete the tasks and scenarios quickly using this system." Questions 7-12 focus on the quality of information provided by the system or process. Example questions include "Whenever I made a mistake using the system, I could recover easily and quickly" and "It was easy to find the information I needed." Finally, Questions 13-16 focus on the interface quality of the system or process. Example questions include "I liked using the interface of this system" and "This system has all the functions and capabilities I expect it to have."

The research team included five additional questions that were custom developed for the current study. The questions compared the new content creation pipeline to the USMC's current ways of developing immersive instructional content. The five questions were as follows:

- "The amount of time to complete was worth the product"
- "The number of steps to complete made sense for the product"
- "The number of people required to complete was not over expectations for the product"
- "The level of technical knowledge to complete was appropriate"
- "This system and process makes sense for automation"

These were worded in the same direction as the PSSUQ, with smaller numbers indicating more favorable responses.

Procedure

The usability test occurred during the course of a 2.5 day workshop, where the research team described two different sections of the immersive training content creation process. These sections - Powerplant Immersive Exercise and

Immersive Content Creation – involved the participants listening to the process being described, observing the procedure being performed by a member of the research team, and then practice performing the procedure on their own. After completing each section of the multi-day workshop, the participants immediately completed the PSSUQ to provide feedback on that section. This process continued iteratively throughout the multi-day workshop.

Results

Survey means and standard deviations (SDs) are summarized in Table 1. Columns 2-4 contain the PSSUQ scale scores of System Quality (mean and SDs of PSSUQ items 1-6), Information Quality (mean and SDs of items 7-12), and Interface Quality (mean and SDs of PSSUQ items 13-16), respectively. Finally, Columns 5-9 contain the five survey items that were custom developed for the current study: amount of time required, number of steps required, number of people required, amount of technical knowledge required, and the extent to which the process was suitable for automation. Because these were single-item ratings, no means or standard deviations were computed. As a reminder to the reader, all of the items were scored such that smaller values indicate more favorable responses.

Table 1. Survey Results

	PSSUQ Means and Standard Deviations			Custom-Developed Survey Questions				
Source	System Quality	Information Quality	Interface Quality	Time Required	Steps Required	People Required	Technical Knowledge	Suitable for Automation
Immersive Content Creation	3.31 (1.26)	3.08 (1.08)	2.83 (1.15)	2.83	3.67	2.83	3.50	1.67
Powerplant Immersive	2.17 (1.05)	1.93 (0.78)	2.80 (1.57)	2.50	2.60	2.00	2.00	2.00

Two key themes emerged from an analysis of the data.

First, all of the scores were below the scale midpoint of 4.0, which indicates that the participants perceived the new immersive maintenance training process favorably. An analysis of the PSSUQ scale scores indicated that participants thought the system/process was well designed, that it provided useful information, and that the system interfaces made sense. Finally, the custom-developed questions showed that the new immersive content creation process was perceived as favorable regarding the amount of time required, number of steps required, the number of people required, the amount of technical knowledge required, and that it is suitable for automation.

Second and finally, of the two sections that were covered during the 2.5 day workshop, the Immersive Content Creation portion tended to have slightly higher (less favorable) mean responses than the other course. In retrospect, this is due to the inherent level of difficulty associated with 3D content creation, which involves developing 3D models using a LIDAR-based phone application, importing the resulting model into Blender for editing, and then inserting those modified 3D models within the digital training environment. It is also important to note that this process did not include an opportunity for student to practice, due to time and other resource constraints. It is also important to note that much of the aforementioned steps will be automated in the future.

CONCLUSIONS

In this paper, we demonstrated the concept of an entirely web-based immersive content creation pipeline that does not require any programming or graphical design skills for authoring purposes, and also does not require any specialized hardware for visualization purposes. The AR/VR content can be visualized inside multiple device modalities such as desktops, laptops, smartphones, AR/VR goggles, etc. Furthermore, the AR/VR Designer can author student-testing activities that provide practical applications within the Moodle E-learning environment. The capability has the potential to minimize the utilization of physical training assets that take up schoolhouses' valuable resources, thus easing the manpower and logistical burden on the schoolhouses. The underlying single-source-of-truth digital twin enables generation of guided training content through its guided troubleshooting capabilities. Ultimately, immersive training can help achieve the Marine Corps' strategic goal of training technicians to be efficient maintainers.

The immersive content creation process was demonstrated to a sample of USMC training managers and domain SMEs/instructors from the AAS at Camp Pendleton, CA during a 2.5 day workshop. During the workshop, two different components of the immersive content creation process were demonstrated. These components involved the research team describing the process, demonstrating the process, and the participants practicing the task on their own.

The two immersive components were assessed using a validated usability scale. Five additional survey questions were specifically developed for this study that compared the immersive content creation process to current standard USMC content creation processes.

Two key findings emerged from an analysis of the questionnaire responses. First, all mean scores were below the scale midpoint of 4.0, indicating that the participants viewed the new immersive content creation process favorably. Second and finally, one content area – which focused on immersive 3D content creation using a phone-based 3D-scanning application and the Blender video editing tool – had (comparatively) elevated scores, due to some manual steps (which the research team plans to automate in the future) involved in the content creation pipeline; however these scores were still below the scale midpoint of 4.0. Overall, the results suggest that the sample of USMC instructors and training managers perceived the new immersive content creation process favorably, both in an absolute sense and compared to current USMC immersive training creation and dissemination.

Future work in the 3D scanning could involve methods to measure and analyze loss in quality of the source content as it progresses through the content creation toolchain towards a usable immersive content. Furthermore, this research will expand on automating the conversion of 3D-scanned objects to 3D models that can be imported and used in the AR/VR scenes. Finally, the rendering activities can be tracked using Learner Records in an eXperience API (xAPI) for audit purposes and estimating the level-of-effort required for authoring the immersive scenes and assessing the Return on Investment (ROIs) on these activities (e.g., cost savings from immersive training compared to physical trainers, etc.). Performance evaluations of activities such as Installation, Programming, Troubleshooting, etc. of the equipment can also be analyzed.

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