2006-2584: AIRCRAFT MAINTENANCE TECHNOLOGY EDUCATION: INTEGRATING ASYNCHRONOUS TECHNOLOGY & VIRTUAL REALITY

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Aircraft Maintenance Technology Education: Integrating Asynchronous Technology and Virtual Reality

Abstract

This paper describes a research program with an objective to develop and implement an interactive virtual reality (VR) model of the aircraft inspection maintenance process for asynchronous delivery. Existing approaches have not been able to mimic accurately the complexity of the aircraft maintenance process, reporting limited transfer capabilities and student preparedness for the workplace. This use of virtual reality technology will enable educators to create and students to experience the complex aircraft maintenance environment in an educational classroom, a setting where it has not yet been successfully created using traditional multimedia-based technologies. This model will emphasize the curriculum development and workplace preparedness needed by modern aircraft maintenance technology for local, state and national audiences. The primary objectives of this research are curriculum enhancement and assessment of VR as a pedagogical tool. This innovative approach is the first effort to extend tested VR technology to the aircraft maintenance technology curriculum in a two-year college. The outcome of this research will lead to the following: an innovative, high-impact model for curriculum application in aircraft maintenance technology for college students and industry employees; an increased workplace pool of aircraft maintenance technicians prepared for the transition from learning to workforce; a program providing the use of VR technology as a pedagogical tool. The successful completion of this effort will fill a state and national need for well-prepared students entering the aircraft maintenance industry and will provide a better understanding of the use of VR as a pedagogical tool.

1. Introduction

Aircraft inspection is a vital element in assuring safety and reliability of the air transportation system. It is essential to detect defects in the aircraft as soon as possible, before they lead to catastrophic failure and loss of human lives. Some of the previous aircraft crashes have been attributed to faulty maintenance procedures. Visual inspection by a trained human inspector forms an important part of the maintenance procedure, contributing to almost 90% of the visual inspection of an aircraft. The inspector performs both scheduled and unscheduled maintenance of the aircraft and detects fault, defects and potential hazards. Traditionally, the aircraft inspector obtained on-the-job training (OJT), which helped bridge the gap from the classroom teaching to practical workplace environment. This, however, may not always be the best method of instruction [1]. Some of the limitations inherent to OJT include the lack of feedback, the high cost of aircraft exposure, and the limited defect exposure.

Older, more experienced maintenance technicians who typically have extensive Air Force experience are retiring from commercial aviation maintenance and are being replaced by a much younger workforce coming directly from schools. Often, these new graduates have not been exposed to the complex wide-bodied aircraft maintenance environment and, hence, face a steep learning curve because they are not fully prepared to make a smooth transition to the workplace.

Also, these students may never receive hands-on inspecting experience and, as a result, are not adequately prepared for the transition to the workplace.

This paper outlines recent efforts at Clemson University on the use of advanced virtual reality technology to upgrade the inspection skills, reduce human error and eventually improve aviation safety. This paper is organized as follows: Section 2 details the background of the aircraft inspection simulators at Clemson University. Section 3 describes the development of VR simulators with Section 4 outlining the steps followed in integrating the simulators with the aircraft maintenance curriculum at Greenville Tech followed by the summary and conclusion Section 5.

2. Background

Traditionally, aircraft maintenance schools have concentrated on teaching students the theoretical aspects of the inspection procedure. One such program is the Aircraft Maintenance School at Greeville Tech in South Carolina. The program provides two year aircraft maintenance course aimed at training aircraft maintenance technicians for the workforce. A major limitation of the program has been the inability to provide actual hands on training and the practical experience needed to work in a complex aircraft maintenance environment, especially in wide-bodied aircraft. Usually, neither can the aircraft maintenance schools afford the prohibitive costs of acquiring wide-bodied aircraft, nor do they have the hangar facilities to store such aircraft. This leads to training students on smaller aircrafts. However, such training on smaller aircraft may not transfer well to the wide-bodied aircraft. Thus, students trained via traditional methodologies are confronted with on-the-job situations that require them to provide quick and correct responses to stimuli in environments where they have no previous experience and a situation where inspection and maintenance errors can be costly and at times catastrophic. To alleviate some of the shortcomings of these traditional methods, computer technology has been proposed to improve the curriculum and provide practical experience to the students.

Computer-based technologies have been developed that have promised improved efficiency and effectiveness of the inspection procedure. Such training devices are being applied to a variety of technical training applications, including computer-based simulation, interactive videodiscs, and other derivatives of computer-based applications. Computer-aided instruction, computer-based multi-media training and intelligent tutoring systems are already being used today in classrooms to promote active learning. Computer-based simulators have been previously used to provide much needed practical experience to novice students, ranging from surgery training to flight simulators.

In visual inspection training, the earliest effort using off-line inspection training was by Czaja and Drury [2], who used keyboard characters to develop a computer simulation of a visual inspection task. Low fidelity inspection simulators with computer-generated images to develop off-line inspection training programs have been used by Latorella et al. [3] and Gramopadhye et al.[4] for inspection tasks. Drury and Chi-Fen [5] studied human performance using a high fidelity computer simulation of a PCB inspection task. Kundel et al. [6] have applied advanced technology to the inspection of X-rays for medical practice. However, they are not widely adopted due to the low-fidelity and limited interaction in such simulators. Virtual reality (VR) simulators have been proposed to overcome these shortcomings.

Virtual reality has been defined as a computer simulated 3D environment in which the objects can be manipulated by the user through a standard input device such as a keyboard or mouse. The display technology can range from the computer monitor to specialized head-mounted displays(HMDs). A model of the object is created using a 3D modeling software and rendered on the screen. Due to advances in the computer graphics industry, it is now possible to render and interact with high polygon count objects in real-time (>30fps). Using a VR simulator, we can more accurately represent complex aircraft inspection and maintenance situations, enabling students to experience the real hangar-floor environment. The instructor can create various inspection and maintenance scenarios by manipulating various parameters – for example, defect types, defect mix, defect severity, defect location, defect cues -- reflective of those experienced by a mechanic in the aircraft maintenance hangar environment. As a result, students can inspect airframe structure as they would in the real world and initiate appropriate maintenance action based on their knowledge of airframe structures and information resources such as on-line manuals, airworthiness directives, etc. Their performance in tackling these scenarios can be tracked in real-time with the potential for immediate feedback. Students will be able to grasp the links between various visual cues presented, the need for specific inspection items and potential maintenance solutions. Repeated exposure to various scenarios along with classroom teaching will help them link theoretical scientific knowledge, for example, physical and chemical characteristics of structures, to various engineering solutions. The result is an innovative curriculum application, one in which the student has the added advantage of simulator experience in addition to the theoretical knowledge.

3. Software development

The integration of technology and theoretical aspects of learning to aid training has been used for decades. The earliest simulators built were for military and research purposes. The computers used to run these simulations were expensive and hence these simulators were limited to research facilities. With the improvements in the commodity graphics market, we can now render more complex environments within these simulators for a fraction of the price. The visual realism and real-time interaction make it feasible to develop a desktop simulator for the aircraft inspection tasks. The current hardware used to develop the simulator (Figure 1) consists of a Dual Xeon processor machine with GeForce 6800 video card and 1 GB of RAM, all for a total cost of less than $3000.

a. HMD and 6DoF mouse **b.** HMD optics **c.** Touch screen WindowVR

Figure 1: Hardware used to develop and test the simulators

The first aircraft inspection simulator developed at Clemson University was called Automated System of Self Instruction for Specialized Training (ASSIST). The simulator consisted of 2D interfaces and a collection of photographs that were presented with instructions to a novice trainee inspector. The results of the follow-up study [7] conducted to evaluate the usefulness and transfer effects of ASSIST were encouraging with respect to the effectiveness of computer-based inspection training, specifically in improving inspection performance.

To add more realism and interactivity to the inspection simulations, an immersive simulator called INSPECTOR was developed. INSPECTOR uses photographs obtained from an actual aircraft as textures in the cargo bay inspection simulation. The main environment consists of a simple wire-frame cube, texture-mapped to resemble the aft cargo-bay of the aircraft. The simulator along with the real environment it is representing is shown in Figure 2. Note that the simulator does not have any depth cues or shadows due to the use of textures in the image. The software is capable of interacting with a variety of input and output devices from fully immersive head mounted displays, to the keyboard and mouse. The instructor can customize the training scenarios using simple image manipulation software such as Adobe Photoshop. The instructor can modify the textures used in the scenarios to include defects such as cracks, corrosion broken conduits in the simulator. The performance of the subject in the simulator can be recorded and stored for later offline analysis. Process and performance measures such as accuracy, defects detected, defects missed and time to completion can be recorded and the subject can obtain feedback on their performance in the simulator [8].

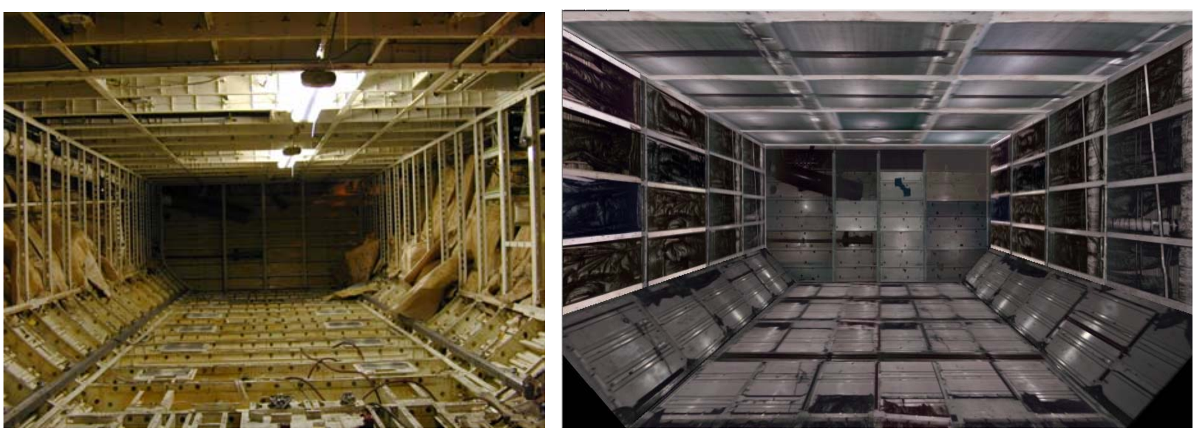

Figure 2: Actual cargobay(left) with the texture mapped cargobay(right).

In addition to using texture mapped environments in the simulator, it is also capable of rendering 3D models of the environment. The 3D model of the environment is built using Alias Wavefront Technologies [9] software called Maya and rendered on the desktop using OpenGL [10] and C++. The graphical user interface (GUI) presented to the user was developed using SDL and uses simple scripts to control the behavior of the simulator. Figure 3 shows the rendering of the 3D cargobay. Notice that the use of 3D models leads to a more realistic environment with shadow-casting lights and depth to the environment.

Another important simulator developed during this period is the borescope simulator. The borescope is a tool used to inspect the internal parts of the engine for defects such as cracks, stress fractures and corrosion. The borescope consists of a handheld unit and a long, flexible, fiber-optic cable as shown in Figure 4. The handheld unit consists of a full color LCD screen and a mini-joystick. The fiber-optic cable is connected to the tip of the handheld unit and has a camera and light source at the other end. The joystick controls the articulation of the fiber-optic tip attached to the unit. Preliminary user testing using the standard presence questionnaire [11] showed that the simulator Figure 5 is visually similar to the actual device [12]. Figure 6 shows the model of the engine blades developed for use in the borescope simulator.

Figure 3: Enhanced VR cargo bay model

Figure 4: Video borescope

Figure 5: Virtual borescope simulator

Figure 6: Engine blades modeled (right) from the actual engine (left)

Figure 7 shows the hardware setup of the lab at Greenville Tech with a participant using the inspection simulator. The hardware components include a Virtual Research HMD and 6 degree-of-freedom Flock of Birds tracker integrated with the helmet. User motion in the immersive environment is through button presses in the hand-held 6-DOF mouse. The mouse is also used to select and highlight defects within the environment, which are stored for later offline analysis of the subject's performance in the simulator. The WindowVR consists of a 17'' flat-panel, touch-sensitive display suspended from an immobile stand. The WindowVR consists of a 2-way directional joystick to control the motion of the subject in the VR environment and a 6DOF tracker embedded within the display to obtain the orientation. Notice that the simulator can be run on either the HMD or the WindowVR depending on the level of immersion required and the experience level of the student trainee.

Figure 7: User testing of the training scenarios; **a:** Window VR, **b:** HMD

4. Curriculum development and assessment

To integrate the different training simulators with the Aircraft Maintenance Technology curriculum, it was necessary to devise a curriculum development and assessment plan. Along with the training provided using the Virtual Reality simulators, the current educational material is enhanced by integrating a computer-based inspection training program focused on improving inspector performance entitled GAITS (General Aviation Inspection Training System) [13] into the curriculum. GAITS was developed using the task analytic approach for aircraft inspection that is anticipated to standardize and systematize the inspection process.

To facilitate an effective redesign of the curriculum, an appropriate assessment methodology had to be devised. This involved developing course objectives. Using Bloom's taxonomy descriptors [14, 15], goals for student outcomes at the course level were developed for a prototypical course. These address the nature of the desired outcomes, such as knowledge, comprehension, or analysis. These refined outcomes are used to organize daily topics, develop lesson plans, construct exercises, and develop supporting material, integration exercises, simulation tests, software support manuals and examinations. The methodology used to apply the Bloom's Taxonomic approach to the prototypical course is illustrated in Figure 8.

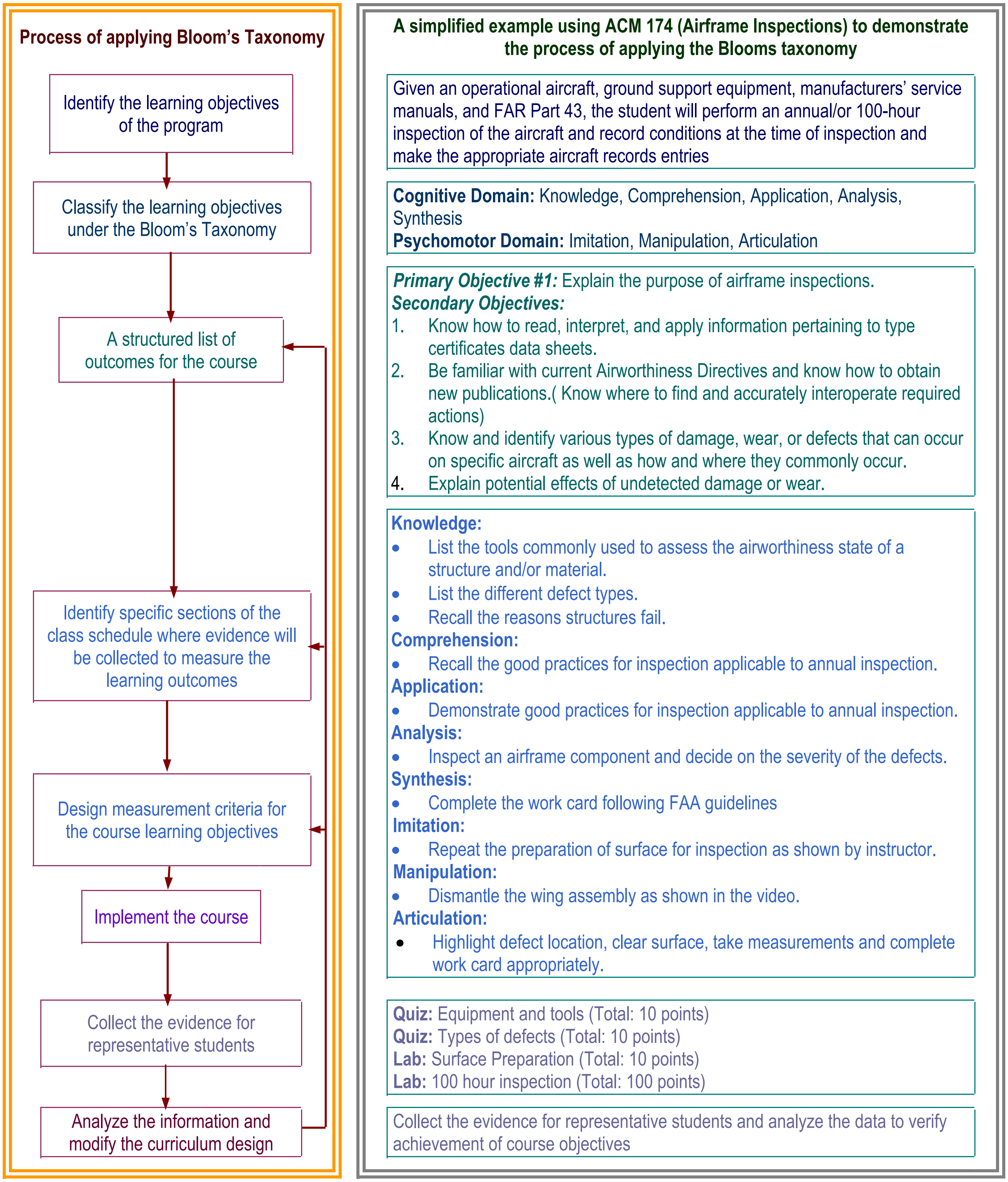

Figure 8: Applying the Bloom's Taxonomic approach to a prototype course.

5. Summary and conclusions

Existing multimedia approaches, while valuable, have not been able to mimic accurately the complexity of the aircraft maintenance process, reporting limited transfer capabilities and student preparedness for the workplace. As a result, students trained with this methodology face a steep learning curve in on-the-job situations where mistakes can have potentially catastrophic consequences. Providing students with the total immersion afforded by virtual reality will give them a more realistic, hence accurate, view of the airframe structure and complex inspection/maintenance environment, one that is more effectively internalized and transferred to the workplace. The integration of this technology in a systematic and scientific manner will allow us to study the impact of the different enhancements to the curriculum. This innovative research represents a much-needed first effort to extend tested VR technology to the aircraft maintenance technology curriculum in a two-year college allowing for a better understanding of the use of VR as a pedagogical tool. The successful completion of this research shows promise in fulfilling a state and national need for well-prepared technicians entering the aircraft maintenance industry. Most importantly results of this research can be extended to a broader range of SME&T areas thereby making significant impact on student learning.

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References

1. Federal Aviation Administration, (1999) Written Comments; Public Responses to the July 6, 1998, "Revision of Certification Requirements: Mechanics and Repairmen," Notice of Proposed Rule Making (Notice No. 98-5) FAR PART 66 NPRM.

2. Czaja, S.J., Drury, C.G. (1981), *Training Programs forIinspection*, Human Factors 23 (4), 473–484.

3. Latorella, K.A., Gramopadhye, A.K., Prabhu, P.V., Drury, C.G., Smith, M.A., Shanahan, D.E. (1992), *Computer-simulated Aircraft Inspection Tasks for Off-line Experimentation*, Proceedings of the Human Factors Society 36th Annual Meeting, Santa Monica, CA, 92–96.

4. Gramopadhye, A. K., Drury, C. G. & Sharit J. (1997), *Feedback Strategies for Visual Search in Airframes Structural Inspection*, International Journal of Industrial Ergonomics. pp 333-344.

5. Drury, C.G., Chi, C.F. (1995), *A Test of Economic Models of Stopping Policy in Visual Search,* IIE Transactions. 27, 382–393.

6. Kundel, H., Nodine, C., Krupinski, E. (1990), *Computer displayed Eye Pposition as a Visual Aid to Pulmonary Nodule Interpretation*, Investigative Radiology, 25, 890–896.

7. Nickles, G., Marshall, J., Gramopadhye, A. K. & Melloy, B. (2001), *ASSIST: Training program for inspectors in the aircraft maintenance industry*, International Encyclopedia for Ergonomics and Human Factors. UK: Taylor and Francis.

8. Vora, J., Nair, S., Medlin, E., Gramopadhye, A. K., Duchowski, A. T., & Melloy. B. J. (2001), *Using Virtual Reality to Improve Aircraft Inspection Performance: Presence and Performance Measurement Studies*, The Human Factors and Ergonomics Society Annual Meeting. Minneapolis, MN.

9. Alias Wavefront, Maya 3D modeling tool, www.alias.com, Last accessed 18 January, 2006.

10. OpenGL Graphics API, www.opengl.org, Last accessed 18 January, 2006.

11. Witmer, B.G., Singer, M.J. (1998). *Measuring Presence in Virtual Environments: A Presence Questionnaire*, Presence 7 (3), 225–240.

12. Vembar, D., Sadasivan, S., Duchowski, A., Stringfellow, P., Gramopadhye, A. (2005), *Design of a Virtual Borescope: A Presence Study*, Proceedings of 11th International Conference on Human-Computer Interaction, Las Vegas, NV

13. Jacob, R. J., Raina, S., Regunath, S., Subramanian, R. C., and Gramopadhye, A. K., (2004) "Improving Inspector's performance and reducing errors - The General Aviation Inspection Training Systems (GAITS)." In proceedings of the Human Factors and Ergonomics Society Meeting, New Orleans, LA.

14. Bloom, B.S. (1956). "Taxonomy of educational objectives: The classification of educational goals." Handbook I, Cognitive Domain. New York; Toronto: Longmans, Green.

15. Anderson, L.W., & Krathwohl, D.R. (2001),"A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives." New York: Longman.