A MOBILE APPLICATION OF AUGMENTED REALITY FOR AEROSPACE MAINTENANCE TRAINING

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Abstract

Aircraft maintenance technicians (AMTs) must obtain new levels of job task skill and knowledge to effectively work with modern computer-based avionics and advanced composite materials. Traditional methods of training, such as on-the-job training (OJT), may not have potential to fulfill the training requirements to meet future trends in aviation maintenance. A new instruction delivery system could assist AMTs with job task training and job tasks. The purpose of this research is to analyze the use of an augmented reality (AR) system as a training medium for novice AMTs. An AR system has the potential to enable job task training and job task guidance for the novice technician in a real world environment. An AR system could reduce the cost for training and retraining of AMTs by complementing human information processing and assisting with performance of job tasks. An AR system could eliminate the need to leave the aircraft for the retrieval of information from maintenance manuals for inspection and repair procedures. AR has the potential to supply rapid and accurate feedback to an AMT with any information that he/she needs to successfully complete a job task. New technologies that promote smaller computer-based systems make the application of a mobile AR system possible in the near future.

Introduction

Aviation maintenance facilities for general, commercial, and governmental organizations operate, inspect, and maintain complex aircraft structures and systems with many highly interrelated components. Many complex interrelated systems are necessary to maintain aircraft. The complex interrelated aspects of aircraft maintenance can be divided into four key categories: software, hardware, environment, and liveware. These four categories are often identified by the term SHEL [1]. Liveware refers to the human element of the aircraft maintenance system. Aircraft maintenance technicians (AMTs) are the liveware in the maintenance system.

The U.S. Government Accounting Office [2] reports that in the coming years this issue becomes much more critical as the majority of experienced AMTs will be replaced with much younger AMTs that lack experience and have minimal exposure to various defects and aircraft types. As work experience increases, AMTs develop a schema for visual inspection. The development of a schema assists with perceiving faults and helps technicians reason whether the item being inspected is airworthy [3]. Unfortunately, many years of experience are necessary for a novice AMT to develop a schema equivalent to that of an expert for visual inspection, fault recognition, and repair. Additionally, a large number of experienced AMTs will retire in the very near future, leaving novice AMTs in the hands of less knowledgeable mentors [2].

One key job task AMTs perform is visual inspection. This method of inspection allows room for innumerable errors due to the lack of human reliability and lack of training methods available to teach the skills for visual inspection. Visual inspection and the majority of aviation maintenance job tasks require perception and human reasoning. Unfortunately for AMTs, the search and decision making skills which involve human perception and reasoning are typically flawed [4]. The identification of components (e.g., fuel pump, oil pump, etc.) or the identification of faults (e.g., corrosion, cracks, distortion, etc.) requires the ability to perceive certain characteristics that should not exist for specific items. AMTs must take into account many characteristics of components in order to recognize faults when they are present. AMTs must identify the components, recognize the fault, (e.g., crack, corrosion, etc.) and reason whether the fault is critical through its characteristics (e.g., length, width, location) that are present [4]. Due to the aircraft's highly interrelated components and complex systems, it may be difficult for AMTs to identify the characteristics of all types of faults and subsequently troubleshoot various systems from one aircraft to another.

AMTs also conduct routine maintenance and replacement of parts; repair surfaces for both sheet metal and composite materials; and inspect for corrosion, distortion and cracks in the fuselage, wings, and tail [2]. Regardless of the task, aircraft technicians must always refer to the maintenance manual for the specific aircraft to obtain proper procedures and specifications. A great amount of time is spent searching for instructions, which increases maintenance time, worker stress, and decreases overall job performance. Neumann and Majoros identify that 45% of an AMTs shift is spent finding and reading instructional procedures for job tasks [5].

In order to increase passenger safety, minimize incidents, and accidents associated with aircraft maintenance errors, new computer-based technologies could be integrated into the training of AMTs. An augmented reality (AR) training system could possibly reduce errors associated with aircraft maintenance in two ways. First, AR could allow for an efficient method of retrieving information. The information retrieved could be the equivalent to an expert's recall from long-term memory. An expert in aviation maintenance can be defined as someone who has accomplished various aircraft maintenance tasks numerous times; often through a process of overlearning that leads to automaticity for regularly occurring job tasks. Errors are less likely to occur when experts perform a job task [5, 6]. Novice technicians are prone to error, especially under stressful conditions [5]. An application of an AR system that delivers expert levels of information in real time to novice workers in a real world setting could reduce job task related errors.

Second, AR could complement human information processing by facilitating a transition to expert levels of knowledge in a shorter span of time. The supply of efficient and effective feedback may reduce the likelihood of maintenance errors because AR could provide virtual objects that have locations associated with a real world environment [5]. When an AMT views a work piece (e.g., aircraft part or component) both real and virtual objects (e.g., text, flags, arrows, avatars, etc.) could be presented in one spatially integrated scene.

The aircraft maintenance infrastructure should consider the implementation of alternative training methods that could act as job performance aids. The aircraft maintenance infrastructure could benefit from new technology that allows information to become embedded into a system that an AMT uses while performing job tasks. Training has been identified as a primary intervention to improve the effectiveness, efficiency, and overall performance of AMTs. Unfortunately, traditional training methods, such as on-the-job training (OJT), may not be capable of fulfilling the requirements for future trends in aviation maintenance and training for maintenance; systems are becoming too complex to allow workers with a novice level of knowledge to perform maintenance. Additionally, expert AMTs are often too busy with maintenance tasks that are operationally necessary to divide their efforts between conducting OJT and their primary work function (i.e., aircraft maintenance).

Traditional OJT may not be able to provide the necessary training to novice technicians as it has done in the past. The sophistication of the aircraft alone demands new training interventions for AMTs [2]. The OJT environment (i.e., real world maintenance setting) may be an excellent choice for training AMTs if the proper feedback and appropriate information became readily available without having to leave the aircraft.

One way to reach the goal of delivering OJT at the aircraft is through the use of an AR system. AR is a machine vision and computer graphics technology that merges real and virtual objects into unified, spatially integrated scenes [7]. Unlike virtual reality, AR systems blend the real world and virtual world (e.g., objects, text) in a real-time environment [7]. AR may have the capability of assisting with meeting training needs and could eliminate training and recurrent training because cognitive tasks can be carried out for the human by the AR system. Therefore, it may be possible to design training functions into the AR system that are concurrent with the job tasks [5].

AMT Job Description and Certification

Job Description

AMTs work in a number of technical occupations, which include avionics, airframe, powerplants, and non-destructive testing. The majority of work occurs in hangars, on flight lines, and at certified repair stations. Aircraft maintenance requires a high level of physical activity and the physical demands can sometimes become grueling, strenuous, and may decrease work performance [8]. AMTs should be comfortable with heights and operating heavy equipment, along with squeezing into and working in tight confined spaces. Hangars tend to be noisy and hazardous work environments. These characteristics are attributable to moving aircraft and various types of equipment necessary to perform and accomplish job tasks.

Despite adverse weather, work conditions, heights, and harmful chemicals, AMTs must execute a standard of high workmanship and craftsmanship in accordance to certification. The majority of maintenance and minor repairs for scheduled airlines occur on the flight line. These factors are not often considered but do affect the performance and productivity of AMTs. These are only a few examples of the demands on an AMT. Aviation maintenance requires special attention due to the complexity of the aircraft; it is imperative that novice AMTs receive guidance during their training. An AR system could allow for a high level of workmanship and high work productivity at an early stage of a AMTs career (i.e., while working at a novice level).

Certification

The Federal Aviation Administration (FAA) provides the regulations for the certification of AMTs through a prescribed curriculum [9]. The FAA addresses experience requirements and states that each applicant must present proper documentation of certification from a school certified under Federal Aviation Regulation (FAR) Part 147 Aviation Maintenance Technician Schools, or provide evidence of:

(a) At least 18 months of practical experience with the procedures, practices, materials, tools, machine tools, and equipment generally used in constructing, maintaining, or altering airframes, or powerplants appropriate to the ratings sought; or,

(b) At least 30 months of practical experience concurrently performing the duties appropriate to both the airframe and powerplant ratings [9].

Subpart D 65.79 Skill Requirements of FAR 147, states that each applicant must successfully pass an oral and practical exam for the appropriate rating. The tests cover the applicant's basic skill in performing practical projects on the subjects covered by the written test for that rating. As an example of work required, an applicant for a powerplant rating must show his ability to make satisfactory minor repairs to, and minor alterations of, propellers [9].

Any further training for AMTs will consist of OJT, computer based training (CBT) and/or video-based training. Seminars may also be included into a training program. Generally, seminars and workshops are provided for employees of scheduled airlines. On occasion, general aviation facilities send their AMTs to workshops and seminars for new general aviation aircraft that have advanced technologies (e.g., glass cockpits and composite structures).

Traditional Methods of Training AMTs

Overview of Current Training

Typically following certification, AMTs receive training from the following three methods: OJT, computer-based training (CBT), and face-to-face training. These methods have proven useful and helpful throughout the years. Unfortunately, these training methods have limitations. The sophistication of aircraft technology and the reduced number of expert AMTs available to teach novice technicians is negatively affecting novice AMT training [2].

OJT

OJT is the traditional method for teaching maintenance inspection and repair. Unfortunately, OJT may not be the best method for training because the feedback to learners may be infrequent and unmethodical [3]. OJT may be viewed as an apprenticeship where a novice AMT is mentored by an AMT who is an expert. There are many reasons why the hangar environment may not be optimal for traditional OJT. First, the work environment tends to be stressful during aircraft inspection and maintenance. Organizational conflict can arise when training needs and operational needs compete for resources. Secondly, hangars are noisy because of operating equipment (e.g., ground power units, hydraulic pumps, compressors, etc.) necessary to perform job tasks. Thirdly, training various job tasks requires an explanation of theory, principles, and functions. The majority of senior AMTs specialize in aircraft maintenance, not instruction and theory, so training maybe suboptimal. Fourthly, many maintenance job tasks are in areas of confined space that allow access for only one AMT at a time; confined spaces make it almost impossible to teach certain job tasks with two AMTs colocated. Finally, complex job tasks may require repetitive training to ensure mastery of the associated skills. Difficult tasks, such as engine removal/replacement or engine overhaul, cannot be learned by a novice technician with a single explanation. These factors affect OJT by increasing worker/trainee stress, constraining available time, and decreasing employee work productivity.

At times, OJT may be an unstructured approach for learning job tasks. Often each AMT has an individualized way of accomplishing a task and subsequently he/she teaches the task in a unique way. These individual teaching methods and job task steps may not be captured in maintenance manual procedures. An AR system may permit standardization for training by allowing novice AMTs the ability to retrieve standardized training and guidance information.

AMTs visually inspect and perform routine maintenance (e.g., hydraulic filter changes, lubrication) in a timely fashion. Any discrepancies or non-routine repairs (NRR) found must be recorded up and corrected before the aircraft is returned to service. Usually during inspection, there are NRR's found, especially with aging aircraft. These discrepancies create more work to be accomplished in the same span of time, thus increasing time constraints and stress. Manufacturers prescribe work hours for maintenance job tasks. Some maintenance facilities offer incentives to AMTs that performed faster than the manufacturer prescribed time. Added pressure on AMTs can increase stress and reduce job performance.

Unfortunately, the pressure to accomplish job tasks and NRR's found increases stress, time constraints and reduces or eliminates the possibility for a novice technician to learn a task in an optimal learning environment [10]. Such circumstances are often found throughout aviation maintenance facilities. The implementation of OJT is less than optimal the majority of the time.

AMTs are expected to become productive in a short span of time after their arrival to a repair facility. This is a very high expectation with regard to the complex nature of the trade. AR may have the ability to provide a structure or framework with increased levels of standardization when compared to traditional methods of OJT.

Face-to-Face Training

Face-to-face training is conducted through seminars and workshops. Often seminars and workshops provide group training sessions to introduce new aircraft technologies. Face-to-face training is an effective way to teach new tasks, but time away from the workplace can be a negative factor. Seminars are usually no longer than a workweek long. New technologies (e.g., composite material repair and digital avionics repair) often require attendance to follow-up seminars in order for AMTs to fully learn the techniques associated with new technologies. Seminars and workshops can be effective, but these approaches to training cost companies lost work-hour time and reduced short-term productivity. Finally, seminars are typically more useful for experienced technicians that have knowledge of structural composite repairs and trouble shooting techniques; seminars reflect the operational need for expert AMTs to maintain complex aviation systems. They are often not designed to meet the needs of novice AMTs [2].

CBT

Computer-based training is typically designed as a tutorial or role-play scenario [11]. CBT programs can be interactive unlike video-based media. These training programs have been implemented to train AMTs. These applications have shown to be effective for training technicians [11]; however, CBT devices and video are located in a classroom environment, which may set limitations for application. Many tasks may be better learned in an actual work environment with the proper and necessary equipment. Furthermore, the majority of CBT cannot be tailored to fit the individual needs of the student.

Computer-based training is a regularly used instructional medium for providing an initial understanding of systems on an aircraft (e.g., landing gear, struts, generators, A/C packs etc.). Extensive job task training through the use of CBT is limited due to complexity and costs associated with developing and maintaining instructional material [11]. The need to capture various types of aircraft components and faults into video and/or CBT becomes an almost impossible task.

AR as a Training Medium

What is AR?

AR is any scene or case in which the real environment is supplemented using computer generated graphics. AR displays consist of a real environment with graphical enhancements known as augmentations. Milgram and Kishino [12] effectively defined AR and created a mixed reality continuum to classify AR's degree of virtual and real world element integration (see Figure 1).

Figure 1. Milgram's Reality-Virtuality Continuum [7]

Azuma [7, 13] defines the necessary properties that exist in an AR system. AR systems combine real and virtual objects into a mixed reality environment, running interactively, in real time, and accurately align real and virtual objects with each other. Azuma categorizes the components of any AR system into three subsystems: scene generator, display device, and tracking device.

AR may be identified either as an optical see-through technology or as a video-based technology. An optical see-through system employs a helmet or head mounted display (HMD) that allows the user to view the real world with a virtual world projected onto combiner lenses stationed in front of the eye. Video-based systems display the mixed reality world on a computer monitor. Both types of systems typically use an optical recognition approach for registering real and virtual elements into one spatially integrated scene [14].

The mobile AR system at Embry-Riddle Aeronautical University (ERAU) uses an optical recognition device to identify markers based upon binary numbers (see Figure 2). The markers are placed on the aircraft and on aircraft components. The AR system identifies the binary numbers. The scene generating function of the system and sends users virtual information in the form of text onto a see-through combiner lens the user can position in front of either eye (see Figure 3).

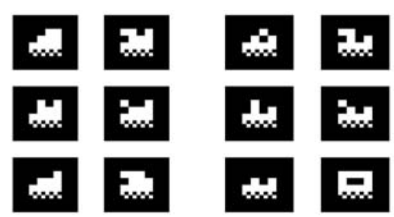

Figure 2. Markers for Optical-Based AR

AR has shown promise in a number of technical fields. AR systems have been used successfully in medicine to provide surgeons computer assistance for surgical procedures [15]. The laser projected AR system superimposes data onto the patient and assists surgeons by delivering virtual information to assist with the procedure [16]. Researchers are experimenting with AR systems to assist with architectural construction, inspection, and renovation [17] . The purpose of this study was to develop an AR system for improving the methods for construction, inspection, and renovation. The AR system was designed to guide workers through the assembly process of a space frame structure to make certain that each piece of the structure was properly assembled and fastened. This AR system directed the workers to the parts and verbal instructions indicate which part should be picked up for use. The worker scanned the item via a barcode to enable the computer to verify that the proper part was selected for use. Once the correct piece has been picked up, a virtual image was superimposed to visually guide installation. Computer generated verbal instructions detailed how to correctly install the component [17].

AR could assist in the same manner with aircraft maintenance (see Figures 3 and 4). As with the surgical procedures in medicine and the guidance procedure with architectural design, AR systems have the potential of superimposing the necessary information for a job task on a work piece in real time. AR could allow the user to access any maintenance procedures and inspection criterion in a real world work setting. The amount of time spent retrieving information from the maintenance manuals to assist with the sensation, perception, and reasoning of faults for troubleshooting, removal and repair could be eliminated.

AR Paradigm for Training AMTs

The aircraft maintenance infrastructure could benefit from the use of a new instruction delivery system. The use of an AR system may save time and reduce the cost of training and retraining of certain psychomotor and cognitive tasks (e.g., troubleshooting system malfunctions). These types of highly technical procedures must be reintroduced in order to keep technicians current. One important goal of AR is to provide scenes that are annotated with information that is acquired through training along with supporting novice AMTs with inspection tasks that are rarely encountered.

Neumann and Majoros [5, 14] propose that an AR system will complement human information processing during the performance of an aerospace maintenance task by controlling attention, supporting short and long-term memory, and aiding information integration [14]. Some of the positive benefits of an AR system include improved recall, control of attention during training, and can provide concurrent training. Furthermore, AR could assist with the removal and repair of items by graphically depicting the necessary information over the real world without having to leave the aircraft.

An AR system could assist with a number of training methods for aircraft technicians. The AR system will supply all the necessary information including location, description, function, and the necessary instruction for inspection, troubleshooting, removal and repair. AR could generate rapid feedback allowing for a faster development of a schema than with traditional OJT. AR could drastically reduce the time necessary to perform inspections and repairs. All inspection lists, fault attributes, and trouble shooting techniques have the ability to exist over the real world.

Figure 3. Mobile Augmented Reality System with Helmet Mounted Display at ERAU

Figure 4: Oil Pump Labeled with Markers for Optical Recognition

AR could also facilitate a standardization of training. Training is conducted differently by various organizations. AR could not only standardize training, but may also redefine OJT by generating rapid and accurate feedback to allow for self-instruction. This method could be ideal for training new technicians entering the field of aviation maintenance. The system has the capability of allowing novice technician to retrieve information equivalent to an expert in the field. Additionally, in the case of AR-based training, skills first acquired in a mixed reality setting would serve for subsequent skill application in the real world and this may redefine how workers are trained [15]. Majoros and Neumann [14] propose that an AR system will make some training methods needless because of the computers ability to complete cognitive tasks for the user.

Cognition, Recall, and Long-Term Memory

An AR system aids in the interface of multiple senses, which is believed to complement human information processing by aiding information integration through multi-modal sensory elaboration [18]. AR can create a framework associated with the specific job task that facilitates learning and aids recall. Researchers at ERAU [18, 19] propose that the multi-modal elaboration occurs through the use of the multiple senses that include visual, spatial, proprioceptive, and audio. Furthermore, the combination of the visual and spatial senses could allow AR to force learning advantages by amplifying subject material through multiple channels of memory [20].

Neumann and Majoros [5] propose that the virtual objects associated with the work piece (e.g., oil pump, fuel pump, etc.) are the basis for a link into memory. The links are referred to as an array of graphical descriptions in a work piece. The scene created by AR through the real and virtual world may create the framework for AMTs to remember lists of items. AR may allow for an increased probability of storing information into long- term memory. Proper encoding of information could also aid in the recall process. The virtual text labels or virtual overlays in general, become associated with the real world object and encoded into memory as one visual image. In addition, Neumann and Majoros [5, 14] propose that spatial cognition is a fundamental element of AR and of the learning process. AR could complement the spatial cognition of aircraft technicians by combining text and the real object without the need to view external sources (e.g., CD-ROM or microfiche) to gain instruction for the task. In return, a successful interpretation and relationship could exist between human and machine allowing for more effective and efficient inspections and repairs.

Experiment

Purpose

The purpose of this research is to teach a selected job task from a 100 hour inspection checklist in accordance with Appendix D of the Federal Aviation Regulations [9]. The research to be conducted in the Spring of 2006 will be a follow-up study to replicate the findings of other researchers at ERAU [21]. The task will be to inspect the propeller mounting bolts and safety wire for signs of looseness on a Cessna 172S.

Design

The experiment will consist of 36 ERAU students. Participants for this study will be randomly drawn from the population of students undergoing AMT training and initial certification at ERAU. The experiment will measure the effects of an AR training paradigm as it compares with the traditional learning paradigms of print-based material, video-based material. The participants will be randomly assigned to one of the three groups. The experiment is a three-way between subjects, or a 3 x 2, design. There are two independent variables. The first independent variable is represented by the mode of information presentation and it has three levels, or factors. The factors are: video-based presentation, AR-based presentation, and print-based presentation. The second independent variable is represented by time and it has two factors. The factors are a three-minute break in time prior to the post-instructional recall test and a seven day break in time prior to the long-term retention recall test. The dependent variables for this study are immediate recall and long-term recall. Alpha is set to .05.

Procedures

The participants will be randomly assigned to a group on the given day of experimentation. The participants will be given a synopsis of the purpose and procedures for the experiment. Consent forms will then be required in order to participate. After consent has been given, the participants will be given a test to determine visual acuity. The 36 participants will be divided into groups of 12 and each will be given instruction for their assigned group. Each group will then be given an eight-minute instructional session to learn about the propeller, its mounting bolts, and associated safety wire. The participants will then be given a recall test to measure how much knowledge was gained through the instructional delivery mode they used. A second recall test will occur seven days later. The test will be the same as the immediate recall test; the purpose of the second test is to measure how much information the participant is able to recall from long-term memory.

Conclusion

The aircraft maintenance system relies on a complex system of systems often analyzed with the SHEL model [1]. The liveware element of the SHEL model, the AMT, is central to a successful maintenance effort. Standardization of training is needed and consideration must be given to alternative methods for teaching job tasks and training AMTs. The traditional methods of training have proven useful throughout the years. However, these methods may not be suitable for future trends in aviation. Advanced training methods become important with development of highly sophisticated aircraft and aircraft systems. In order to maintain a high standard of safety that minimizes incidents and accidents associated with aircraft maintenance, more emphasis should be placed on training AMTs [2]. Furthermore, a great deal of time is spent retrieving instruction for job tasks. AR may eliminate the time spent retrieving information by supplying the important information associated with aircraft maintenance while eliminating the need to leave the aircraft.

An AR system has shown promise in a number of technical fields, such as medicine and architectural construction and renovation. Aircraft maintenance could benefit from AR, as have the surgical procedures in medicine, by superimposing virtual data onto the aircraft and its components. AR could also reduce the cost of training and retraining by configuring the real world work setting and real world work piece into a training medium. The system can incorporate any required training criteria to allow novice AMTs to train on the actual aircraft. The AR system could allow novice technicians to retrieve information equivalent to an expert's retrieval from long-term memory.

AR may also complement human information processing during the performance of aerospace maintenance tasks by controlling attention and aiding recall through multi-modal sensory elaboration. The combination of the visual and spatial senses could allow AR to facilitate learning by amplifying subject material through multiple channels of memory. AR may increase the probability of encoding information into long-term memory, thus aiding in information recall.

An AR system could provide the method of training AMTs necessary to meet the advanced needs of sophisticated aircraft systems. AR has the ability to structure OJT. This can be accomplished by incorporating various training needs that are necessary for training AMTs. AR could give novice technicians the ability to receive training on real work items by delivering vital information needed to accomplish job tasks.

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