Evaluation of Interaction Devices for Projector Based Virtual Reality Aircraft Inspection Training Environments

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Abstract. The Aircraft maintenance and inspection is a complex system wherein humans play a key role in ensuring the worthiness of the aircraft. Traditional visual inspection training consisted mainly of on-the-job training (OJT). While OJT provides novice inspectors with the hands-on experience critical to effective transfer, it lacks the ability to provide real-time feedback and exposure to various scenarios in which to inspect.

With advances in technology, computer simulators have been developed to train the novice inspector and reduce the learning curve inherent with transitioning from the classroom to the workforce. Advances in graphics and virtual reality (VR) technology have allowed for an increase the sense of involvement in using these simulators. Though these simulators are effective, their deployment in aircraft maintenance training schools is limited by the high cost of VR equipment. This research investigates the effectiveness of different interaction devices for providing projector based simulated aircraft maintenance inspection training.

Keywords: computer input devices, industrial inspection, virtual reality, human computer interaction.

1 Introduction

Human inspection reliability plays an important role in guaranteeing the airworthiness of the aircraft fleet. Training has been found to be a useful tool in improving the reliability of the human inspector. Previously, this training consisted mainly of on-the-job training (OJT). However, with advances in technology, computer simulators have been developed to train the novice inspector in the inspection procedures and reduce the learning curve inherent while transitioning from the classroom to the workforce. Using advances in graphics and virtual reality technology, there is an increase the sense of involvement in using these simulators. Research conducted at Clemson University has investigated the use of virtual reality (VR) for aircraft maintenance inspection training and has been successful in demonstrating that there is significant performance improvement following training. The above mentioned

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inspection training simulator is immersive and was implemented using a head mounted display (HMD) and a 6-DOF mouse. Development of virtual reality (VR) simulators has kept up with the advances in technology and there is a tendency to fall into the trap of ‘gold plating’. This results in the technology being expensive and its benefits are lost as the colleges and small aviation maintenance firms can’t afford to implement such solutions. There is a need to have a selective fidelity approach to find the trade-offs in using VR simulators for training. As a first step to address this problem, current research evaluates the level of presence experienced by participants performing a visual inspection task using a VR cargo-bay simulator at different levels of immersion ranging from complete immersion using a HMD (Head Mounted Display) to a very low level of immersion using a basic desktop. As a part of this study, different interfaces need to be developed for the simulator for the different levels of immersion fidelity conditions to find the best interface for each display condition. Projector based VR is becoming popular and has an advantage as most classrooms already have the equipment. The challenge in implementing projector based VR lies in the trainee’s interaction with the VR environment. This research investigates the effectiveness of different interfaces using a modified off-the-shelf gamepad for providing projector based simulated aircraft maintenance inspection training.

2 Background

Aviation industries need qualified and proficient aircraft maintenance technicians to keep aircraft in peak and safe operating condition, by performing scheduled maintenance, making repairs, and completing inspections required by the Federal Aviation Administration (FAA). Growth in air traffic, due to anticipated economic and population growth, coupled with the need to replace retiring experienced aircraft maintenance technicians, are two factors contributing to the strong employment outlook [1, 2]. Unfortunately, aircraft technical programs and curricula have not kept pace with technology changes to the aircraft and the maintenance environment. Most importantly, students do not receive hands-on inspecting experience and, as a result, are not adequately prepared for the transition to the workplace. A major limitation has been the inability of the programs to create realistically the experience of the complex aircraft maintenance environment, especially wide-bodied aircraft. Most schools do not have hangars to house such planes and the cost of having a wide-bodied aircraft is prohibitive. Further emphasizing the problem, the training provided to students on smaller aircraft does not necessarily transfer to wide-bodied aircraft. Thus, students trained via traditional methodology 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 [3]. A system is needed that realistically mimics the complex aircraft maintenance environment for use in the education and training of aircraft maintenance technicians. In response to this need, recent research efforts have looked at closing this gap by using technology to bring the complex wide-bodied aircraft maintenance environment into the classroom.

Visual inspection by humans is a widely used method for the detection and classification of nonconformities in industry. In the aviation industry, sound aircraft inspection and maintenance are an essential part of safe and reliable air transportation. Aircraft inspection is a complex system with many interrelated human and machine components [4]. 90% of all aircraft inspection is visual in nature conducted by human inspectors [5]. Thus it is critical that a high level of inspection performance is achieved but human inspection is not 100% reliable [6, 7]. It is critical to deploy strategies that will reduce human error and improve human performance. Human inspectors have the flexibility to adapt to various tasks and scenarios and improving their inspection process could increase their effectiveness.

Training has been shown to be effective in improving visual inspection performance [8].

With computer technology becoming cheaper, the future will bring an increased application of advanced technology in training. Many of these training delivery systems, such as computer-aided instruction, computer-based multimedia training, and intelligent tutoring systems, are already being used today.

In the domain of visual inspection, the earliest efforts to use computers for off-line inspection training were reported by Czaja and Drury [9], who used keyboard characters to develop a computer simulation of a visual inspection task. Since these early efforts, low fidelity inspection simulators with computer- generated images have been used to develop off-line inspection training programs for inspection tasks [10]. Similarly, human performance using a high fidelity computer simulation of a printed circuit board inspection has been studied [11] while another domain which has seen the application of advanced technology is radiology.

However, advanced technology has found limited application for inspection training in the aircraft maintenance environment. Currently, most of the applications are restricted to complex diagnostic tasks in the defense and aviation industries. The message is clear: we need more examples of advanced technology applied to training for inspection tasks, examples that draw on proven principles of training.

The use of offline virtual reality (VR) technology has been studied to overcome the problems with inspection errors and the limitations of 2D simulators [12]. Virtual reality (VR) technology offers a promising approach. It has been shown that in aircraft inspection tasks there are positive transfer effects between virtual and real world environments [13]. In addition, the participants who experienced high involvement in the simulator felt that these experiences were as natural as the real world ones. Using VR, the research team can more accurately represent the complex aircraft inspection and maintenance situation, enabling students to experience the real hangar-floor environment. The instructor can create various inspection and maintenance scenarios by manipulating various parameters 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. The trainee can be exposed to the various defect types and locations before they move on to the inspection of an actual aircraft. In a VR simulator, the trainee can receive performance feedback in an inspection task, during and after the task. Process feedback can also be provided to the trainee after task completion.

For virtual environments, presence, the subjective experience of being in one place or environment even when physically situated in another, becomes the most important criterion. The success of using VR as a tool for training and job aiding therefore should be highly dependent on the degree of presence experienced by the users of the virtual reality environment. The problem with the design of training systems using VR is that designers attempt to replicate as many physical and functional stimuli as possible in the training device. This leads to the devices getting too expensive and there is also the risk of them having higher fidelity on some aspects than others based on the available technology that could lead to ineffective simulators. The higher fidelity in control interfaces can add additional workload that may be detrimental to task performance and learning. It is thus necessary to evaluate the design and carefully determine the extent to which fidelity should be built in. Here the concept of selective fidelity [14, 15] can be used which would be more focused on trainee learning requirements than on analytical and technological shortcomings.

3 Methodology

This research looks at the effect of control fidelity on task performance and presence in a virtual reality aircraft inspection training simulator based on a projector based display. A modified Witmer and Singer [16] Presence Questionnaire is used to assess presence and inspection accuracy is used to assess task performance.

3.1 Participants

This study used 18 volunteers from Clemson University as participants. The age of the participants ranged from 22 to 36 years. They were screened for visual acuity (20/20 natural or corrected) and color vision. It has been demonstrated [17] that student subjects can be used in lieu of industrial inspectors.

3.2 Stimulus Material and Equipment

There are two key control aspects which must be considered for interaction with the simulator: the first is the user's ability to change view and the second is his ability to select targets. In the HMD-based VR simulator, trainee manipulated his view of the environment by naturally walking and looking around in the environment, as the view was mapped to the position and orientation of a 6DOF tracker attached to the HMD (Figure 1). Additionally, the trainee selected defects using a cursor controlled by a hand held 6-DOF mouse. In the projector-based VR simulator, the trainee's position and orientation is fixed (facing the screen) and the view is limited to the display on the screen. To manipulate the environment in the projector-based VR, the trainee must consciously change the view. Three interaction techniques were prototyped and evaluated for interacting with the projector based simulator.

The principal hardware components are described as follows. Ascension Technology Corporation's Flock of Birds (FOB) tracking system is used for rendering the virtual scenario with respect to the participant's movements where applicable. A 1024x768 resolution projector, displaying the VR environment on a screen approximately 12 feet in front of the participant was used while the control interface was a Gravis Eliminator Pro gamepad (Figure 2) which has a directional D-pad joystick and 10 buttons. In all the conditions, the simulator is launched on a 1.5GHz dual Xeon processor Dell personal computer with an NVidia GeForce 6800 Ultra graphics card, running the Linux (Fedora Core 4) operating system.

In all three interface conditions, the buttons 1-4 on the gamepad were used to control the motion of the user – step left, right, front and back - which can be compared to walking in the VR environment. This control was available at all times. The participant selected defects by guiding the targeting cursor onto the defect and pressing button 5 on the gamepad.

The first interface (A) is the lowest fidelity control condition. Here the manipulation of the D-pad joystick was used to change the view of the environment – rotate left, right, up or down - relative to the original view. This can be compared to the head orientation in the HMD. The targeting cursor was fixed at the center of the display. The user had to manipulate the environment to align the defect with the targeting cursor and press button 5 on the gamepad for defect selection.

The second interface (B) the user could manipulate both the environment and the targeting cursor. The joystick was overloaded to provide both orientation and targeting information. The trainee would have to switch between using the joystick to change the view of the environment and controlling the cursor to target defects on the screen. This was accomplished by having the participant depress button 6 to toggle between the orientation and targeting control. In the orientation control mode the manipulation of the joystick was used to change the view of the environment – rotate left, right, up or down - relative to the original view. In the targeting mode, the trainee selected defects by guiding the targeting cursor onto the defect and pressing button 5 on the gamepad. The orientation was fixed in this mode but the position controls (buttons 1-4) were active.

Fig. 1. HMD

Fig. 2. Gravis gamepad

Fig. 3. FOB tracker

The third interface (C) was the highest fidelity control condition. In this control condition, the orientation information was streamed from the Flock of Birds (FOB) tracker (Figure 3) and the manipulation of the gamepad was used to change the view of the environment. Rotating the gamepad left, right, up or down caused the orientation to rotate left, right, up or down relative to the original view. In this interface, the targeting cursor could be controlled by the D-pad joystick and defects were selected by pressing button 5. The cursor could be controlled concurrently with the orientation control. In addition to this, by depressing button 6 the participant can toggle to a mode in which the orientation is fixed and the targeting cursor can be controlled using the joystick for target selection within the view. Depressing button 6 toggles the stat of the interface and the orientation control is activated mapping the current position of the gamepad to the orientation of the scenario.

Fig. 4. Aft cargo bay

Fig. 5. Familiarization scenario

The scenarios used in this study are variations of a virtual reality model of an aircraft aft cargo bay similar to the one in a Lockheed L1011 aircraft (Figure 4).

Five variants of the cargo bay scenario were used for this study: A familiarization scenario (Figure 5) with the different types of defects highlighted was the first scenario. The purpose of this scenario is to familiarize participants with virtual reality and to allow them to become accustomed to the cargo bay environment. This scenario also presents highlighted examples of the five different types of defects used in the study. Defect types are crack, corrosion, broken electrical conduit, abrasion and hole.

The second scenario was the selection training scenario (Figure 7) where the trainee could get acclimated to the control interface and practice manipulating their view in the environment. This scenario also displayed various targets in the cargobay environment which the participants could practice selecting using the defect selection mechanism.

Fig. 6. Selection training scenario

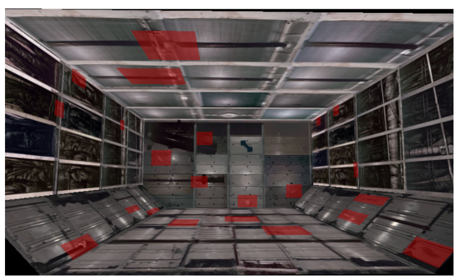

Fig. 7. Inspection task scenario

Participants perform the inspection task using three additional multiple defect inspection scenarios. These scenarios (Figure 7) were constructed to be equivalent in task difficulty (identical distribution of defect types and similar locations) and contain twenty-two defects of the five above-mentioned types.

3.3 Procedure

The participants were first asked to complete a consent form, a demographic questionnaire, and given instructions to ensure their understanding of the experiment. All the participants were then immersed in the familiarization scenario to familiarize them with VR, the cargo bay environment, and the different types of defects. This was followed by introducing the participant to the control mechanism followed by a two minute manipulation and defect selection practice scenario with the first interface. They were then asked to perform an inspection task in a multiple defect environment using the same interface. The task involved the participants searching for defects in the virtual inspection scenario. Once they found a defect, they marked it in the scenario by using the target selection mechanism. If the selection was correct, the defect was then highlighted in red. The task was a paced task limited to 5 minutes. A subjective questionnaire was administered after this. This process of defect selection training followed by the inspection task followed by the questionnaire was then performed by the participants with the second interface and so on for all three interfaces. The order in which the participant encountered each of the interfaces was counterbalanced. One of the multiple defect inspection scenarios were presented for each inspection task. The three multiple defect inspection scenarios were counterbalanced to assure that the inspection task was performed an equal number of times in each of the task scenarios for each interface condition.

The questionnaires used for evaluating the participant's perceptions of the interfaces and the training environment were recorded on a 5 point Likert Scale, with 1 being strongly disagree, 5 being strongly agree, and 3 being neutral. A majority of the questions dealt with the perceived ease of use of the interface for navigation within the virtual environment as well as the interaction capabilities or short-comings of either of the input devices for defect selection. The results of the data collected are presented in the next section.

4 Results

4.1 Performance Measures

The mean number of hits for each condition is as shown in Figure 8. The results were analyzed initially using an ANOVA using the PROC MIXED procedure in SAS V9. There was no significant difference found between the three interface conditions for the number of correct defect selections (Hits).

4.2 Subjective Measures

The subjective questionnaire (Table 1) was administered after each interface condition. The scores were analyzed for each question using a Friedman Test on the interfaces blocking on the participants. Then (if significant) a Fisher's protected LSD procedure was used to compare the pairs of means. There was no significant difference between the three control conditions except for questions 6 and 12. The LSD procedure applied to the two questions showed that all the conditions were significantly different. For question 6, interface B scored higher than A and interface

C scored higher than both A and B. For question 12, interface C scored higher than A and interface B scored higher than both A and C.

Table 1. Subjective Questionnaire

1. The environment was responsive to the actions that I initiated.
2. The interactions with the environment seemed natural.
3. I was involved by the visual aspects of the environment.
4. The mechanism which controlled movement through the environment seemed natural.
5. I was able to anticipate what would happen next in response to the actions that I performed.
6. I could examine objects from multiple viewpoints.
7. I was involved in the simulated inspection experience.
8. The control mechanism was distracting.
9. There was no delay between my actions and expected outcomes.
10. I adjusted quickly to the interface used for the virtual environment experience.
11. I felt proficient in moving and interacting with the virtual environment using this interface.
12. I could effortlessly manipulate the mechanism for defect selection in the virtual environment.
13. It was easy for me to select defects using this interface.
14. The control devices interfered with performing the task.
15. I could concentrate on the task rather than on the mechanisms used to perform the task.
16. I would personally prefer this interface for inspection training using virtual reality.

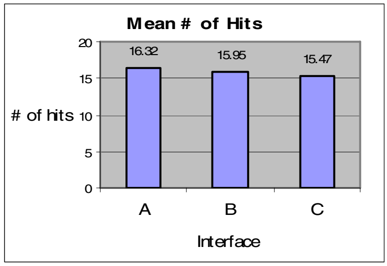

Fig. 8. Performance Measures

5 Discussion

Based on these results we see that there was no difference in the participants' performance for the different control fidelity conditions. This could be explained by the additional workload experienced by the participants in using the higher fidelity interfaces that may have negated the benefits of greater control in the paced task.

The participant's perception of presence in the environment seems to be equivalent with the three control conditions. Increasing the control fidelity allowed for greater interaction with the environment and this was perceived by the participants in their response to question 6. In interface B, independent control of the targeting cursor allowed the participants to select a defect from multiple orientations while the FOB based interface in addition allowed for quick movements allowing greater control of the orientation.

The results of Question 12 are slightly surprising as the FOB based interface had concurrent control of the cursor using the D-pad joystick with the orientation control using the FOB. This could be explained by the experimenter's observation that some participants tended to not use the concurrent control of the cursor. The combination of the two control levels of the targeting cursor using the joystick (concurrent or in fixed orientation mode), and the orientation control using the gamepad may have induced a high level of workload in the search task and the participants may have chosen to discard the higher level of interaction control to optimize the workload level [19].

During the debriefing session at the end of the experiment, the participants noted that they had difficulties in targeting the cursor while using the first interface in which it was fixed at the center. Although many participants found this interface the easiest to get used to, they complained of lack of fine cursor control and hence frustration with selecting defects in the environment. In the second interface, when they had control over the environment versus the cursor movement, they observed that the selection process was much simpler than the first interface. However, some participants noted that it would have been helpful to have a visible toggle notification to inform them of the mode they were presently in. Some participants also noted that although they had to repeatedly look down at the gamepad to ensure that they were pressing the correct buttons due to their inexperience with the gamepad, they got used to the interface after a while. In case of the third interface, since many of the participants had not used an immersive VR environment before, found that they needed some time to get acclimatized to the controls in the environment. While they found that the FOB was responsive to their actions, they suggested that they had difficulties in manipulating the cursor and the gamepad simultaneously, especially while looking up at the ceiling. They observed that they had to overcome this effect by using the toggle button to freeze the frame and then selecting defects.

6 Conclusion

Based on these results revisions are made for the design of the prototype interaction devices for the projector based virtual reality aircraft inspection simulators. Considering the complexity and cost of the FOB based gamepad interface, it is recommended to explore other off-the-shelf solutions to interact with the projector based environment. New video game control devices can be explored to enhance the fidelity of the regular gamepad interface. The Wiimote from Nintendo and Sony's PS3 controller can be explored for providing enhanced orientation and position information. In addition to evaluating performance and presence, it is recommended to evaluate workload while evaluating these interfaces.

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