Simulating On-the-Job Training using a Collaborative Virtual Environment with Head Slaved Visual Deictic Reference

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Abstract

Aircraft inspection is a vital element in assuring safety and reliability of an air transportation system. The human inspector performing visual inspection of an aircraft is the backbone of this process. Training of inspectors is an effective strategy to improve their inspection performance. A drawback of present-day on-the-job training provided to aircraft inspectors is the limited exposure to different defect types. Current research combines the advantages of virtual reality (VR) technology that includes exposure to a wide variety of defects and the one-on-one tutoring approach of on-the-job training by implementing a collaborative virtual training environment. Avatars are used to represent the co-participants in an immersive collaborative virtual environment (CVE). In a CVE, information of where the trainer is focusing can be provide to a trainee as visual deictic reference (VDR) slaved to the head orientation of the trainer. This study evaluates the effectiveness of simulating on-the-job training in a CVE for aircraft inspection training, providing VDR slaved to the trainer's head orientation. Results show that the training was effective in improving inspection performance.

1. Introduction

The air transportation industry is under intense pressure to provide safe and stable aircraft. Part of that safety is ensured by the many human inspectors that regularly search these aircraft for faults, defects, and potential hazards. Training has been found to be a very effective means of improving an inspector's performance [1]. The primary source of training for these inspectors occurs on the job. Unfortunately, this method of training has a number of drawbacks. For example, on-the-job training (OJT) does not allow for effective feedback or proper exposure to different types of defects.

Virtual reality (VR) has been used as an effective training tool since it enables the user to perform under a number of different and controlled scenarios and provides exposure to a wide variety of defects. Previous studies [2, 3, 4] have identified offline training within a virtual environment to be effective in improving aircraft inspection performance. This research carries the use of VR as a training tool further and investigates the effectiveness of using a collaborative virtual environment (CVE) for simulating on-the-job training in a synthetic aircraft inspection environment. A CVE allows for the co-immersion of both the trainer and the novice inspector in a virtual aircraft environment facilitating real-time training. The ability of the participants to communicate and collaborate while performing search task in the shared environment influences the success of such a training system. The presence an animated character or an 'avatar' representing the position and orientation of the collaborators in a virtual environment facilitates learning by simulating the visual aspects of human interaction in a shared environment. Even avatars with rather primitive expressive abilities have the potential to create a strong sense of collaboration in a CVE system. As avatars take on a personal role, thereby increasing the sense of togetherness, it is important that they realistically embody human nonverbal communication [5]. The avatars used in the CVE in Clemson University's Virtual Reality Eye Tracking laboratory are capable of torso movements along with head and eye rotations for effective collaboration.

In a collaborative training task, there is a need for additional communication tools in order to display what one is looking at or referencing. Such a tool can be provided by deictic references, visual, verbal or both. Past studies have demonstrated the importance of deictic references in a desktop CVE [6] for understanding the co-participant's perspectives. Verbal deictic references alone can lead to miscommunication and disorientation. Thus there is a need for visualization of the deictic references of the participants in order to determine what a co-participant is referring to, and where and what they are looking at.

Visualization techniques like a light-spot or extending a light ray from the users' hand have been used previously. Additionally, research has shown that the point of emergence (e.g. head slaved, gaze slaved etc.) of such a visual deictic reference (VDR) has an impact on the performance of the participants of the CVE performing a collaborative task. Head orientation has been shown to be a good indicator of focus of attention and it has been seen that head orientation contributes greatly to the overall gaze direction. This research explores the use of VDR for providing training in a CVE and this paper describes a study which evaluated its effectiveness using VDR slaved to head orientation.

2. Methodology

2.1 Subjects

This study used 16 students enrolled at Clemson University as participants. They were screened for visual acuity (20/20 natural or corrected with contact lenses), color vision, and our ability to calibrate an eye-tracker with the participant's eye movements. It has been demonstrated [7] that student subjects can be used in lieu of industrial inspectors.

2.2 Technical Details

The experimental was conducted using the Virtual Reality aircraft inspection simulator [8] developed at Clemson University. The virtual environments are driven by a 1.5 GHz dual-CPU PC with 1GB RAM and an NVidia GeForceFX 5950 graphics card running Red Hat Linux (v8.0 Kernel 2.4.20). Multimodal devices in the lab include V8 Virtual Research head mounted displays (HMD) (Figure 1) that offer 640x480 pixel resolution for each eye, with separate video feeds for the left and right eyes and a 75.3º x 58.4º visual angle. HMD position and orientation is measured using an Ascension Technologies 6-degree of freedom (DOF) Flock of Birds electromagnetic tracker, mounted on the top of the HMD. A binocular eye-tracker (Figure 2) is integrated within one of the HMD's. The eye tracking unit is a video based, corneal reflection unit, built by ISCAN. A 6DOF mouse (Figure 1) is used either as a virtual wand for pointing in the CVE or for selecting defects in an inspection task scenario.

Figure 1. HMD and 6-DOF mouse

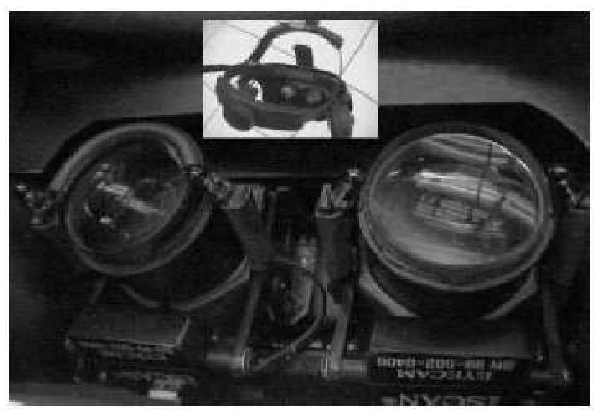

Figure 2. Binocular eye tracker optics in HMD

Vspec, Inspect and Inspector are the software components used in this study, custom developed by Clemson University researchers. The Inspector program displays the VR scenario to the participants while recording their eye movements. Vspec performs offline analysis of the participant's point of regard (POR) data. The CVE is enabled by Inspect. Furthermore, no data is recorded in the CVE.

Our CVE was implemented by extending a single-user virtual environment to two or more participants. Our shared state repository model is realized by a client-server architecture (star topology), where many clients can connect to the central server. The server contains the only truly valid copy of the world and all world logic runs on the server. Clients enqueue user/world input, and then send these input requests to the server. The server then processes each input, and pushes a new world state to each client. To compensate for the delay between sending new input to the server and receiving an updated world state, each client attempts to predict future world states. Multithreaded clients manage the head position and orientation and eye tracking devices only when these devices are active. The client can be thought of as a specialized dumb terminal, since the only processing it performs (other than marshaling user input) concerns representation of the world to the user.

Avatars (Figure 3) used in our CVE [9] are based on MD3 models (model format courtesy of Id Software). Each avatar's eye direction is mapped from the tracked point of regard (POR) of the avatar's human counterpart. Furthermore, since our eye tracker returns (0, 0) during blinks, we model the avatar's eye blinks by texture mapping a closed eyelid during blinks. Other than the eye movements, the avatars are capable of head rotation and torso movements which follow predefined animation sequences based on the position of the HMD tracker.

Visual deictic reference for the novice is slaved to the orientation of the tracker in the HMD of the expert and is implemented by displaying a small red dot (Figure 3) at the point of intersection of a ray cast by the head orientation and the virtual scenario. The expert gets real time feedback of where he is pointing, i.e. the VDR he provides to the novice, in the form of a blue dot. Head-slaved deictic reference conveys the orientation of the novice's gaze to the expert. Thus, both of the participants in the CVE are provided information regarding what the other person is looking at thus, allowing for the expert to ascertain that he is communicating effectively.

Figure 3. Avatar of trainee in CVE as viewed by trainer and the avatar of the trainer

2.3 Stimulus

The scenarios used in this study were 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 (Figure 5) were used for this study. The familiarization scenario was the first scenario, which familiarized the participants with virtual reality and allowed them to become accustomed to the cargo bay environment. This scenario had all the different types of defects highlighted in red boxes with their names beside them. Three inspection scenarios used -- two multi defect task scenarios for the pre-test and post-test and one scenario for the training session in the CVE or the exposure session -- were developed to be representative of the real-world environment. These inspection scenarios had equivalent difficulty levels in terms of the number and the types of defects and their location. Each inspection scenario contained a total of 22 defects of types cracks, corrosions, holes, abrasions and broken electrical conduits.

There were 9 cracks, 5 corrosions, 5 holes, 2 abrasions, and 1 broken electrical conduit in each of the three scenarios.

Figure 4. Lockheed L1011 aft cargo bay

Figure 5. Virtual reality model of aft cargo bay

2.4 Experimental Design

Based on a Pretest-Posttest Control Group Design [10], the participants were randomly assigned to two groups: treatment and control. The treatment group received training using the CVE where they observed an expert inspector perform an inspection task while being co-immersed in the CVE. The control group did not receive the training but were immersed in the scenario.

The expert selected to provide the training in the CVE was a graduate student with prior experience with the VR simulator and training in the theoretical concepts of search strategy. The expert performed trial inspection tasks and data was collected on his inspection performance. He was provided with sufficient training until he was able to identify 100% of the defects and his inspection time became consistent over a series of trials.
The experiment was administered according to the sequence shown in Figure 6. Performance and process measures were recorded in the inspection tasks.

	Familiarization →	**Pretest** →	**Treatment** →	**Posttest**
Treatment group Randomly assigned	Familiarization	Inspection Task	CVE Training + Exposure	Inspection Task
Control group Randomly assigned	Familiarization	Inspection Task	Exposure	Inspection Task

Figure 6. Experimental design

2.5 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.

They were then asked to perform an inspection task in a multiple defect environment. The task was an unpaced task: the participants were instructed to terminate the task when they wished. One of the two multiple defect inspection scenarios was used for this task. The two multiple defect inspection scenarios were counter balanced to assure that both groups received the same number of orderings of the two scenarios. 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 pointing and clicking using a 3D mouse. If the selection was correct, the defect was then highlighted in red. The eye movements of the participants and the selections they made by clicking the 3D mouse were recorded.

The participants in the control group were then immersed in the exposure scenario. They were allowed to spend as much time as they wished in this scenario.
The participants in the treatment group were co-immersed with the trainer in the CVE training scenario. The training session in the CVE was an unpaced observational task, where the participants were required to position and orient themselves so as to face the red dot as the trainer performed the inspection task.

All the participants were then asked to perform a second inspection task in a multiple defect environment. The task was again an unpaced task and the participants could terminate the task when they wished. The participants were immersed in the multiple defect inspection scenario that they had not been exposed to in the first inspection task. The eye movements of the participants and the selections they made by clicking the 3D mouse were recorded. The participants were not given feedback on their performance for either task.

3. Results

Data collected on performance and process measures were analyzed using Microsoft Excel 2003. We measured the effect of the training on the novice inspector's inspection performance and visual search process.

The performance measures were accuracy (the number of defects detected) and efficiency (time taken for the task in seconds). The process measures were collected by analyzing the point of regard (POR) data [11] of the participants recorded by the eyetracking equipment. The process measures collected were the number of fixation points, the number of fixation groups, and the mean fixation duration in milliseconds. Fixation points are identified by isolating fixations from saccades using a velocity filter with a threshold value set at 130 degrees of visual angle/second. Fixation grouping is performed by condensing a string of consecutive fixation points to a single fixation by finding the centroid of the group and verifying that each fixation group's duration is greater than or equal to the minimum theoretical fixation duration of 150ms.

For the control group, the difference between the post test and the pre test represents the effect of practice while, for the treatment group, the difference represents the effect of the training coupled with the effect of practice. The effect of training can be isolated by comparing the difference (post test – pre test) for the treatment group with the difference for the control group.

The experimental design was the 'Pretest-Posttest Control Group Design'. There was one independent variable, the treatment condition, which had two levels: training (treatment group) and no training (control group). We use a t-test to analyze the performance and process data.

Measures	**Means of the difference** (Post test - Pre test)		**t Stat**	**p <**
	Control	Treatment		
Number of defects detected	1.375	5.25	2.529	**0.016***
Time taken for the task (sec)	-212.013	193.65	2.268	**0.022***
Number of fixation points	592.5	67684.5	-2.289	**0.035***
Number of fixation groups	-25.5	186.5	-1.986	**0.041***
Mean fixation duration (ms)	-188	15.5	-1.081	0.153

*** Significant**

Table 1. Results: Performance and process measures

3.1 Performance measures

Table 1 presents the results for the performance and process. The t-test of the difference in accuracy shows that the improvement for participants who received training was significantly higher than that of the participants in the control group ($p < 0.05$). Figure 7 presents this result graphically.

The t-test of the difference in time taken to complete the inspection task shows that the participants who received training took significantly more time ($p < 0.05$) in the post test compared to the participants in the control group This result is shown graphically in Figure 8.

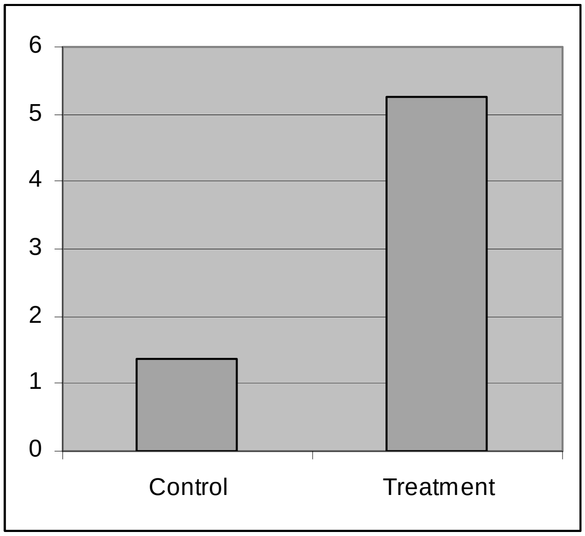

Figure 7. Mean difference: Number of defects detected

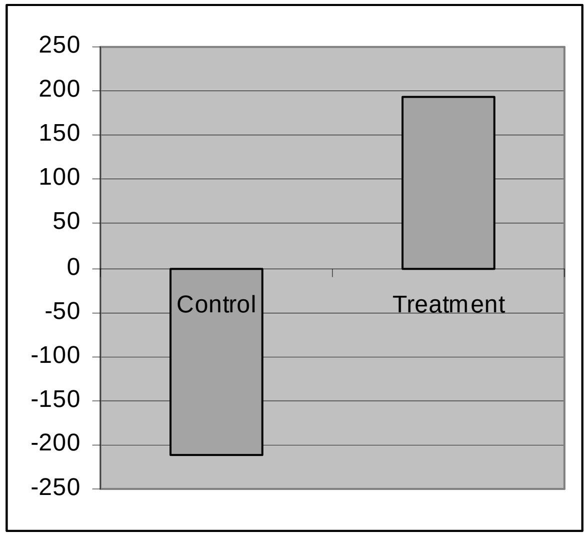

Figure 8. Mean difference: Time taken for task

3.2 Process measures

The process measures were available only for six subjects in the treatment group and seven for the control group due to loss of eye tracking data when the simulator failed to record the point of regard (POR) information sent by the eye tracking computer. Hence process data for one randomly selected subject in the control group was dropped and analysis was performed with a sample size of six per group.

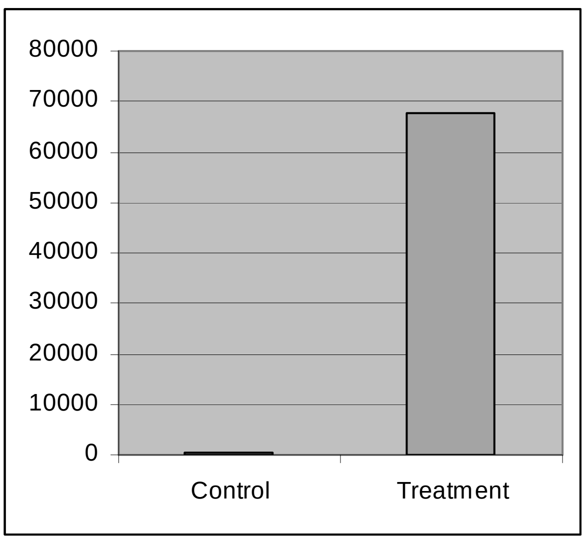

Figure 9. Mean difference: Number of fixation points

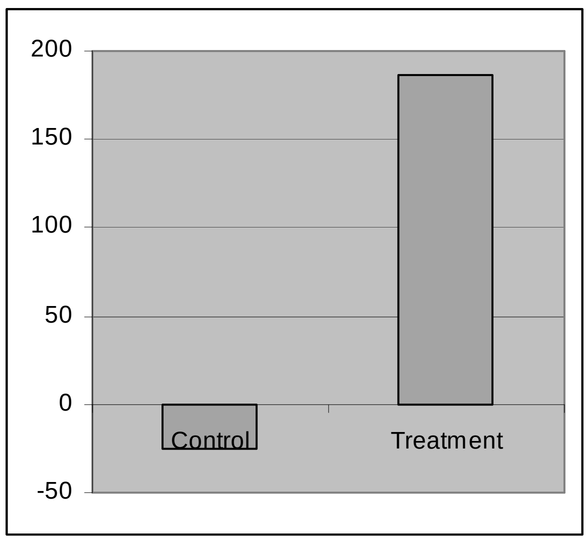

Figure 10. Mean difference: Number of fixation groups

Using a t-test on the difference in number of fixation points, we found that the participants in the treatment group had a significant increase in the number of fixation points in the post test as compared to the participants in the control group ($p < 0.05$). This is graphically represented in Figure 9.

The t-test of the difference in the number of fixation groups shows that the participants who received training had a significant increase in the number of fixation groups in the posttest as compared to participants in the control group ($p < 0.05$). This result is shown graphically in Figure 10.

There was no significant difference found in the mean fixation duration between the treatment and control group (Figure 11).

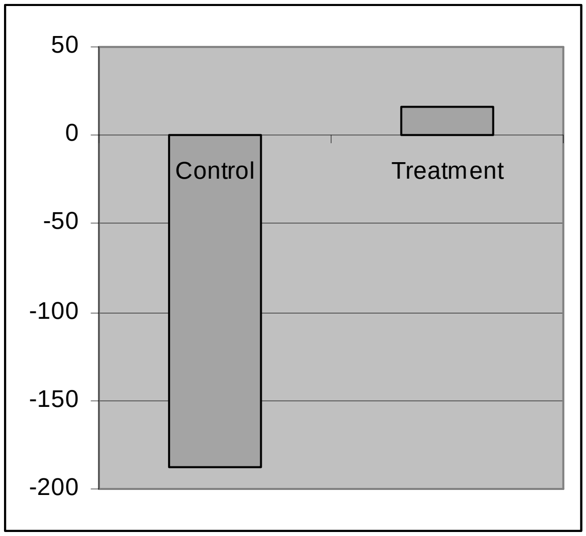

Figure 11. Mean difference: Mean fixation duration

4. Discussion

The objective of this study was to determine if search strategy can be taught using simulated on-the-job training using the collaborative virtual aircraft inspection environment aided by displaying visual deictic reference slaved to the head orientation of the trainer. The effectiveness of this training was evaluated by comparing the inspection performance of a group of participants who were administered this training to that of a group of participants who did not receive the training. Process measures were analyzed to understand how the training affected the participants' search strategy.

4.1 Performance Measures

The results show us that the search strategy training provided was effective in improving the accuracy of the novice inspectors in detecting defects, but, we also see a significant increase in the time they take to perform the search task. Thus there is a speed accuracy tradeoff observed for the task. On observing the time taken for completing the task in the pre-test and post test, we see that the participants in the treatment group appear to take more time in the post test compared to the pretest, while the participants in the control group appeared to take less time in the post test compared to the pretest. This could be due to the fact that the participants in the treatment group adopted a much more thorough search strategy similar to that of the expert.

4.2 Process Measures

The process measures show us that the participants who received training appear to have executed a larger number of fixations after training. They also had a significantly larger number of fixations groups after training. The slower paced and thorough inspection strategy adopted by the participants in the treatment group would explain the increase in time taken for the task. It was observed that the participants who received the search strategy training appeared to adopt a search process which was similar to the search strategy of the expert inspector which tended towards a more systematic search strategy.

Collecting eye tracking data during an inspection task in a virtual reality simulator gave us useful information that enabled us to better interpret the participant's cognitive process during inspection. The different process measures collected from the eye tracking data reflect the search strategy adopted.

5. Conclusions

From the results of this study, it can be concluded that subjects can be trained to adopt an expert's search strategy using simulated on-the-job training in a CVE. The training is effective in improving inspection performance. With an increase in performance, there was an increase in time taken to complete the task. Thus it has been found that a speed accuracy trade-off exists in the application of this training. It has also been shown that eye tracking information can be used to interpret the cognitive processes adopted by an expert inspector while performing a search task. Providing VDR in the CVE slaved to the head orientation has been found effective in representing the area of interest of the co-participant in a collaborative virtual environment. The results of this research have applications in aviation inspection training and in other collaborative training applications using virtual environments.

Reference

1. Gramopadhye, A.K., Drury, C.G., and Prabhu, P.V., (1997). Training strategies for visual inspection. Human Factors and Ergonomics in Manufacturing, 7(3), 171-196.
2. Vora, J., Nair, S., Medlin, E., Gramopadhye, A. K., Duchowski, A., Melloy, B., and Kanki, B.(2001). Using Virtual Reality Technology to Improve Aircraft Inspection Performance: Presence and Performance Measurement Studies. Proceedings of the Human Factors and Ergonomics Society Meeting, Minneapolis, 1867-1871.
3. Sadasivan, S., Stringfellow, P., Nalanagula, D., Castle, C., Washburn, C., Kanki, B., Duchowski, A., Leonard, M., and Gramopadhye, A. K. (2004). Using Virtual Reality Technology to Support Aircraft Maintenance Training. Proceedings of the IMAGE Society Conference. Scottsdale, AZ. CD-ROM.
4. Nair, S., Medlin, E., Vora, J., Gramopadhye, A. K., Duchowski, A., Melloy, B., and Kanki, B. (2001). Cognitive Feedback Training Using 3D Binocular Eye Tracker. Proceedings of the Human Factors and Ergonomics Society Meeting, Minneapolis, 1838-1842.
5. Vuilleme, A. Capin T., Pandzic, I., Magnenat, N., (1999). Nonverbal Communication Interface for Collaborative Virtual Environments. Virtual Realty. Vol. 4, No.1. Springer. pp. 49-59.5.
6. Vertegaal R., (1999). The GAZE groupware system: mediating joint attention in multiparty communication and collaboration. Proceedings of the SIGCHI conference on human factors in computing systems: the CHI is the limit, Pittsburgh, PA. 294 - 301.
7. Gallwey, T. J., and Drury, C. G. (1986). Task complexity in visual inspection. Human Factors, 28: 595-606.
8. Duchowski, A. T., Medlin, E., Gramopadhye, A. K., Melloy, B. J., and Nair, S. (2001). Binocular eye tracking in VR for visual inspection training. . Proceedings of the Virtual Reality Software & Technology (VRST) conference. Banff, AB, Canada, ACM., 1-8.
9. Duchowski, A. T. Cournia, N., Cumming, B., McCallum, D., Gramopadhye, A. K., Greenstein, J. S. Sadasivan, S., and Tyrrell, R. A., (2004). Visual Deictic Reference in a Collaborative Virtual Environment. Proceedings of the Eye Tracking Research & Applications (ETRA) Symposium, San Antonio, TX, ACM, pp. 35-40.
10. Campbell, D.T., and Stanley, J.C., (1966) Experimental and Quasi-Experimental Designs for Research. Houghton Mifflin Co.
11. Duchowski, A. T., Medlin, E., Cournia, N., Gramopadhye, A. K., Melloy, B. J., and Nair, S. (2002). 3D eye movement analysis for visual inspection training. Proceedings of the Eye Tracking Research & Applications (ETRA) Symposium, ACM. New Orleans, LA. 103-110.