Can We Use Technology to Train Inspectors to Be More Systematic?

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Abstract. Inspection quality is dependent on the ability of inspectors to weed out defective items. When inspection is visual in nature, humans play a critical role in ensuring inspection quality with training identified as the primary intervention strategy for improving inspection performance. However, for this strategy to be successful, inspectors must be provided with the needed tools to enhance their inspection skills. In this article we outline efforts pursued at Clemson University, focusing on the development of computer-based training systems for inspection training and discuss the results of some of the research briefly.

Keywords: Computer Based Training, Visual Inspection, Search Strategy.

1 Introduction

Visual inspection by humans is a widely used method for the detection and classification of nonconformities in industry. Inspection by humans is not perfectly reliable and it is critical to improve the inspector's performance. Human inspectors have the flexibility to adapt to various tasks and scenarios and improving their inspection process could increase their effectiveness. Visual search and decision making are the two components of a visual inspection process. Visual Search is an important component of the Visual Inspection Process. It is the first step in an inspection task and it involves searching for nonconformities in an item. Past research has shown improvement in visual search behavior with training. The most important aspect influencing visual search is information. Information can be of various types, including defect and location related, performance related, and process. Visual search strategy is a form of process information that can help in improve the accuracy and efficiency of a visual inspection task. Visual search strategy has been categorized as random, which is a memory less process where fixations can occur anywhere in the search field, and systematic, where perfect memory is assumed and no two fixations will occur at the same location. Generally, real world search processes fall in between these two extremes. Inspection performance has been shown to increases when the search strategy tends to be more towards systematic, as the inspection coverage is then exhaustive and no overlap exists between successive fixations. Literature on inspection has shown that moving inspectors from adopting systematic search over random search has significant impact in reducing inspection times and improving

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defect detection. This paper outlines the use of both low and high fidelity inspection tools in promoting systematic search process leading to superior inspection performance. Specifically the paper discusses a Contact Lens Inspection Training Simulator, VisIns a PC based simulator; Printed Circuit Board simulator; ASSIST - Automated System of Self Instruction for Specialized Training; and finally a VR based inspection tool in achieving the aforementioned objectives.

2 Background

Visual inspection by humans is a widely used method for the detection and classification of nonconformities in industry. Human inspectors have the flexibility to adapt to various tasks and scenarios and improving their inspection process could increase their effectiveness.

Since human inspection remains a central part of quality control, it is necessary to focus on the two functions of human inspection. The visual inspection process are search and decision making[1, 2]. The inspection process in general consists of the visual search process that aims at carefully searching for flaws -- "items that appear differently than the inspector would expect" [3] -- and the decision making process that consists of producing a judgment about the rejectability of the selected item -- "whether it constitutes a fault, an item which meets the criteria for rejection" [3]. Speed and accuracy are the two key variables used in measuring inspection performance. Speed is the measure of the time taken to search for and spot defects or to proceed if none are found while accuracy is the ability of an inspector to correctly identify defects and categorize them.

Inspection processes have been shown to be less than reliable, especially with human inspectors [4]. In an effort to eliminate human error from the inspection system, automated microprocessor-based automated inspection systems were explored [5]. While automation is viewed as the solution to eliminating problems associated with human error, it is not applicable in many industries and processes and it still cannot surpass the superior decision making ability of a human inspector. Human inspectors are more suited for the examination type of inspection tasks wherein the inspector has to search and later decide whether the item is to be accepted or rejected [6]. Training has been shown to be a potentially powerful technique for improving human inspection performance [7, 8].

Feedback training and feedforward training are the predominant training methods in use. Embrey [9] has shown that both knowledge of results (feedback information) and cueing (feedforward information) were effective in improving inspection skills, while Annett [10] found that cueing was equivalent to, or better than, knowledge of results. Megaw [11] mentioned feedback and feedforward information as factors affecting inspection performance while Drury and Prabhu, [12] present evidence supporting the use of feedforward and feedback training in aircraft inspection. Feedback training provides inspectors with information on their past performance or information on the process they adopted in different situations. In a simulated two dimensional airframe component inspection task, process feedback has been shown to improve search strategy [8]. Feedforward training provides prior information, such as information on the defects present, specific locations of defects, or special strategies.

Feedforward training has been found to be effective in past studies providing prior information on faults in industrial inspection.

Visual search is the first step in a visual inspection task and it involves searching for nonconformities in an item. Czaja and Drury [6] have shown improvement in visual search behavior with training. The most important aspect influencing visual search is information. Information can be of various types, including defect and location related, performance related, and process. Visual search strategy is a form of process information that may help to improve the accuracy and efficiency of a visual inspection task. Visual search strategy has been categorized by Megaw and Richardson [13] as random, which is a memory less process where fixations can occur anywhere in the search field, and systematic, where perfect memory is assumed and no two fixations will occur at the same location. Generally, real world search processes fall in between these two extremes. Megaw and Richardson [13] state that inspection performance increases when the search strategy tends more towards systematic, as the inspection coverage is then exhaustive and no overlap exists between successive fixations. They also note that the underlying eye movements of experienced inspectors are far from random. Schoonard et al. [14] found that in chip inspection, trained inspectors adopted a better inspection strategy than novice inspectors. Kundel and LaFollette [15] used fixation analysis to determine that experienced radiologists used a more systematic strategy while inspecting chest radiographs than untrained subjects. It has been shown in the field of radiology that providing an expert's search strategy to a novice can improve the novice's strategy [15]. Wang et al. [16], showed that search strategy can be taught. Graphical cognitive feedback of search strategy has also been shown to enhance visual inspection performance [17].

3 Computer Technology for Training

With computer technology becoming cheaper, the future will bring an increased application of advanced technology in training. In the past, instructional technologists have offered numerous technology-based training devices with the promise of improved efficiency and effectiveness. Many of these training delivery systems, such as computer-aided instruction, computer-based multimedia training, and intelligent tutoring systems, are already being used today, ushering in a training revolution.

In the domain of visual inspection, the earliest efforts to use computers for off-line inspection training were reported by Czaja and Drury [6], who used keyboard characters to develop a computer simulation of a visual inspection task. Similar simulations have also been used by other researchers to study inspection performance in a laboratory setting. Since these early efforts, Latorella et al. [18] and Gramopadhye et al. [17] have used low fidelity inspection simulators with computer-generated images to develop off-line inspection training programs for inspection tasks. Similarly, Drury and Chi [19] studied human performance using a high fidelity computer simulation of a printed circuit board inspection while another domain which has seen the application of advanced technology is the inspection of X-rays for medical practice.

The following section describes some computer based training systems and briefly describes some of the studies conducted using these systems.

4 Technology Based Training Systems – An Overview

Different computer based training systems are discussed below along with research conducted which will illustrate the use of technology to improve human inspection performance.

4.1 Contact Lens Inspection Training Program

This is a low fidelity training program that was used to train inspectors in the contact lens manufacturing industry. The training program was developed using well defined training methodology and images captured from actual contact lenses. When implemented, it resulted in improved inspection performance [20]. Figures 1 and 2 show screenshots of the training system and the details of the program can be found in Gramopadhye et al. [21].

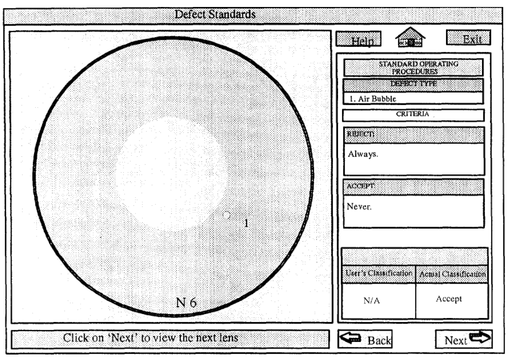

Fig. 1. Inspection screen

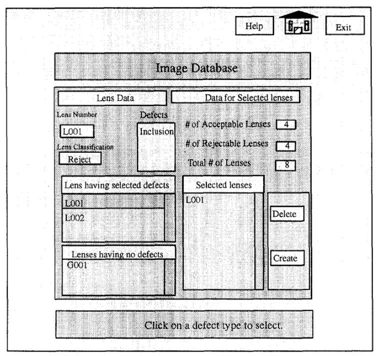

Fig. 2. Results screen

4.2 Visual Inspection Software (VisIns)

The VisInS system is a generic PC based inspection simulator that can be used to simulate the visual search and decision making components of the inspection task. The details of the simulator can be found in Koeniget al. [22]. Screenshots of the simulator are shown below in Figure 3.

Using this simulator various studies were conducted [23, 24, 25, 26] which illustrate the effectiveness of the system in providing inspection training. These studies evaluated different strategies to train inspectors to adopt a systematic inspection strategy. The images below illustrate screenshots of the static (Figure 4) and dynamic (Figure 5) systematic search strategy training.

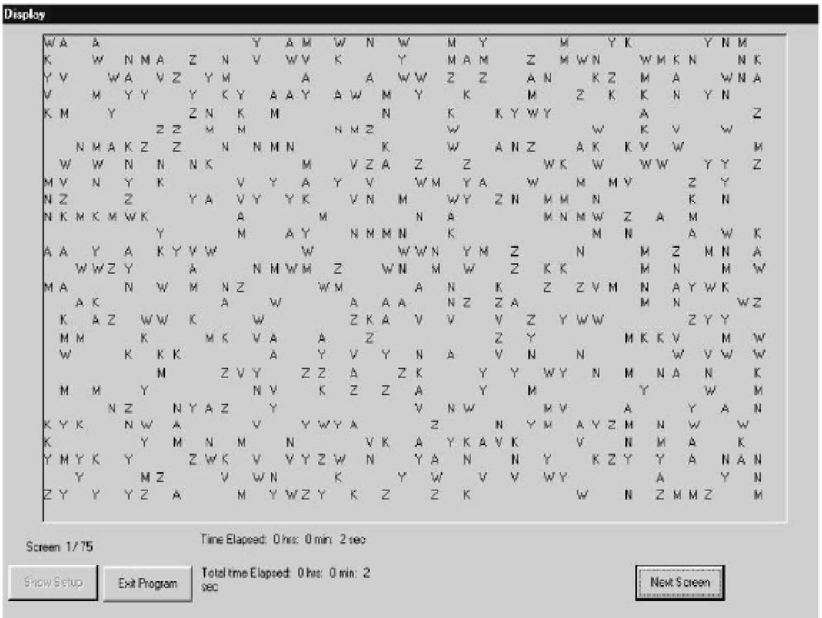

Fig. 3. The VisInS system

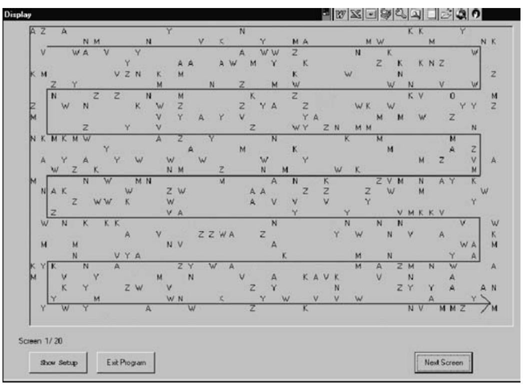

Fig. 4. Static training scenario

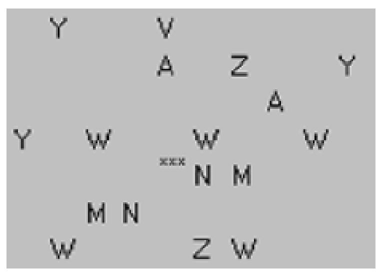

Fig. 5. Dynamic training scenario

4.3 PCB Inspection Simulator

This inspection simulator was developed in order to study function allocation issues in context of a visual inspection Printed Circuit Board (PCB) task. The system can support controlled studies on a printed circuit board inspection task in either human, automated, or hybrid mode. Details of the simulator can be found in Jiang et al. 2002 [27]. The simulator can operate in three separate modes:

1. Human inspection mode: In the human inspection mode, the computer presents the human with a series of PCB images. As each image is displayed, subjects visually search for faults. Once searching is completed, the subjects classify the image based on the severity of the fault(s). Once the image is classified, the inspector can view the next image. The system is designed to operate in two separate modes: with immediate feedback, as in training, and without feedback, as in practice.
2. Computer inspection mode: In the purely automated inspection mode, the operation of the computer parallels that of the human system with the exception that there is no feedback provided. The role of the human is supervisory in nature.
3. Hybrid inspection mode: In the hybrid inspection mode (Figure 6), both the search and decision-making functions are designed so that the functions can be performed cooperatively. The alternatives with parallel human and machine activities enable dynamic allocation of search and decision-making functions.

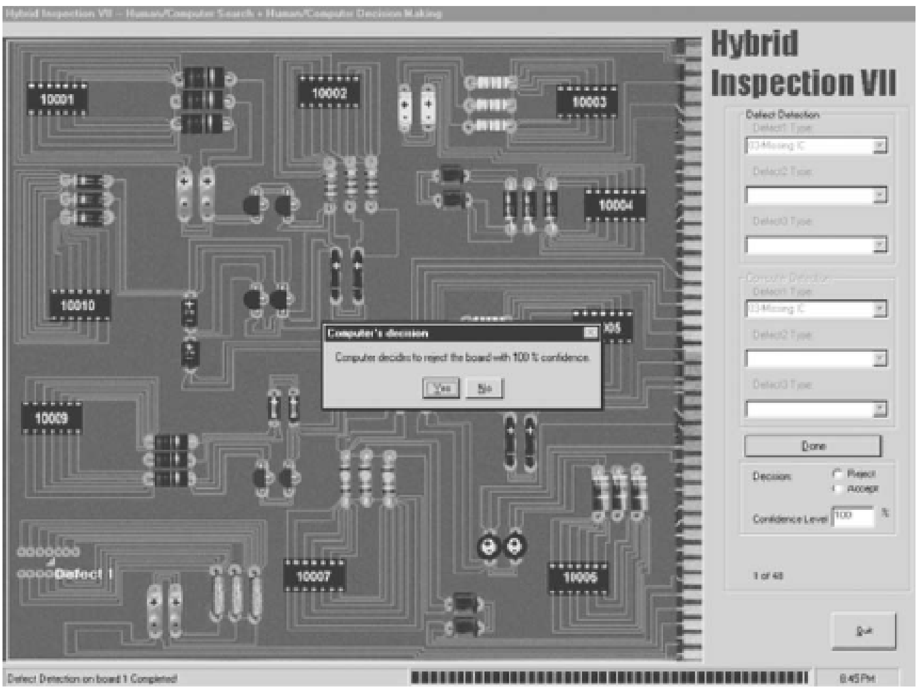

Fig. 6. PCB simulator in the hybrid inspection mode

Studies conducted using the simulator have illustrated its potential in providing training and also have looked at the interaction between human inspectors and computers [28, 29] specifically, the effect of system response bias on inspection quality performance. Search strategy training has also been tested using the PCB simulator using eye tracking information of an expert inspector [30]. The search strategy information was provided to the trainees in three modes – static display

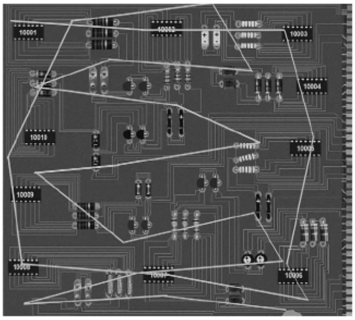

Fig. 7. Static training display

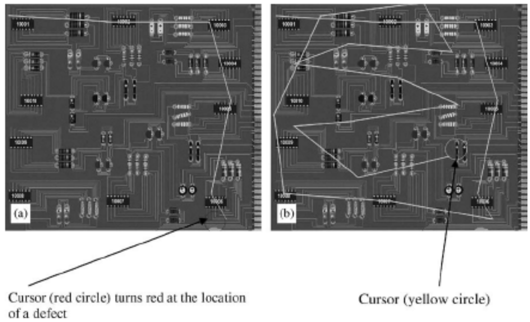

Fig. 8. Hybrid training display

(Figure 7), dynamic display and a hybrid display (Figure 8) of the eye movement information. All three conditions were found to be beneficial in training the novice inspectors to adopt a more systematic search strategy.

4.4 Automated System of Self Instruction for Specialized Training (ASSIST)

ASSIST is a PC based computer simulator for aircraft inspection training. The software consists of three parts: a general module (Figure 9) to provide potential inspectors with general information such as the role of an inspector, factors affecting inspection, safety and inspection procedures; a task simulation module (Figure 11) that allows the trainee to conduct a simulated inspection of an aft cargo compartment; and an instructor's utilities module (Figure 10) that allows an instructor to review a trainee's performance and also configure tasks. The simulated inspection even includes simulated ambient noise such as rivet guns, hangar door horns and other sounds found in a hangar where inspector may be working. During the simulation, the trainee visually searches for and classifies any defects and writes up a computer generated non-routine card. He or she is provided with immediate feedback on his or her performance. Studies [31] using this simulator have demonstrated its effectiveness.

4.5 Virtual Reality Aircraft Inspection Simulator

Despite their advantages, existing multimedia-based technology solutions, including low fidelity simulators like ASSIST, still lack realism as most of these tools use only two-dimensional sectional images of airframe structures and, therefore, do not provide a holistic view of the airframe structure and the complex maintenance/inspection environment. More importantly, the technicians are not immersed in the environment, and, hence, they do not get the same look and feel of inspecting/maintaining a wide-bodied aircraft. To address these limitations, virtual reality (VR) technology has been proposed as a solution. The development of the VR simulator [32] was based on a detailed task analytic methodology [33]. Various scenarios (Figure 12), representative of the aft cargo bay, wing and fuselage of a wide-bodied aircraft, were developed. One of the studies [34] conducted using the VR simulator was to train novice inspectors to adopt an expert inspector's search strategy

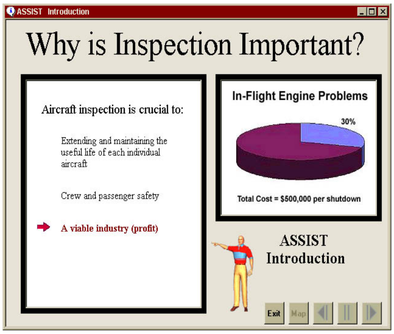

Fig. 9. General inspection module

Fig. 10. Instructor's utility module

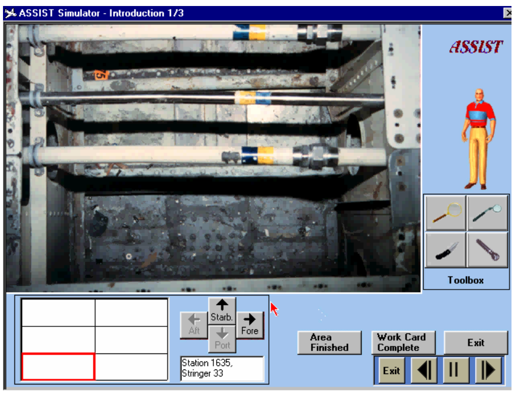

Fig. 11. Simulation training module

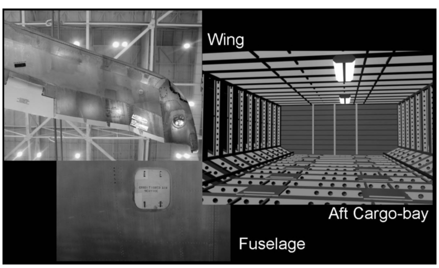

Fig. 12. VR training scenarios

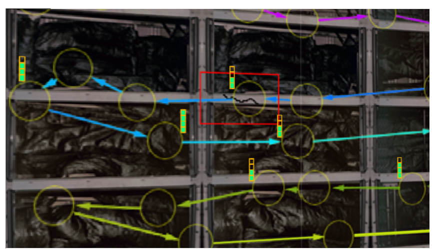

Fig. 13. Search strategy training display

obtained from eye tracking information (Figure 13). The results showed that the training was effective in improving performance and the adoption of the systematic search strategy.

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