EVALUATING THE ROLE OF HUMANS IN HYBRID INSPECTION SYSTEMS

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Humans and machines each have their own advantages and disadvantages in performing visual inspection tasks. In order to capitalize on the respective advantages and offset the disadvantages of humans and machines, hybrid inspection systems have been proposed. In response, research was conducted to evaluate three different inspection systems: a human inspection system and two hybrid inspection systems (computer search/human decision-making inspection system, human/computer share search/decision-making). Results from the study showed that humans working in conjunction with computers on search and decision-making tasks yielded the best system performance.

INTRODUCTION

Visual inspection is a task in which products are examined to detect defects, and decisions are rendered as to accept or reject these products according to the severity of the defects (Hou, 1992). These two functions, visual search and decision-making, are central to inspection and have been shown to be the primary determinants of inspection performance (Drury, 1978; Sinclair, 1984; Drury, 1992). Because of the role of the inspection process, any improvements in inspection performance have the potential to reduce the number of defective products reaching the consumer.

As inspectors, humans and automated systems each have their own advantages and disadvantages (Jiang, Gramopadhye, and Melloy, 2003). Humans are good at detecting signals in overlapping noise spectra and can make inductive decisions in new situations; however they are limited in their computational ability and short-term memory. On the other hand, machines are good at computation, memory storage and retrieval, but are poor at detecting signals in noise and have very little capacity for creative or inductive functions (Kantowitz and Sorkin, 1987). One direct comparison study showed that both human and machine systems performed poorly in inspections, although humans did perform marginally better than the particular automated inspection system that was tested (Drury and Sinclair, 1983).

In order to capitalize on the respective advantages (and offset the disadvantages) of humans and machines, hybrid inspection systems have been proposed. There are nine alternate inspection systems, illustrated in Table 1, based on whether search and decision-making tasks could be performed by humans, computers or both. Alternative 1 is a pure human inspection system since humans perform both search and decision-making tasks while Alternative 2 is a pure automated inspection system. Alternatives 3 through 9 are various hybrid inspection systems with the search and decision-making tasks being performed by humans, computers, or both. In response to the need of addressing performance assessment issue, a PCB-based visual inspection simulator (Jiang, Bingham, Master, Gramopadhye and Melloy, 2002) was used. This study aims to measure best system performance for varying levels of response biases for three alternate inspection systems--a human inspection system, which serves as a benchmark; a computer search / human decision hybrid inspection system, Alternate 4 in Table 1, which performed very well in the previous study (Hou, Lin, and Drury, 1993); and the most flexible
hybrid system, a human/computer search human/computer decision-making hybrid inspection system, Alternate 9 in Table 1. Traditionally, inspection performance has been measured using speed, accuracy, flexibility, reliability, and cost. Since the measures of flexibility, reliability and cost are difficult to measure quantitatively in a laboratory study and are more appropriate in an industrial context (Hou et. al, 1993), the current study uses only speed and accuracy measures to evaluate best system performance.

### METHODOLOGY

**Subjects**

The subjects were 6 students, both graduate and undergraduate, enrolled at Clemson University between the ages of 18 and 28. Students can be used as subjects in lieu of inspectors because as Gallwey and Drury (1986) have shown, minimal differences exist between inspectors and student subjects on simulated tasks. The subjects were screened for 20/20 vision, corrected if necessary, and paid $5.00/hour for their time.

**Stimulus Material**

The task was a simulated visual inspection of a printed circuit board implemented on a Pentium III computer with a 19” high-resolution (1024 x 768) monitor. The input devices were a Microsoft standard keyboard and a Microsoft mouse. The task consisted of inspecting simulated PCB images developed using Adobe PhotoShop 5.5 for six categories of defects – missing components, wrong components, inverted components and misaligned components, trace defects and board defects. Four categories of defects could occur on any of these four individual components: resistors, capacitors, transistors and integrated circuit.

**Human inspection system:** In this system, humans exclusively performed a computer-simulated visual inspection task consisting of visual search and decision-making components with computers being used only for displaying the PCB images. During visual search, PCB boards containing 1, 2, 3, or no defects were presented to the subjects, whose task was to locate all potential defects and name them. After locating the defect, they clicked the mouse on it and chose its name from a dropdown box listing all possible defects. Then, the subjects made their conformance decisions, indicating if the board conformed or not by clicking on the corresponding button on the screen. Once the board was classified, subjects moved to the next image of the next board by clicking on the “next” on the screen. Each inspection task consisted of 48 randomly ordered PCB boards--12 of each zero-defect, single-defect, two-defect, and three-defect boards.

**Computer-search / human-decision hybrid inspection system:** In this system, unlike in the human inspection one, computers searched for defects while humans made the decision on the board. The computer search was simulated based on the values of input parameters (e.g., search time).

**Human+computer search/ human+computer decision-making hybrid inspection system:** In this system, both computers and humans searched for defects and made the decision on the board with the human having the final decision about whether to accept or override the computer’s decisions.

### Table 1 Allocation alternatives in hybrid inspection task (Hou, Lin & Drury, 1993)

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Search</th>
<th>Decision-making</th>
<th>System Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Human</td>
<td>Human</td>
<td>Human</td>
</tr>
<tr>
<td>2</td>
<td>Computer</td>
<td>Computer</td>
<td>Computer</td>
</tr>
<tr>
<td>3</td>
<td>Human</td>
<td>Computer</td>
<td>Hybrid</td>
</tr>
<tr>
<td>4</td>
<td>Computer</td>
<td>Human</td>
<td>Hybrid</td>
</tr>
<tr>
<td>5</td>
<td>Human</td>
<td>Human + Computer</td>
<td>Hybrid</td>
</tr>
<tr>
<td>6</td>
<td>Computer</td>
<td>Human + Computer</td>
<td>Hybrid</td>
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<tr>
<td>7</td>
<td>Human + Computer</td>
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<td>8</td>
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<tr>
<td>9</td>
<td>Human + Computer</td>
<td>Human + Computer</td>
<td>Hybrid</td>
</tr>
</tbody>
</table>

Table 1 Allocation alternatives in hybrid inspection task (Hou, Lin & Drury, 1993)
search or decision-making. Figure 1 shows a typical decision-making response by the computer. The human then decides to accept or reject this decision.

**Experimental Design**

The study used a 3 (response bias) x 2 (hybrid inspection systems) +1 (human inspection system) within subjects design. The three levels of response bias used were conservative, high misses/low false alarms; neutral, equal false alarms and misses; and risky, high false alarms/low misses. The two levels of inspection systems used were Computer Search Human Decision-making Hybrid Inspection System (CSHD), and Human Computer Share Search and Decision-making Hybrid Inspection System (HCS). A pre-test using the Human Inspection System (HIS) served as benchmark. To cancel out the order effects, all 6 subjects went through all 6 experimental conditions in a counterbalanced order using a 6 by 6 Latin square design.

**Procedure**

The study took place over an eight-day time period. On Day 1, each subject was required to complete a consent form and a demographics questionnaire. Following this step, instructions were read to the subjects to ensure their understanding of the experiment. Next, all the subjects were trained and given three separate tests before beginning the experiment. On Day 2, subjects were administered a pre-test of one trial block consisting of 48 PCB boards under the purely human inspection system. From Day 3 to Day 8, subjects were assigned to each of the six treatments

![Figure 1 Screenshot of a hybrid inspection system](image)

**RESULTS**

The performance measures consisted of accuracy and speed. Mixed Model Analysis of Variance (MANOVA) and preplanned linear contrasts on the different performance measures were used to analyze the seven treatments—one human inspection system, three computer-search human-decision-making inspection systems, and three human computer share search and decision-making inspection systems. Specifically, the analysis was conducted on hit rate and false alarm rate for the accuracy measure, and mean search time, mean stopping time and mean inspection time for the speed measure.

The analysis of variance indicated a significant treatment effect on the hit rate ($F(6,30) = 69.53$, $p < 0.0001$), the false alarm rate ($F(6,30) = 8.82$, $p < 0.0001$), and the mean search time($F(6,30) = 6.91$, $p < 0.001$). No significant treatment effect was found for either the mean stopping time or the mean inspection time.
The preplanned linear contrast indicated that the HCS system performed the best in all terms of speed and accuracy measures. It also indicated that the risky system performed the best in terms of accuracy measure.

**DISCUSSION**

The most salient finding of the research is that humans working in conjunction with computers on both search and decision making tasks yielded the best system performance. Although the purely human inspection system performed the worst in both search and decision-making tasks, results from the current study indicate that integrating humans with computers in the inspection process actually improves inspection speed and accuracy.

Since humans and computers need to work together, it is important to look at the interaction between them, especially the effect of computer performance on the human inspectors. In response to this issue, this study went further to research the effect of the response bias as an indication of computer performance, an area that had never been studied before. The results revealed that the risky system was the best in terms of accuracy measures. The nature of errors made by computers helps to explain this result. False alarms made by the system are commissive errors, which the inspectors cannot overlook if they are paying attention to the system, whereas misses are omissive errors which the subjects are likely to miss if they are not paying attention (Sanders and McCormick, 1993). Since the risky system had more hits and more false alarms, once humans noticed those false alarms, they could take into account the system errors when they made the decisions on the boards and, as a result, dramatically reduced the false alarm rate. Therefore, by taking into account the computer performance and correcting system errors, the human inspectors improved the overall system performance. Because of the role of the inspection process, any improvements in inspection performance have the potential to reduce the number of defective products reaching the consumer.

In summary, this research has demonstrated that the human computer share search and decision making system gave the best overall performance for a selected set of parameters. Further work is needed to evaluate the various alternatives under additional situations. However, the adaptability of humans was again demonstrated by this study, indicating that humans will continue to play a vital role in future hybrid systems.

**REFERENCES**


Gallwey, T. J., 1982, Selection Test for visual inspection on a multiple fault type task, Ergonomics, 25(11), 1077-1092.


