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HIGH-DEFINITION TELEVISION EVALUATION FOR REMOTE HANDLING TASK PERFORMANCE

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ABSTRACT

High-definition television (HDTV) transmits a video image with more than twice the number (1125 for HDTV to 525 for standard-resolution television) of horizontal scan lines than standard-resolution television provides. The improvement in picture quality (compared to standard-resolution television) that the extra scan lines provide is impressive. Objects in the HDTV picture have more sharply defined edges, better contrast, and more nearly accurate reproduction of shading and color patterns. Because the television viewing system is a key component for teleoperator performance, an improvement in television picture quality could mean an improvement in the speed and accuracy with which teleoperators perform tasks. This paper describes a suite of three experiments designed to evaluate the impact of HDTV on the performance of typical remote tasks. The performance of HDTV was compared to that of standard-resolution, monoscopic, monochromatic television and to standard-resolution, stereoscopic, monochromatic television in the context of judgment of depth in a televised scene, visual inspection of an object, and performance of a typical remote-handling task.

The results of the three experiments show that in some areas HDTV can lead to improvement in teleoperator performance. The HDTV is superior to standard-resolution monoscopic, monochromatic television and

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to standard-resolution stereoscopic, monochromatic television for remote inspection tasks; it is less proficient than standard-resolution, monoscopic, monochromatic television for interpretation of object distance in the remote area. The HTDV leads to a lower rate of errors committed while performing remote-handling tasks, but it does not reduce the amount of time necessary to perform the tasks.

INTRODUCTION

In a plant that employs remote-handling techniques for equipment maintenance, operators perform maintenance tasks by using primarily the information from television systems. The efficiency of the television system has a significant impact on remote maintenance task performance.

The HDTV was evaluated as part of the Consolidated Fuel Reprocessing Program at Oak Ridge National Laboratory in cooperation with the Power Reactor and Nuclear Fuel Development Corporation (PNC) of Japan. The HDTV transmits a video image with more than twice the number of horizontal scan lines as standard-resolution television (1125 for HDTV to 525 for standard-resolution television). The resulting improvement in picture quality (compared to standard-resolution television) is very impressive. Objects in the HDTV picture have more sharply defined edges, better contrast, and more nearly accurately reproduced shading and color patterns. To the casual observer, the HDTV picture provides greater sensation of depth. Because operators of remote-handling equipment depend on television systems as the single most important cue necessary to do work, such an improvement in television picture quality could mean an improvement in the speed and accuracy with which they perform their tasks.

This paper describes experiments designed to evaluate the impact of HDTV on the performance of typical remote tasks. The experiments described in this paper compared the performance of four operators using HDTV with their performance while using other television systems. The experiments included four television systems: (1) high-definition color television, (2) high-definition monochromatic television, (3) standard-resolution monochromatic television, and (4) standard-resolution stereoscopic monochromatic television. The stereo system accomplished steroscopy by displaying two cross-polarized images, one reflected by a half-silvered mirror and one seen through the mirror. Observers wore a pair of glasses with cross-polarized lenses so that the left eye received only the view from the left camera and the right eye received only the view from the right camera.

Three tasks were completed in the experiment: a test of depth perception, a small-scale remote-handling task, and a visual inspection task.

Experiment 1: Depth Perception

A test of depth perception evaluated the ability of the sharper HDTV image to provide depth information. The depth-perception test required operators to adjust the apparent distance to a section of PVC pipe so that the pipe section was the same distance away as a second, stationary section of pipe. Measurement of the alignment error (the difference in portion of the two pipe sections along the depth axis) of the pipe sections allowed a comparison of performance in a situation requiring accurate perception of distances from televised scenes.

Figure 1 is a photograph of the apparatus used in this experiment. The operators sat directly in front of a television monitor, which showed the upper half of the two pipes. No other portion of the apparatus was visible during testing.

Operators were required to adjust the apparent distance to one section of pipe so that it appeared the same distance away as the second (stationary) section of pipe. Measurement of the alignment error (the difference in position of the two pipe sections along the depth axis) of the pipe sections allowed comparison of performance in a situation requiring accurate perception of distances within televised scenes.

The standard deviations of the distribution of alignment errors are measures of operator sensitivity to distance differences in the remote area.[1] The size of the standard deviation is related to the size of the area in which the operator can make no differentiation between object distances. It is a measure of the operator's zone of uncertainty; within the area described by the standard deviation, the operator is unable to judge distances. The smaller this area is, the smaller the distance differences detectable by the operator. Thus, the standard deviation may serve as a figure of merit for the television systems in the area of transmission of depth information. For the task used in this experiment, the best performance was achieved when operators used the stereo television system (see Table 1). It produced the lowest standard deviation of alignment errors, indicating that operators using the stereo system were able to reliably detect smaller differences in distance than operators using the other television systems.

While the depth-perception task showed a significant performance advantage for stereo television, it may be that the task emphasized the type of depth information provided by stereo television. Because the visual field provided by the task was simple and structured, it may be that cues improved by the HDTV system had no effect within this task. Stereo television provides cues from retinal disparity, which continue to function in such a visual environment. Other cues are derived by comparing perspective, size, texture, and patterns of light and shadow. These cues may be enhanced by the higher resolution provided by HDTV. Information from this type of cue was not present in the depth-perception task used in this experiment. The relative performances of

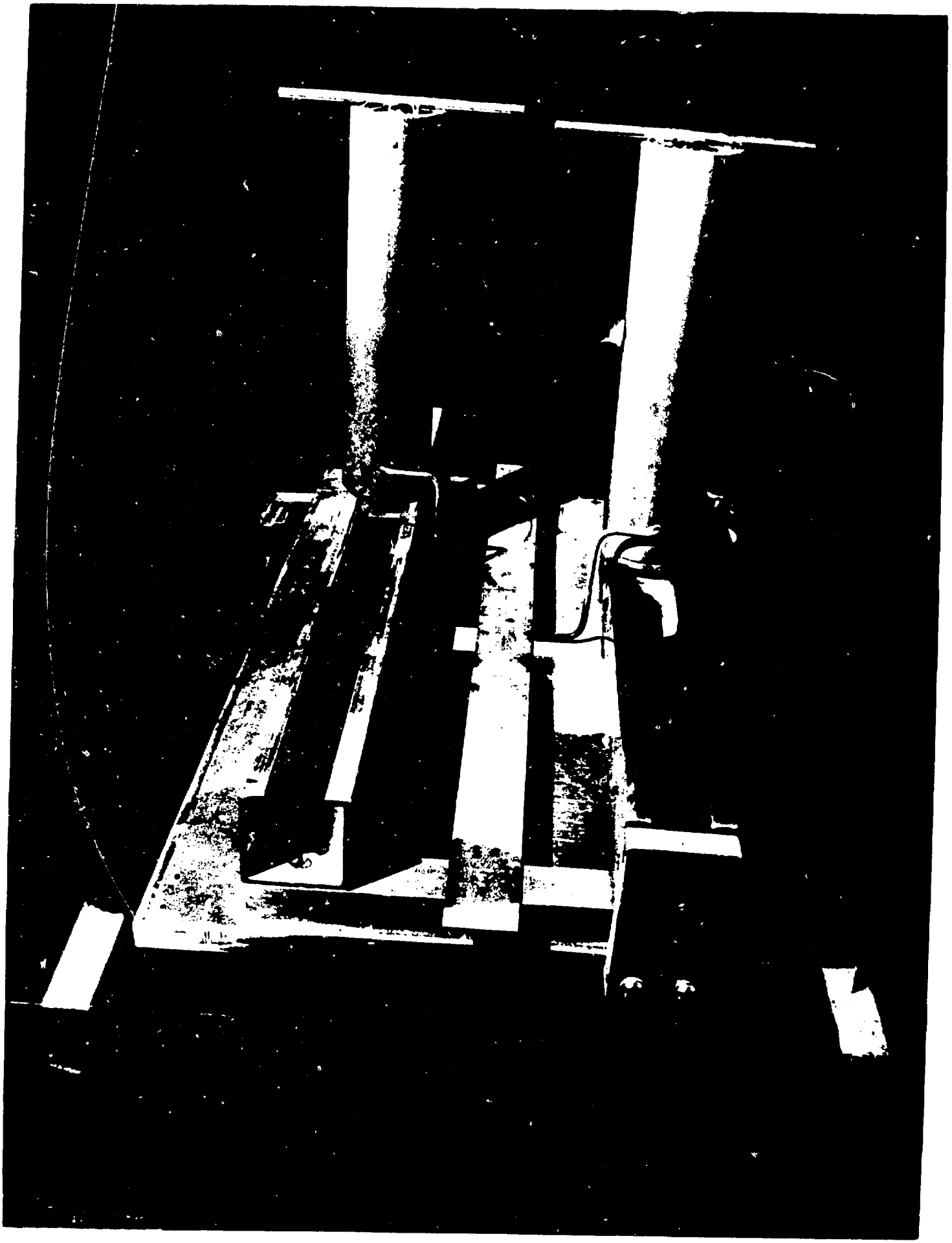

Fig. 1. Depth-perception task.

Table 1. Standard deviations and averages of alignment errors for trials beginning with 50-mm separation between pipe sections--depth-perception experiment.

TV system	Standard deviation (mm)	Average (mm)
High-definition color television	7.48	-0.67
High-definition monochromatic television	8.10	-0.90
Standard-resolution monochromatic television	9.70	-0.05
Standard-resolution stereoscopic television	5.70	-0.42

the television systems in the depth-perception experiment may not be directly translatable to all situations that require depth judgments.

Experiment 2: Remote Handling

Remote-handling tasks require dexterous manipulation using television as the primary sensory mode. Visual information (including information pertaining to depth and alignment) is crucial for good remote-handling performance. Precise alignment in three-dimensional space is a task that is particularly dependent upon accurate visual information.

The task for this experiment required operators to pick up four 1.75-in. electrical connectors (with the threaded rings removed) and plug them into four sockets. Figure 2 is a photograph of the task. Without precise alignment of the male and female portions of the connectors, coupling is impossible, and damage to the connectors is likely.

Two measurements of performance were made: the time required to complete each task and the number of errors committed during task performance. The latter was recorded by an observer during testing. The observer recorded occurrences of four types of errors: misalignments, misses, drops, and damage.

An analysis of variance[2] (ANOVA) was performed on the average of each operator's score in each session. There were no statistically significant differences between the television systems on task time for this task. Figure 3 illustrates the mean differences between systems for the time in seconds required to perform tasks and shows that, on average, operators completed tasks more quickly with HDTV than with the other television systems. However, this difference was not statistically significant.

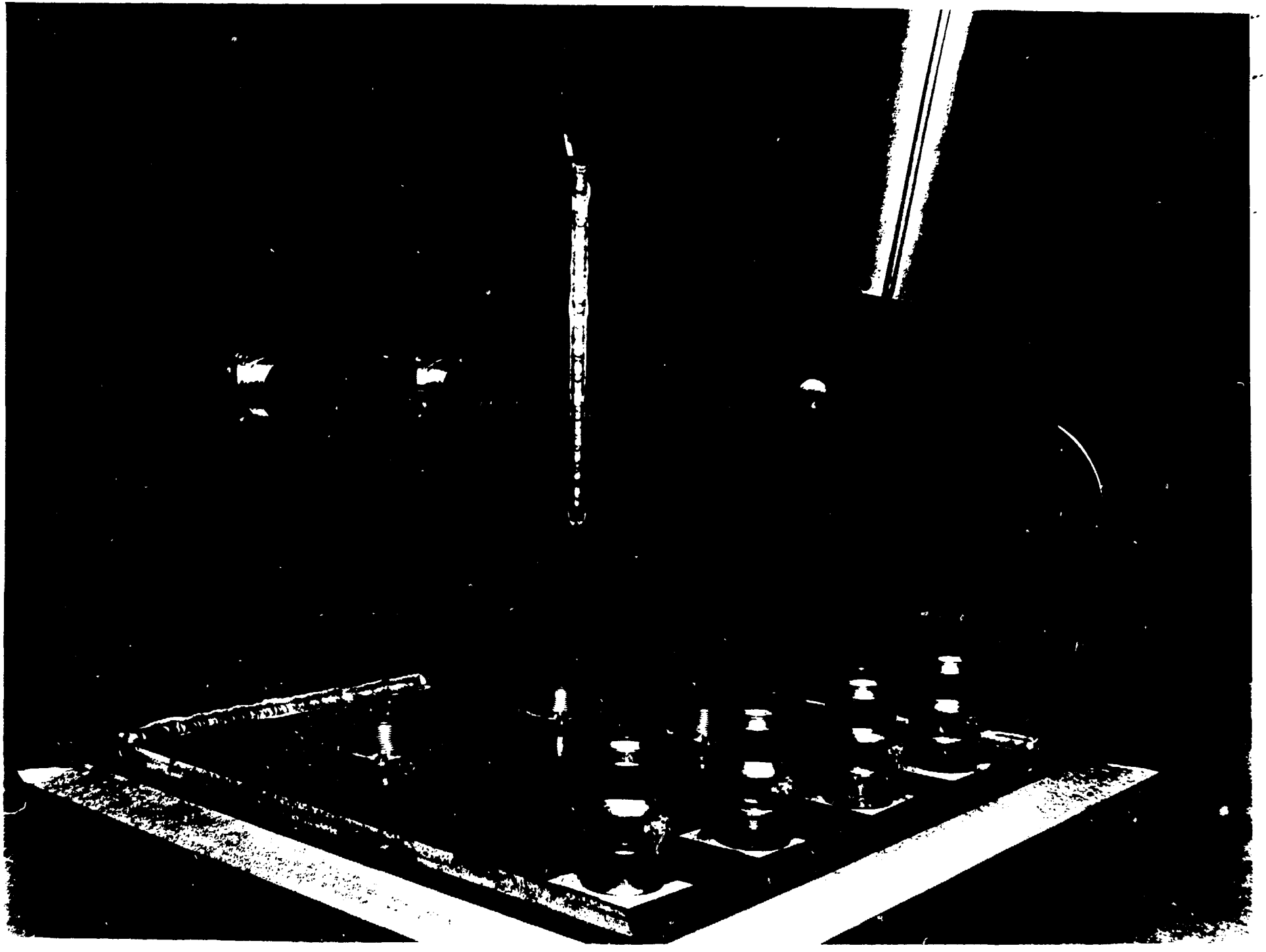

Fig. 2. Remote-handling task.

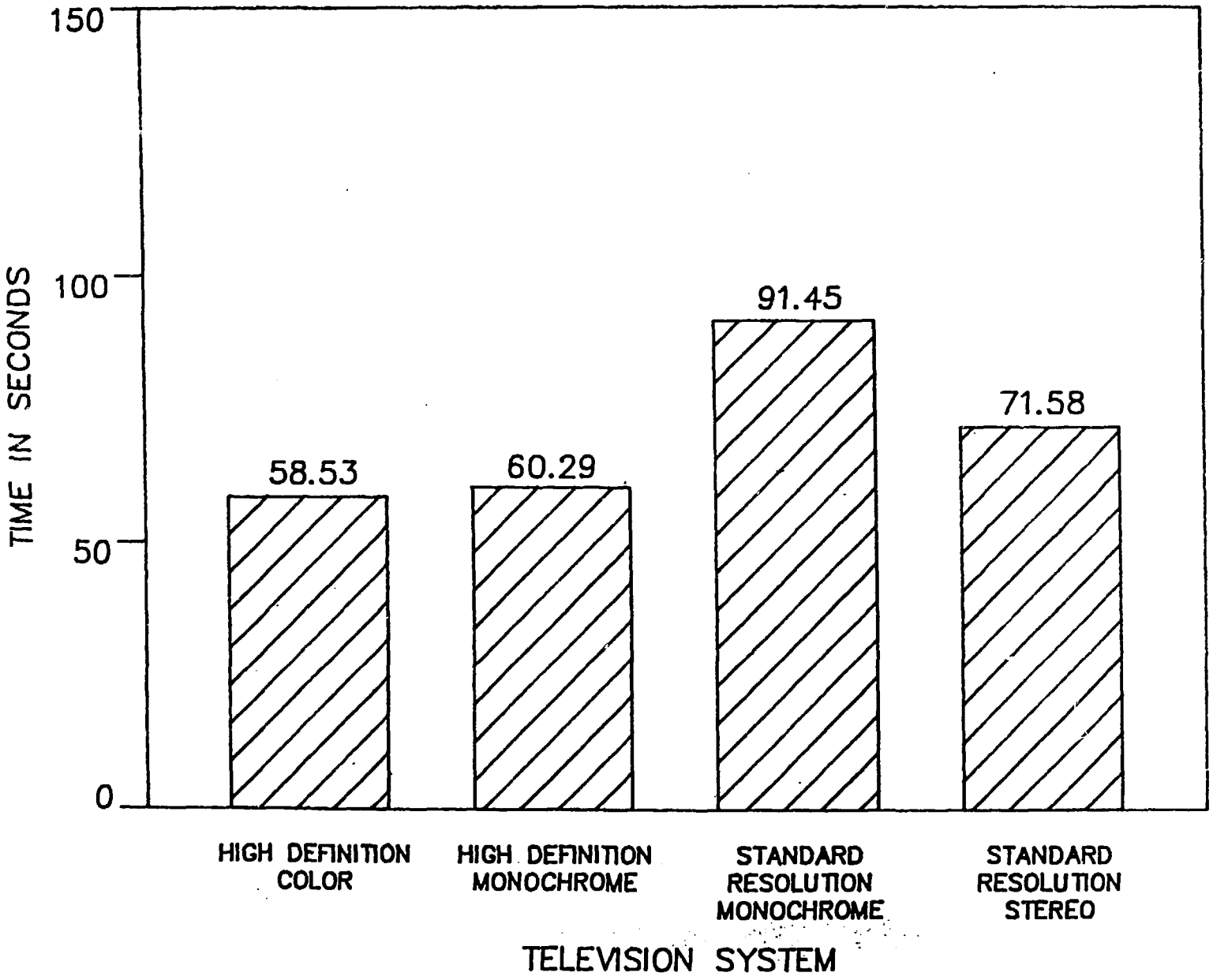

Fig. 3. Mean time to complete the task with each television system.

There was a significant difference between the television systems for the number of errors. Figure 4 shows the mean number of errors per trial for each of the systems. Pair comparisons performed on the data indicate that there was no difference between the two HDTV systems (color and monochromatic) but that the two standard-resolution, monochromatic systems (monoscopic and stereo) both produced a higher average number of errors per trial. Operators using the monoscopic system also committed more errors than when using the stereo system.

Experiment 3: Visual Inspection

Remote-maintenance activities in future nuclear fuel reprocessing plants will include such efforts as inspection of welds, pipes, and containers. While some of these tasks may be performed by robots, human inspectors will have a role in inspections. Therefore, a task-assessing remote performance was included in the experiments.

This experiment compared the accuracy with which operators could inspect glass sample bottles with each of the television systems. Participants attempted to identify a sample bottle as flawed or unflawed. Figure 5 is a photograph of the flawed and normal sample bottles used in the experiment. An experimenter placed a bottle on the horizontal member of apparatus, and the operator grasped and rotated the bottle with the manipulator arm. The operator responded to each bottle by indicating whether or not there was a flaw present. A testing session comprised 100 trials, with each bottle presented 50 times. The order of presentation of flawed- and normal-bottle trials was randomized independently for each session.

Analysis of data was by the methods of the Theory of Signal Detection (TSD).[3] The TSD approach yields measures of the sensitivity of operators to objects and of the inspection strategy used by operators. One measure of sensitivity involves plotting the probability of hits (correct identifications of flawed items) versus the probability of false alarms (classifying an item as flawed when it is not). This plot is called an isosensitivity function or Receiver Operating Characteristic (ROC) curve. The ROC curves allow quick comparison of the performances of the television systems. Observer sensitivity can be compared among television systems to determine whether operators are uniformly more nearly accurate with one than with the others; if one outperforms the other systems, it will lead to higher operator sensitivity.

Figure 6 shows the ROC curves for the averages of the three operators. The larger the area under an individual curve, the more sensitive operators were while using that television system. Judging from the ROC curves in Figure 6, the HDTV systems led to greater sensitivity to flaws in the sample bottle than did the stereo and standard-resolution monochromatic systems. The HDTV monochromatic was slightly better than HDTV with color, but this difference is small. The difference between the systems is not large enough to indicate a real performance advantage for HDTV without color over HDTV with color.

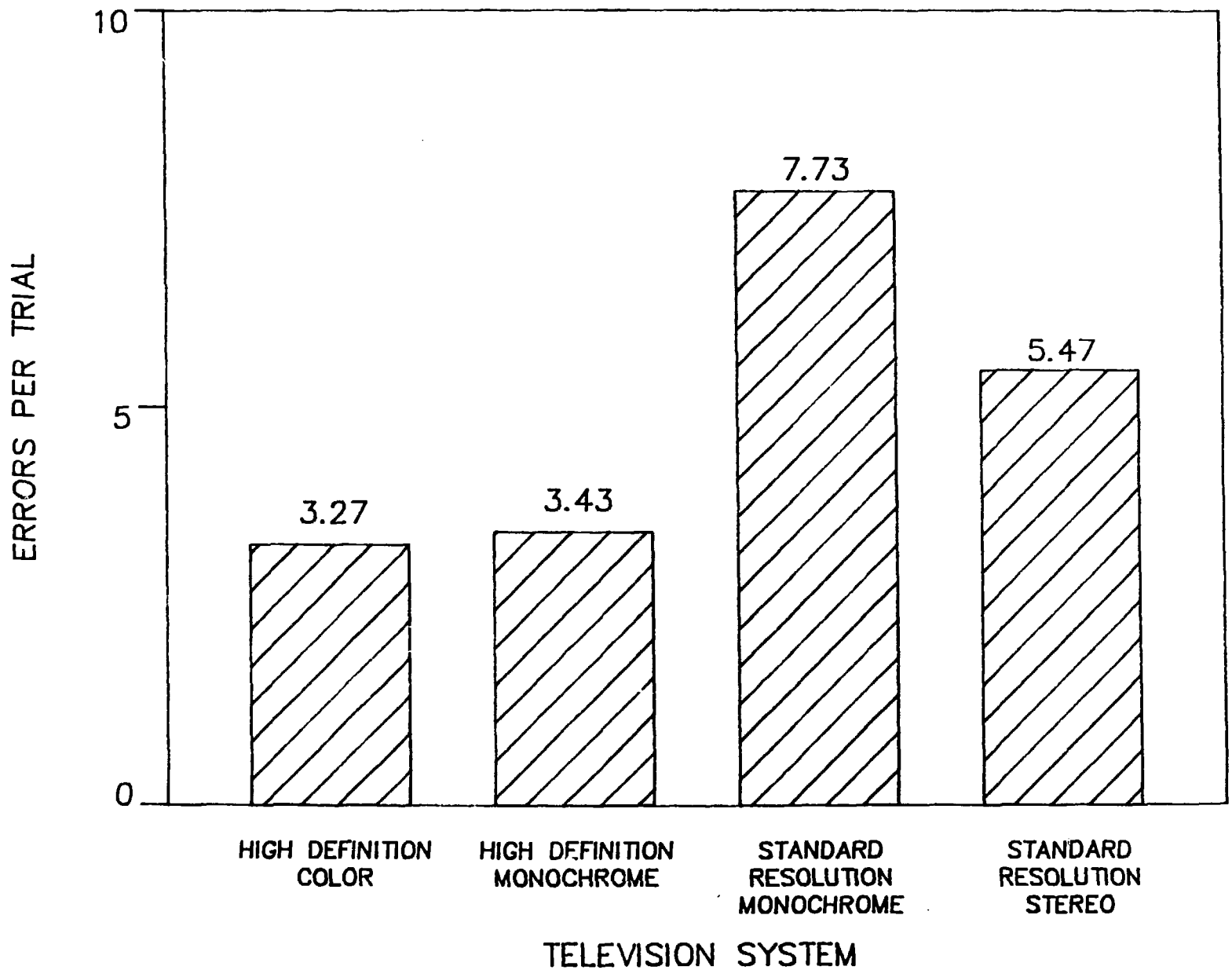

Fig. 4. Mean number of errors per trial for each television system.

Fig. 5. Sample bottles.
(flawed bottle on left)

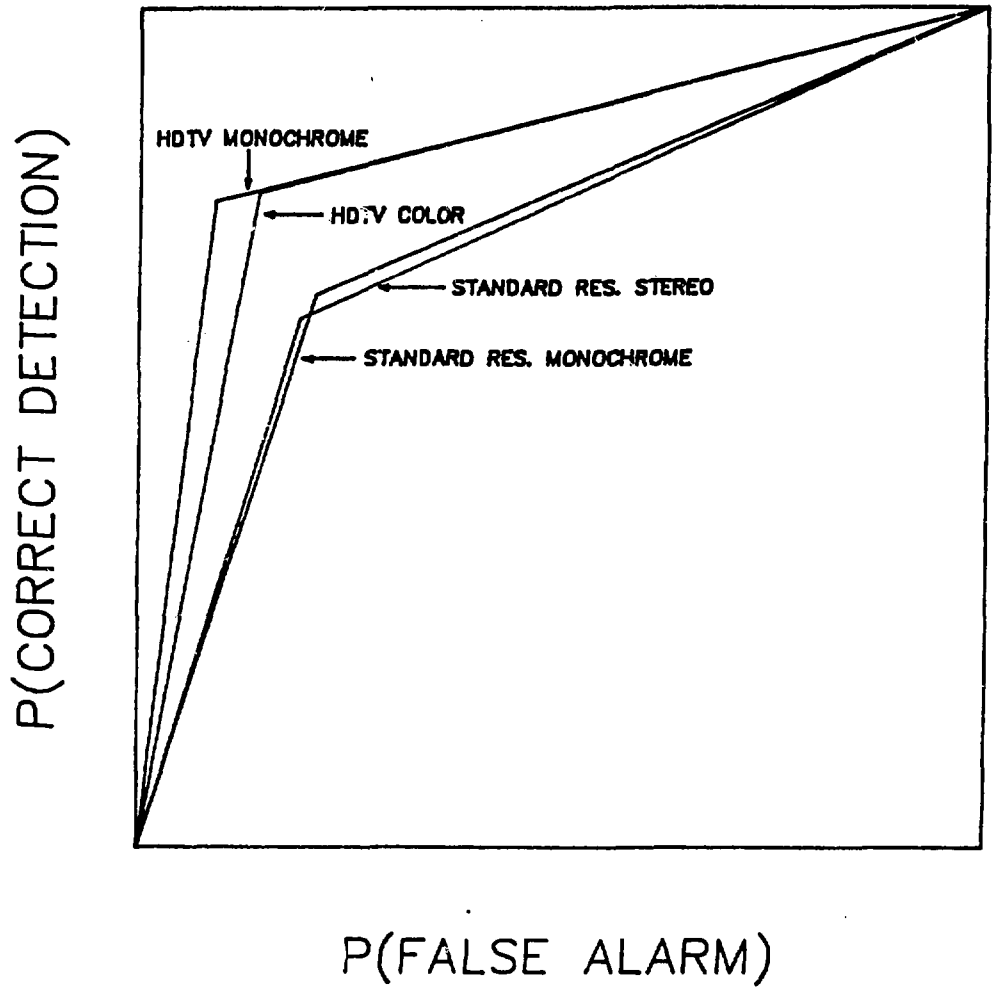

Fig. 6. Receiver operating characteristic (ROC) curve for each television system.

Operator sensitivity was slightly higher with standard-resolution monoscopic television than with the stereo system, but the difference is not large enough to be considered evidence of an advantage for the monoscopic system.

Discussion

These experiments provide an evaluation of high-definition television which is fairly wide in scope. The tasks selected are representative of a variety of the tasks which must be routinely performed to remotely maintain a nuclear fuel reprocessing facility. The results and conclusions are applicable in a wide range of situations. However, in attempting to cover so many different situations, the depth with which each was covered was limited. For example, the experiment concerned with visual inspection was limited to one task. In an operating nuclear facility, many inspection tasks would have to be performed, some with very different types of objects to be inspected and very different types of flaws than those used in the experiment. The difference in tasks might produce different results from the pattern reported here. Inspection for cracks in welds often uses penetrant dyes to highlight cracks, for example. In this situation, there might be a performance advantage for color television systems. Some comments concerning the generalizability of the results from the depth-perception task have already been made. Other tasks that require depth information for successful performance should be defined, and the performance of the different television systems should be evaluated for those tasks.

Summary

The results of the three experiments show that in some areas, use of HDTV can lead to improvement in teleoperator performance. The HDTV is superior to monoscopic, monochromatic, standard-resolution television and to stereoscopic television for remote inspection tasks; it is less proficient than stereo television for interpretation of object distance in the remote area. The HDTV leads to a lower rate of errors committed which performing remote-handling tasks, but it does not reduce the amount of time necessary to perform the tasks.

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