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**ROBOCON: A GENERAL PURPOSE TELEROBOTIC CONTROL CENTER\***

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## ROBOCON: A GENERAL PURPOSE TELEROBOTIC CONTROL CENTER

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### ABSTRACT

This report describes human factors issues involved in the design of RoboCon, a multi-purpose control center for use in U.S. Department of Energy remote handling applications. RoboCon is intended to be a flexible, modular control center capable of supporting a wide variety of robotic devices.

### INTRODUCTION

The Carnegie-Mellon University (CMU) in Pittsburgh, PA recently responded to a request for proposal (ROA DE-RO21-94MC31305, "Applied Research and Development") from the U.S. Department of Energy Morgantown Energy Technology Center (METC) for work to develop a unique, re-configurable operator interface system for use in DOE robotic decontamination & dismantlement (D&D) systems. The re-configurable operator interface is termed RoboCon, for ROBOTics Operator CONsole.

The purpose of this system is to provide a flexible operator interface platform, applicable to many selective equipment retrieval systems, allowing for cost-effective testing and deployment of various robot systems for demonstration and field use. The benefit is to be seen in the ability to control different robot systems through simple interchange of interface modules within the operator's cockpit, and the porting/development of interface display software to a common computing platform. Cost savings can be realized throughout this system, since it represents a powerful and flexible test platform for evaluating the various robotic systems currently available or under development for the Office of Technology Development (OTD) D&D program.

Recognizing the critical need for professional support in the area of human factors/ergonomics, CMU determined that the Robotics & Process Systems Division (RPSD) of the Oak Ridge National Laboratory is uniquely qualified to provide such support. The RPSD has a long history of applied and basic research and development (R&D) in this area. CMU determined that this capability does not exist in the private sector, and, therefore, determined to include ORNL in this R&D task.

RPSD provided R&D support to CMU in the area of human factors/ergonomics for applied telerobotic systems for a variety of inspection, maintenance, repair, and decontamination & dismantlement tasks. This paper documents the results of work that took place within FY 1996. The work included two major human factors task areas: (1) robot task analysis and (2) control center design. In addition to these tasks, RPSD also provided support in the area of operator training and design evaluation. This paper discusses some important issues in each of these areas and presents some preliminary conclusions and recommendations.

### THE DESIGN PROCESS

The ongoing design of the control center involves three phases: (1) robot task analysis; (2) workstation design; and (3) design evaluation. This paper focuses on task analysis and workstation designs. The task analysis generated an exhaustive list of tasks required by the CP-5 mission, which were divided into their smallest meaningful components. The tasks provided the basis for a list of required functions and the necessary controls, displays, and interfaces to be incorporated into the control center. Workstations were designed to incorporate control and display panels while

satisfying ergonomic design guidelines for safe, efficient, system operation and crew interaction.

### Design Guidelines

To satisfy the design requirements for RoboCon, the following general guidelines are being applied:

1. *Simplicity.* The design concept is intended to represent the simplest form consistent with functional requirements and expected service conditions while using the minimum number of displays and controls.
2. *Ergonomic design.* Safe, efficient crew functioning and system performance depends on the fit of the design with human physiological and psychological capacities. Workstation dimensions and designs are intended to accommodate the population of likely operators' body dimensions and requirements for visual displays.
3. *Consistency.* Interfaces are designed to be similar, so operators can operate any piece of equipment without having to adjust to different movements or different displays.
4. *Flexibility.* Wherever possible, controls and displays allow access to more than one piece of equipment or display more than one kind of information. Controls and displays for RoboCon must be capable of adaptation to operating qualitatively different types of remote equipment, e.g., a backhoe or a servomanipulator.
5. *Integration.* RoboCon requires integration of workstations for cooperation and interactive effort, by allowing operators to switch controls, to see each other's camera views, and share control efforts.
6. *Existing components.* Wherever possible, the RoboCon control center concept uses standard, off-the-shelf components that meet or exceed all human factors standards and have demonstrated reliability.

### ROBOT TASK ANALYSIS

In the robot task analysis phase, the control requirements were identified and evaluated from an er-

gonomic perspective. This required listing all functions that must be performed from the control room, organizing functions into related groups, and allocating functions to man and machine. The outcome of this phase of the design was a function plan for the control room workstation. Because the RoboCon system is an emerging system, this concentrated on known examples of equipment which might be operated from RoboCon. The analysis must be reviewed prior to developing final workstation concepts to ensure that the conclusions contained within it remain applicable.

The task analysis provided (1) the functions for the major subsystems of a typical manipulator system including a retrieval manipulator, end-effectors, sensor systems, and transport support system, (2) the functions for vehicular manipulators and, (3) optional functions for some specific types of vehicles.

The RoboCon system will comprise systems capable of teleoperation, autonomous operations and mobile vehicular operations. The user will control the system using manual or supervisory control depending on the particular application and the system in operation. Under manual control the user will control every movement of the machine by directly controlling servomotor operation. Under supervisory control, the user's role shifts from continuous manual control to symbolic interaction, depending on the circumstances. In some cases a combination of manual and supervisory control will be necessary.

### PRELIMINARY CONCEPTS

The purpose of the RoboCon project is to provide a more efficient and safe control center for DOE remote handling and robotics applications. It will do so in part by emphasizing human factors/ergonomics in the development of control center concepts. It will provide what expert operators have asked for in the past:<sup>1</sup>

First, work stations need to support operator efficiency through ergonomic chairs and large, color monitors in optimum viewing locations. Second, an efficient hand-control interface calls for a light, mobile hand-controller with the capacity for resolved bilateral (force-reflecting) position control and adjustable force-reflection. Third, each remote camera needs separate, dedicated controls (a departure from current practice), ideally including the capacity to adjust the location of remote cameras. Finally, the room layout needs to place opera-



tors in close enough proximity for conversation and efficient alternation of work roles.

#### - Displays

It appears that a display arrangement featuring several medium-sized screens capable of providing real-time video images and graphics will provide RoboCon with the best combination of flexibility and functionality. A single large display with small subsidiary displays does not seem appropriate because of a lack of flexibility, particularly in terms of providing multiple video images. Large screen displays are more capable but seem to require too much space and to present images inefficiently in terms of visual angle per image unit. Multiple large displays may provide a more immersive environment in that they can occupy a larger portion of the visual field; but this has not been demonstrated to be advantageous.

Other alternatives have not been considered and may require future investigation. Head mounted displays and other methods for stereoscopic presentation, for example, are favorably regarded in some quarters. However, many of these extremely immersive displays may in fact be counter-productive. They may induce "simulator sickness" or disorientation over long-term use and reduce local (as opposed to remote) situation awareness. Furthermore, stereoscopic television has not been shown to be uniformly beneficial for performance of remote handling tasks.<sup>2, 3</sup>

#### Control Chair

RoboCon users will sit in front of an array of computer graphic and television monitors. The size and number of monitors requires that the seat be some distance from the display screens to give optimal visual angles for displayed images. This means that control consoles must be mounted on or near the RoboCon chair rather than on traditional control/display consoles, which would be attached to the monitor cabinets.

Given the need for chair-mounted consoles, it will be best if the RoboCon chair is static, i.e., fixed in a single position in the cockpit. Some allowance for seat adjustments should be made, for example in seat pan height, backrest slope, and position relative to displays and controls (forward/backward).

*Console Concept: Joystick Compatible.* Figure 1 illustrates the console concept. The console consists of three parts: the primary console is located directly in

front of the user and two secondary consoles are located to the sides of the primary console, forming two wings of the console. The whole console is tilted 11 degrees above the horizontal to provide a viewing surface that is nearly perpendicular to the user's line of sight to the console surface and yet easy to see over for viewing the main displays.

The concept shows two joysticks mounted on the wings. These locations were selected to provide optimal comfort and efficiency for joystick controllers. The locations are approximately equivalent to armrest-mounted joysticks and were selected for optimal comfort and controllability.

*Console Concept: Master-Controller Compatible.* Special chair consoles must be considered for use with replica master controllers. Master controllers will serve as the primary control for such systems and may need to be free to move within much of the operator's 3-dimensional grip radius. To keep this area free of obstructions, it may be necessary to mount consoles to the side of the chair or to re-position them, perhaps stowing them away when not needed.

#### Chair Concept Summary

This sub-section has presented a set of control chair and control chair console concepts suitable for use in the two principle RoboCon missions. These are (1) operation of telerobots that do not include replica master controllers and (2) operation of telerobots that include replica master controllers. Because of the large working envelope of master controllers, the first concept features limited secondary control consoles mounted to the sides of the chair and slightly below the seat pan. The second concept features more powerful and flexible consoles mounted directly in front of the user.

#### OPERATOR TRAINING

Development of training programs begins with identifying the functions to be performed by a system and the characteristics of the users of the system.<sup>4</sup> This permits development of training approaches that match the needs of the mission and the capabilities of the users. Because RoboCon is a system that may operate in a variety of missions and with a variety of different types of users, training programs must, to a certain extent, be developed on an application by application basis. However, some principles for RoboCon training may be developed from the function analysis reported

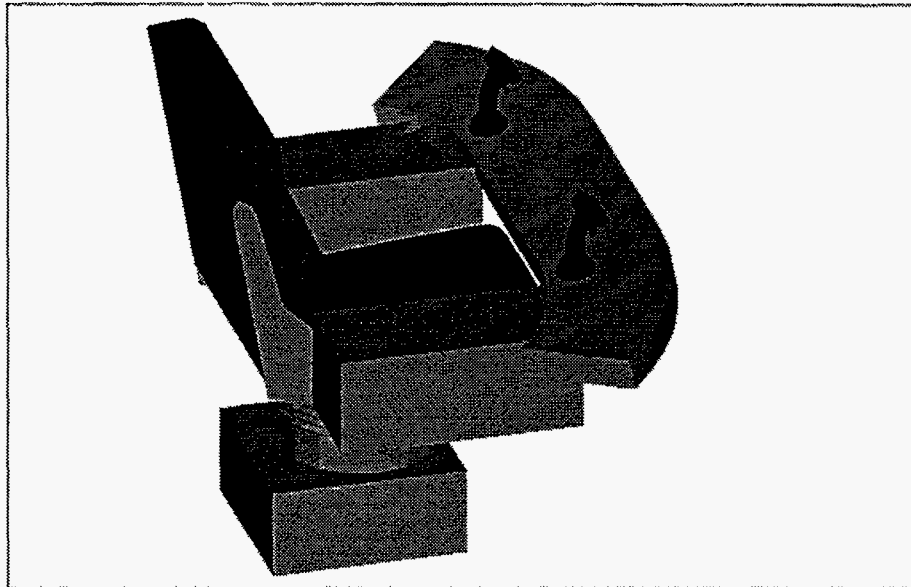


Figure 1. Joystick compatible chair console concept.

in an earlier section of this report. These principles may assume a set of user characteristics based on the most likely set of candidate users of RoboCon . This permits behavioral objectives for a RoboCon training program to be determined.

First, it will be important to teach users to understand the menu structure so that they can quickly find the screens that they need. Users should be able to identify which menu-based controls and displays they need and quickly determine the menu navigation path that will take them to the screens containing them. Training for using the menu system must concentrate on teaching the menu structure. This is a memory ability.

Second, camera control will be important for manipulation and vehicle driving. This may require use of a menu to assign controls to one of a set of available cameras, which will be affected by user training with the menu system. Once the proper camera control to remote camera mapping is established, it will be necessary for operators to be able to quickly select which control they want to use (e.g., pan versus zoom) and which way to activate the control to achieve the desired result. This is, first, a memory ability and then a response orientation ability and an arm-hand steadiness ability.

Vehicle driving, remote manipulation, and tool operation are tasks that are properly application-

specific. All RoboCon applications will require menu navigation and camera control, but they won't all require remote manipulation, for example. Training requirements for these tasks can be outlined, but final training requirements must be determined on an application by application basis.

Because RoboCon is, in essence, a human-computer interface, instructional techniques featuring use of computer simulations seems a naturally applicable technique. Two approaches seem particularly relevant. First, the system could be used to conduct computer assisted instruction (CAI) to introduce users to key system features. This technique has the advantage of actively involving the trainee, providing individualized and self-paced instruction, providing immediate feedback, and the ability to update the training task sequence to meet the needs of new equipment or to respond to weaknesses identified in the course of training or operations.

Second, the system could be used to simulate real operations. Users could be required to complete task scripts (see the section on system evaluation for examples) that introduce them to important features, require successful completion of task-related behaviors, and provide feedback about performance. Scripts could be developed at several instructional levels, from simple ones designed to structure menu system exploration to complete mission scenarios for sharpening the skills of advanced users or introducing them to new missions.

Simulation of real operations in the context of telerobotics should be considered to include performance of real tasks using mock-ups. This sort of exercise provides the most accurate modeling of real-world tasks and should provide the highest transfer of training, providing the task mock-ups are accurate.

Both CAI and simulation are capable of meeting the psychomotor and cognitive abilities needs of RoboCon and, with thoughtful development, be tailored to meet the capabilities of any pool of potential RoboCon users. Other techniques may be useful as supplements. For example, lectures and group discussions of training exercises could be used to highlight key features of the interface and introduce trainees to the goals and requirements of the training. However, the fundamental training techniques should be computer-assisted instruction and simulation, to provide the best transfer of performance from training to actual operations.

Table 1 outlines an instructional program for RoboCon. It is based on the instructional techniques selected above and on the concept of part-task training. Part-task training refers to the idea that complex skills may be learned by attaining proficiency on sub-tasks comprising the complex skill prior to attempting to complete the whole task. This divides the learning into reasonable chunks, which may be easily mastered. Early tasks in the training sequence concentrate on attaining proficiency with a RoboCon component; as trainees proceed through the sequence the sub-tasks are gradually assembled into full-blown system operation. This is clear from the "Needs Addressed" column of Table 1, which shows greater numbers of the training needs addressed by each succeeding exercise. Each exercise builds on the preceding one until the trainee attains complete mastery of the system.

The instructional sequence outlined in Table 1 paints the training program with broad strokes. Each stage in the sequence may require multiple repetitions of the exercise listed to attain proficiency, and full coverage of RoboCon features may require that each exercise in the table is in fact a set of exercises. Full details of a training program for RoboCon are beyond the scope of this document.

## DESIGN EVALUATION

Usability testing is necessary in order to evaluate the design of the RoboCon user interface. An evaluation protocol has been developed and includes three prototype tasks to be used in evaluating the RoboCon

human-computer interface (HCI). Quality assessment of the visual display screens will provide information that will be used in the iterative design process to enhance future versions of the interface system. Specifically, the use of the Questionnaire for User Interaction Satisfaction will prove to be of iterative value in the design process providing further information which may enhance the interface system's overall functionality and efficiency thereby improving operator performance of teleoperation type tasks. An improvement in overall system performance would be the end result making usability testing a highly desirable goal for any evaluation and testing program.

Usability testing or user acceptance testing benefits the design process, improving the functionality of the HCI. The process of iterative design enables the redefinition of design goals and the interface system in accordance with the human factors principles. It is the principles of compatibility, consistency, memory, structure, feedback, workload and individualization that should guide the design process to its completion so that summative evaluation can take place.

The costs of not conducting user acceptance testing include increasing the amount of time spent on the iterative design of the user interface. Since it is the iterative design process and the feedback loop of setting design objectives, testing, and redesigning the interface that results in a usable menu interface, without testing less confidence could be placed in the menu system's ability to allow operators to perform teleoperation tasks.

In summary, the benefits of usability testing involve meeting design objectives in accordance with human factors principles of good design. The principles of compatibility, consistency, structure and memory are of utmost importance to designing the interface in accordance with the human ability to process information in an organized manner through the use of appropriate arrangement and coding factors. The principle of feedback is important to the extent that status indicators are used to send error messages to the operator. And the principles of workload and individualization are important as an optimal level of workload and assessment of computer system expertise will enhance operator performance and reduce errors.

## SUMMARY

This paper describes human factors contributions to the ongoing RoboCon project made by the Robotics & Process Systems Division at the Oak Ridge National

Table 1. Instructional sequence for RoboCon .

Exercise	Objectives	Technique	Needs Addressed
RoboCon briefing	1. Trainees will become familiar with RoboCon controls and displays; 2. Trainees will be prepared for operation in later exercises	Lecture, audiovisual, or CAI	Response orientation
Menu structure introduction	Trainees will become familiar with the arrangement of menu screens	CAI	Memory; Response orientation
Menu operation	Trainees will learn to navigate through the menu structure to find screens needed at various mission phases	CAI or simulation	Memory; Response orientation; Arm-hand steadiness; Control precision
Camera control	Trainees will learn to use video cameras to inspect a remote environment	Simulation (perhaps coupled with CAI)	Memory; Response orientation; Perceptual speed; Arm-hand steadiness; Control precision
Remote operations (vehicle and manipulator exercises should be separate, with vehicle operations coming first)	Trainees will become proficient at operating remote systems in the context of small-scale tasks	Simulation	Rate control; Arm-hand steadiness; Manual dexterity; Response orientation; Perceptual speed; Spatial/mechanical
Mission completion	Trainees will demonstrate ability to complete a typical mission	Simulation	All

Laboratory. These contributions included (1) identification of robot-control center interface criteria, (2) robot function analysis, (3) human-machine interface design and review, (4) development of guidelines for user training, and (5) development of methods for design evaluation.

#### REFERENCES

1. E. Sundstrom, J. V. Draper, A. Fausz, and H. Woods, "Expert Operator Preferences in Remote Manipulator Control Systems," Oak Ridge National Laboratory, Oak Ridge, TN ORNL/TM-12932, June 1995.
2. J. V. Draper, Y. Fujita, and J. N. Herndon, "Evaluation of High-definition Television for Remote Task Performance," Oak Ridge National Laboratory, Oak Ridge, TN ORNL/TM-10303, April 1987.
3. J. V. Draper, S. Handel, C. C. Hood, and C. T. Kring, "Three experiments with stereoscopic television: When it works and why," Proceedings of the 1991 IEEE International Conference on Systems, Man., and Cybernetics, Richmond, VA, 1991.
4. I. L. Goldstein, *Training: Program Development and Evaluation*. Monterey, CA: Brooks/Cole Publishing Company, 1974.

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