RoboCon: Operator Interface for Robotic and Remote Applications

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ABSTRACT

Carnegie Mellon University (CMU) and Oak Ridge National Laboratories' (ORNL) Robotics and Process Systems Division (RPSD), have developed a state-of-the-art robot operator control station, dubbed *RoboCon*, with standardized hardware and software control interfaces to be adaptable to a variety of remote and robotic selective equipment removal systems (SERS) currently funded by the DoE's Office of Technology Development (OTD) Robotics Technology Development Program (RTDP). The human operation and telerobotic and supervisory control of sophisticated and remote and robotic systems is a complex, tiring and non-intuitive activity. Since decontamination & decommissioning, selective equipment removal, mixed waste operations and in-tank cleanup are going to be a major future activity in Department of Energy's (DoE) environmental restoration and waste management (ER&WM) cleanup agenda, it seems necessary to utilize an operator control station and interface which maximizes operator comfort and productivity. The purpose of this system is to provide a flexible operator interface platform, allowing for cost-effective testing and deployment of varied remote & robot systems for demonstration and field-use.The benefit is to be seen in the ability to control different systems through simple interchange of interface modules on the operator's chair, and the porting/development of interface display software to a common computing and programming platform. Cost savings can be realized through this system, since it represents a powerful and flexible test platform for evaluating the various remote systems currently available or under development through the OTD program. The proposed system (see Figure 1:) consists of a large single-screen projection-TV system framed on both sides by several high-resolution TV monitors, stereo speakers, a reconfigurable operator console and control chair module with various removable interface modules (such as joysticks, buttons, touch-screen, etc.), all ergonomically mounted on a raised platform and integrated with the display and control electronics. The embedded computing consists of rack-mounted SUN, SGI and PC-systems used to operate the consoles and to house the remote system-control and interface computing. The entire system is configured to optimize the information display and operational efficiency of a human operator controlling or supervising remote systems, control the display configuration, live video links and graphical overlays and to input information using the hard-wired switches and the touch-screen display.

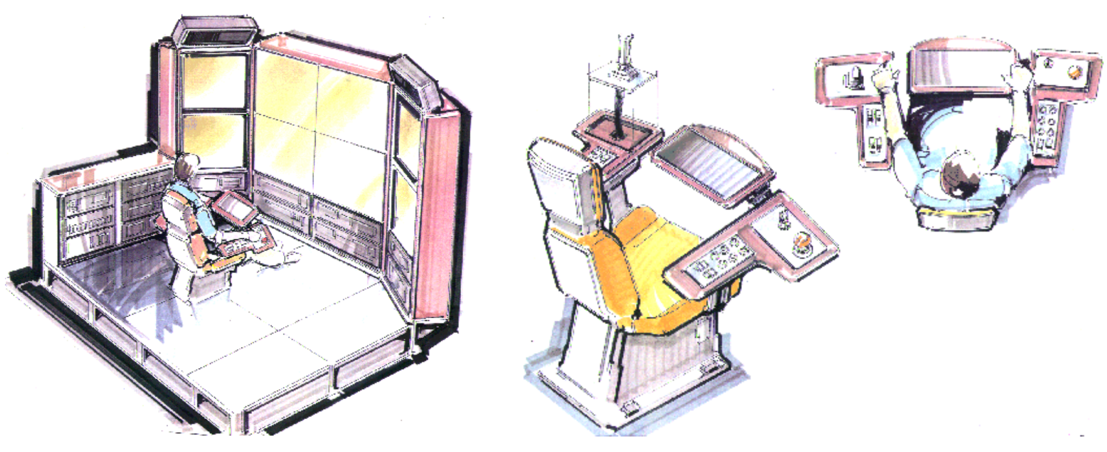

Figure 1: *RoboCon* conceptual system layout with up-close view of operator control-chair module

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1. INTRODUCTION

The purpose of *RoboCon* is to provide a state-of-the-art control station for the evaluation and experimental phases of DoE's Robotics Technology Development Program (RTDP)- and Large-Scale Demonstration (LSD)-program for a variety of focus areas, such as Decontamination and Dismantlement (D&D), Tanks and Mixed Waste. The control station provides the latest in display, control and software technologies for the upcoming testing and experimentation phase of the robotics development program underwritten by the DoE's OST. The console is designed to be flexible in terms of hardware and software configurations, to allow for

- *testing of optimized display and control configurations,*
- *reconfiguration of the control panels and consoles for varied robot systems, and*
- *tailoring of the control station to suit different operators.*

The need for such a control station is to be seen in the assertion that the control station and its interfaces play a big role in the teleoperation tasks of past, current and future robotic systems. The teleoperated robot system is but one part of the puzzle, since the human operator is responsible for controlling it. Hence the efficiency of the operation and most probably also the capability of any system hinges on the adeptness of the operator controlling the machine. The impact of a properly configured control station and operator interface are thus crucial to the accuracy, dexterity and productivity of any operator controlling a remote worksystem. The best configurations for the display and control systems, and the software modules controlling the system displays, interfaces and outputs, need thus to be determined and evaluated through experimentation and real-world validation trials, just as much as the robot system has to be tested and its usefulness validated in such trials. The *RoboCon* system provides the robotics program with such an operator interface testing platform, with the latest in technology, allowing its utility and relevance to extend over the next one to two decades.

The purpose of this system is to provide a flexible operator interface platform, applicable to many robotic applications, allowing for cost-effective operator training, 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 on the operator's chair, and the porting/development of interface display software to a common computing and programming platform. Cost savings can be realized through this system, since it represents a powerful and flexible test platform for evaluating the various robot systems currently available or under development for the OTD D&D program. We developed the system performance specifications with the assistance of the staff at the Oak Ridge Robotics and Process Systems Division (RPSD), before we began to design and detail the overall layout of the system. We focussed our attention on ensuring that the *RoboCon* system is able to interface to, at the beginning, to several key DoE robotics systems, such as *Rosie*, *Houdini* and the *DAWM* (Dual-Arm Work Module). However, the architecture of the system is such that every system abiding by some very generic interface requirements will be able to be easily interfaced to *RoboCon*. The system has simple menu- and graphics-driven software modifications interfaces to be used by a trained programmer, in order to allow the interface of a new robotic system, without the need for extensive re-design, electrical routing and long-winded software developments.

2. BENEFITS & APPLICATIONS

The *RoboCon* system is a solution to harness the powers of the latest in display and controls technology (hardware and software) and allow it to be configured to best suit the individual remote device, task and operator. The *RoboCon* system allows for the standardized training and evaluation of remote-equipment operators. In addition, it represents an experimental platform that provides the robotics development testing agenda a reconfigurable platform to test new display configurations, operator console layouts and functionalities, computing platforms, communications protocols and other hardware control interfaces such as joysticks, track-balls, and other master input devices.

As such, its applications are fairly broad, except that we believe it to have a potentially large impact in several areas, such as:

1. **training and certification of remote equipment operators within the DoE (via the IUOE),**
2. **find use as an integral element of any ongoing/future Large-Scale Demonstrations (such as Hanford, etc.),**
3. **crucial element of telerobotic performance testing for existing robotic systems hardware (*Rosie, HOUDINI, DAWM*, etc.),**
4. **use as a tool for human factors research ongoing at DoE laboratories, and**
5. **setting standards for interface modes and protocols for future robotic systems.**

Alternate uses are currently envisioned for this system, including the ability to provide supervisory displays and possibly controls for different robot systems in different activities. The *RoboCon* control station chair, due to its modularity, can accommodate different control panels and consoles, control CPUs and even control software as long as all the interface specifications (mechanical, power, data) are adhered to. The benefit of developing the *RoboCon* system, is thus the need for only small and reduced complexity and cost consoles for current or future robot developments, since the backbone (displays, power and computing) and the development environment (software modules, computing platforms and development packages) have already been developed and can thus be provided.

3. SYSTEM DESIGN

3.1 System Specifications

The *RoboCon* system was developed based on a generic description as defined below:

"RoboCon is a state-of-the-art standardized and reconfigurable operator control console to enable (i) unified human-factor evaluations, (ii) training, (iii) operation and (iv) hardware/software interface standardization associated with remote operation of DoE's remote/robotic heavy-equipment/D&D/SER, mixed waste and in-tank remediation systems, using a common electrical interface standard, reconfigurable interface- and display-configuration software, and display modules.

Based on this description, a set of key design drivers was formulated, which can be summarized as follows:

- **Display - Reconfigurability**
  - *We need the ability to rearrange and reconfigure display modules*
  - *We need the ability to combine and locate video/data anywhere on the displays*
- **Electrical Interfaces - Generic and Accessible**
  - *Provisions need to be made for types (analog, binary, serial, parallel, E-net, etc.), speeds (low and high bandwidth) and quantities (numbers of pins) of interfaces*
  - *We will need to maximize interface-capabilities for existing DoE remote systems*
  - *We need to improve the ease of interfacing to equipment sensors & actuators (console) and custom input devices (control chair panels)*
- **Software - Usability and Capability**
  - *We need to use OEM software wherever possible - in the areas of GUI & COMM especially*
  - *We need simplicity of reconfiguration of display types/pages, etc. using touch - i.e. avoid the use of keyboard except for start-up and log-in*
  - *We should implement point-and-click/drag iconic configuration programming to minimize programming skills and -time required by configurer/operator.*

These design drivers were then turned into a set of performance specifications, which included the following:

- **Display**
  - *Use of modular stackable/moveable CRT-display modules (1 to 2 operators)*
  - *CRT and projection screen display systems (15 to 75+ KHz)*
  - *Video- (8x8) and data (n x) -switching capability*
  - *Inclusion of sound feedback and recording (incl. video)*
- **Control Chair**
  - *Control chair with controllable height, displacement, rotate, recline, etc.*
  - *Configurable chair to allow use with 'manipulatorized' remote systems*
  - *Customizable and exchangeable chair panels for various remote systems*
  - *Touch-screen input for setup and real-time configuration*
  - *Console-mounted data-interface connections to receive/send system info*
- **Power/Computing/Interface Console(s)**
  - *Segregated and moveable units with standardized and accessible connects*
  - *Powered by 115VAC, 3 x 30A circuits*
  - *UPS backup for computing systems (not displays)*
  - *Standardized interfaces for current and future DoE remote systems*
- **Software Systems**
  - *Off-the-shelf display (LabView^{TM}) and communications (NDDS^{TM}) systems*
  - *Iconic, mouse-driven display-layout configuration by developer/operator*

3.2 System Overview

The RoboCon system is highly reconfigurable, by virtue of allowing any display configuration to be implemented. Some of the possible configurations, including the main implemented configuration, are shown in Figure 2:.

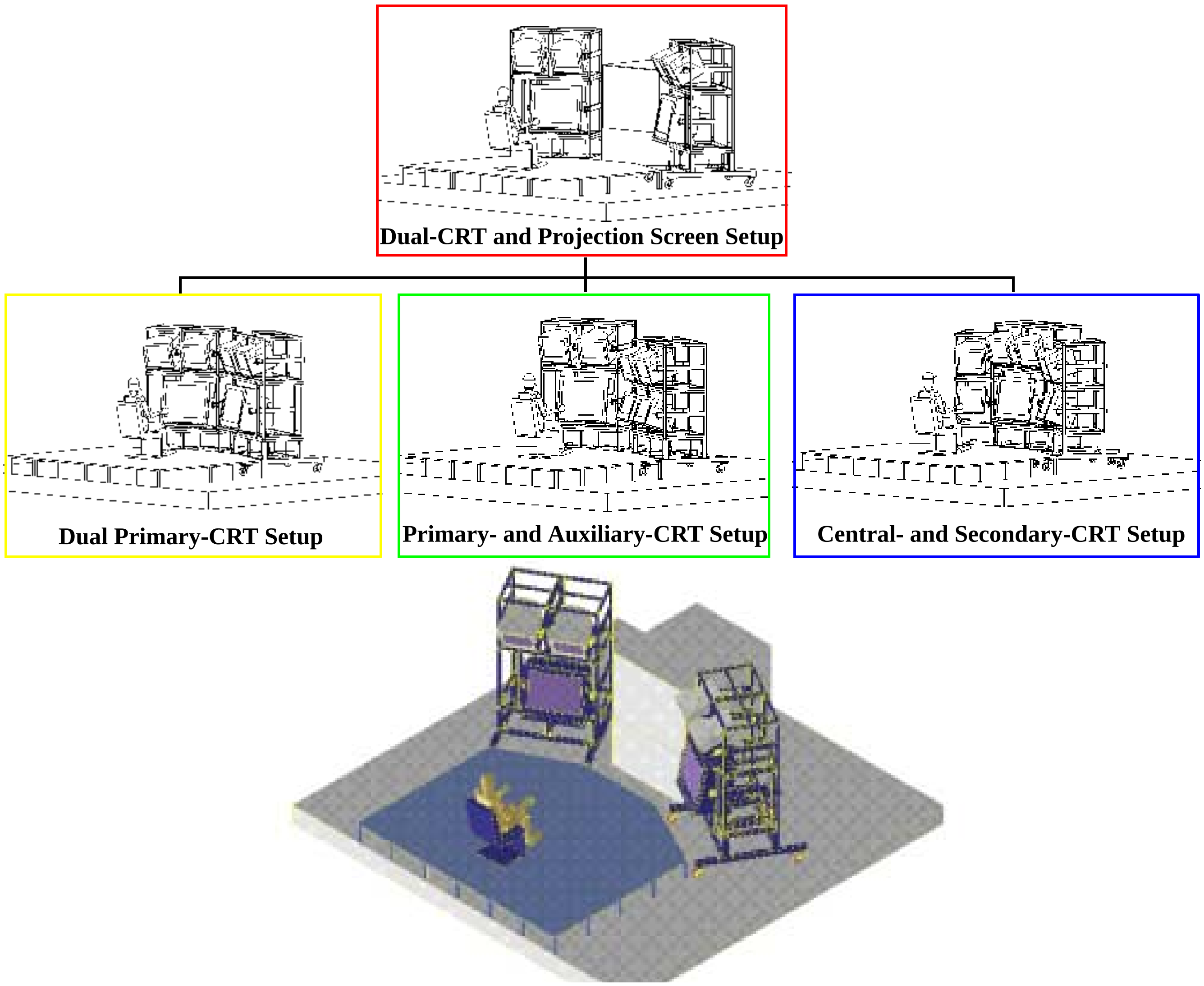

Figure 2: RoboCon Display Configurations, including the basic/proposed version

A diagrammatic architecture of the complete *RoboCon* system is depicted in Figure 3: on page 5. Notice that the operator communicates through the touch-screen, which displays LabView^{TM} GUI-pages running from a local PC with additional A/D inputs from the chair input devices, and communicating with a SUN-SPARC machine via NDDS over ethernet. The SUN runs the master LabView^{TM} controller and NDDS dispatcher, controlling the video-switcher and sending reformatted GUI-pages to the SGI, which then creates several display pages blended with multi-video inputs from any external video sources. Communication to and from the outside is accomplished through an interface rack, where signals can come in via various media (serial, parallel, ethernet, analog, binary, etc.), and are then converted into low- and high-bandwidth data- (incoming) and control-streams (outgoing). The *RoboCon* display system will then display process and control data based on the operator-selected GUI-format, while sending control packets from the control devices (joysticks, buttons, etc.) to the robot controller via the interface box.

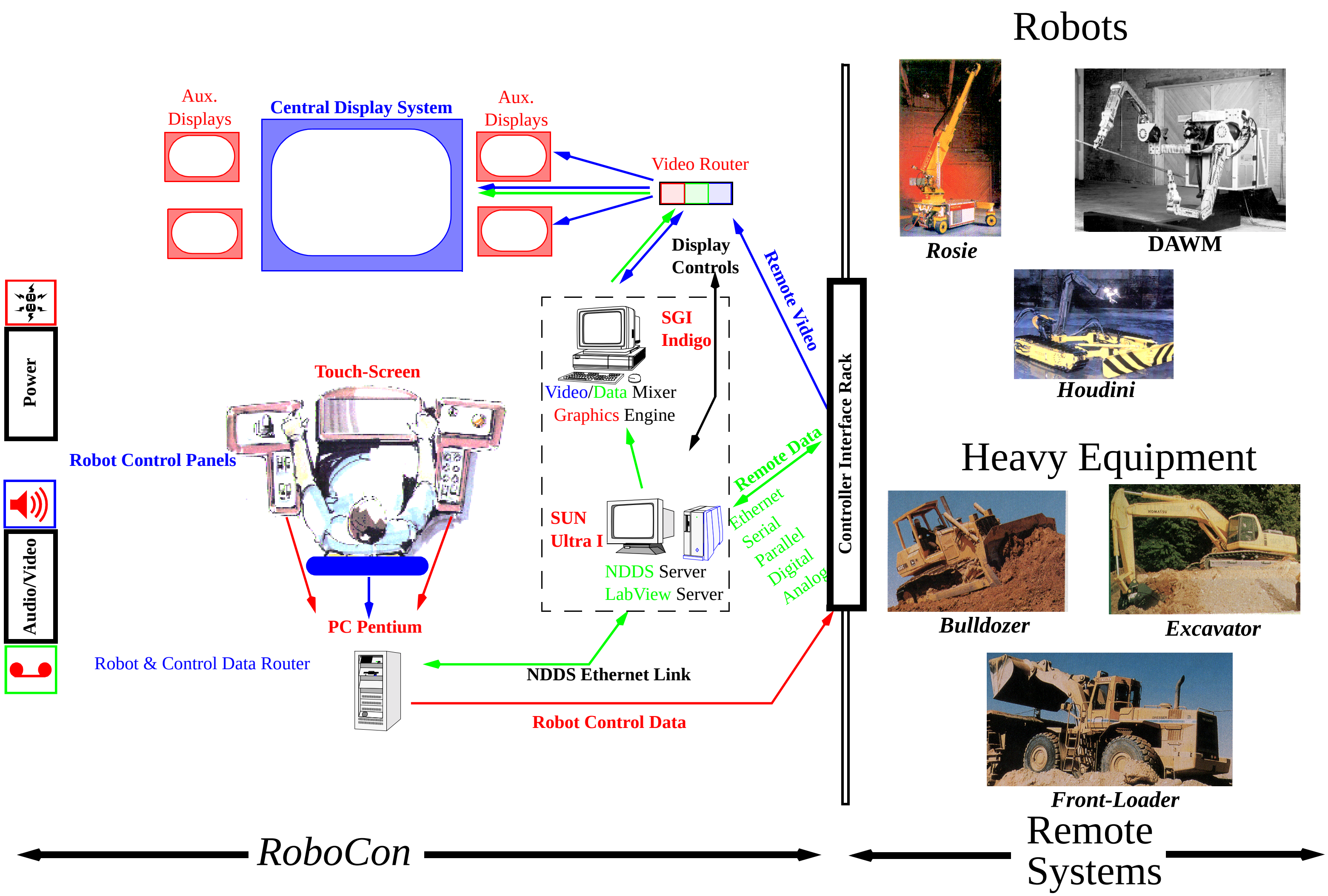

Figure 3: *RoboCon* Operational Diagram

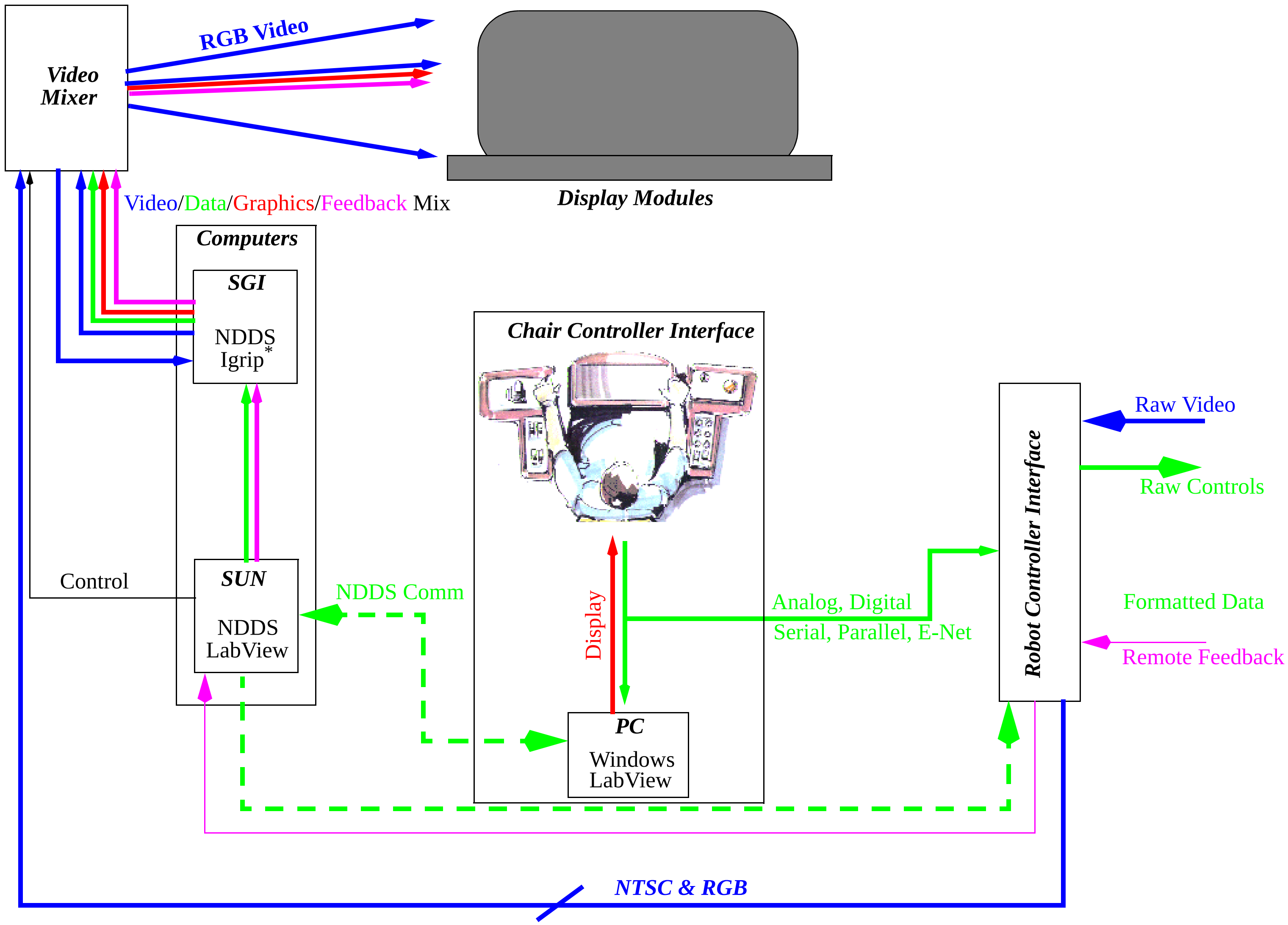

Figure 4: *RoboCon* signal-flow diagram

The signal flow from the outside and within *RoboCon* is as shown in Figure 4: on page 6. Notice that all video and audio signals coming from the remote equipment are patched through to the video router, while all feedback signals are passed on to the SUN (via different formats such as serial, parallel, E-net, etc.), where they are used for display purposes via LabView, or passed on to the PC for touch-screen display. Commands generated at the control chair are either packetized and sent via communications link (serial, parallel, ethernet) to the remote equipment, or if time-critical, passed on directly in their raw format (analog, binary, etc.). All display-screens and video-overlays are handled by the SUN and SGI, and then routed to different displays via the video-switcher.

4. PROTOTYPE SYSTEM

4.1 Pictorial Descriptions

The *RoboCon* prototype was completed and demonstrated to the DOE at CMU, using a pre-prototype teleoperated tank cleanup system, dubbed *Houdini*. The final system was shrouded and painted upon conclusion of the functional demonstration, with a final overall look as shown in Figure 5:

Figure 5: *RoboCon* Final System Picture

The chair-console for *RoboCon*, was molded in fiberglass and painted, while an ABS-shroud was poured for the touch-screen (also painted). The PC computer-system was mounted on rails and packed behind the operator's chair, again shrouded with fiberglass-molding, and finished off with a removable anodized panel, allowing access to the rear of the chair. The finished operator console platform, including the movable platform, the armrest and interface consoles, the articulated touch-screen and the operators' chair, are shown in Figure 6:.

Figure 6: *RoboCon* Operator Platform: Chair, Panels and Touch-screen

The seated depiction of the same system is shown in Figure 7::

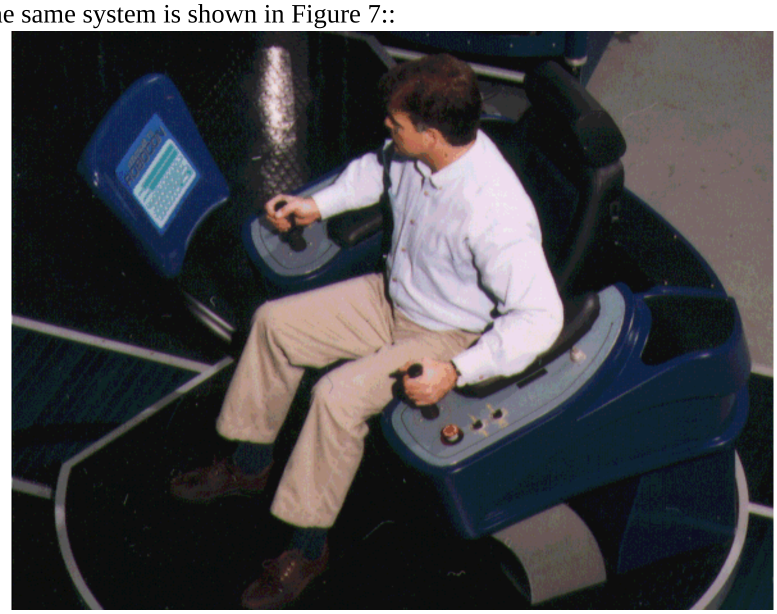

Figure 7: Operator seated in *RoboCon* system

• **Control Panels**

The control panels, which were designed for the *Houdini*-system demonstration, are depicted in Figure 8:, showing the left panel which includes a track-control joystick and a two-dimensional camera-pan controller, and the right console, which contains another track control joystick, as well as an emergency-stop button, and reconfiguration switches to collapse/expand the robot, and to raise/lower the front-mounted plow of the tank-robot:

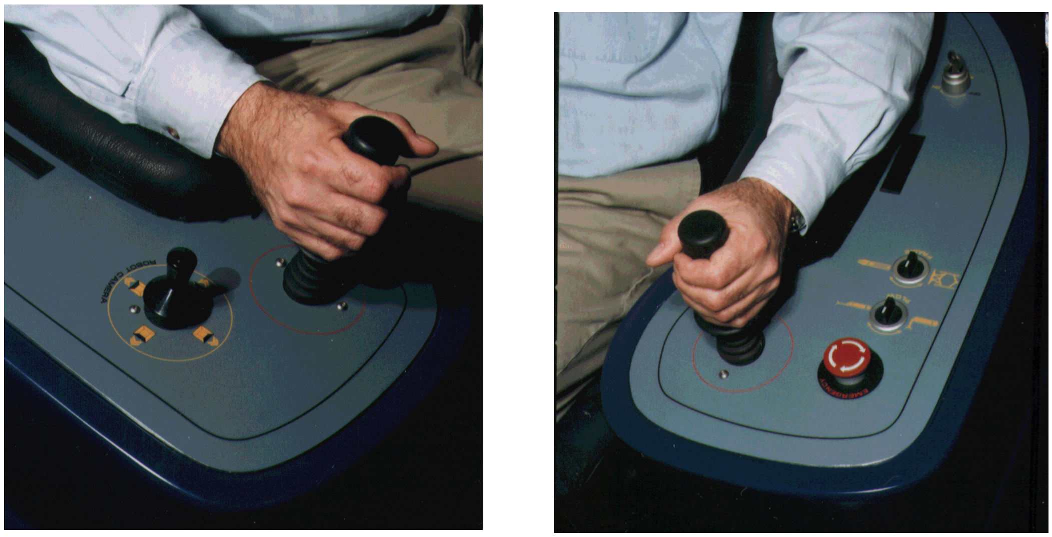

Figure 8: *Houdini* control panels (left and right)

The control panels were designed so as to be easily removable. The actuation, internal removable cabling and hinges, are shown in Figure 9::

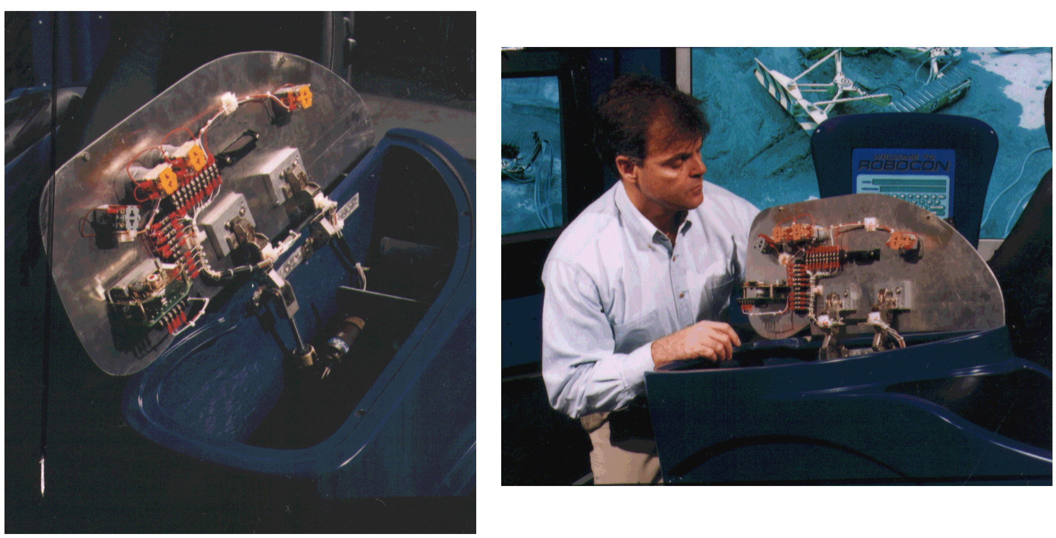

Figure 9: Control panel internals and mechanical (hinges), & electrical (connectors on panels) interfaces

• **Rack Panels**

The panels on all racks were laid out carefully, and laminated with photographically-generated displays in order to properly label all connections. An example of this process can be seen in Figure 10: on page 10, depicting the power control rack and audio/video control panels:

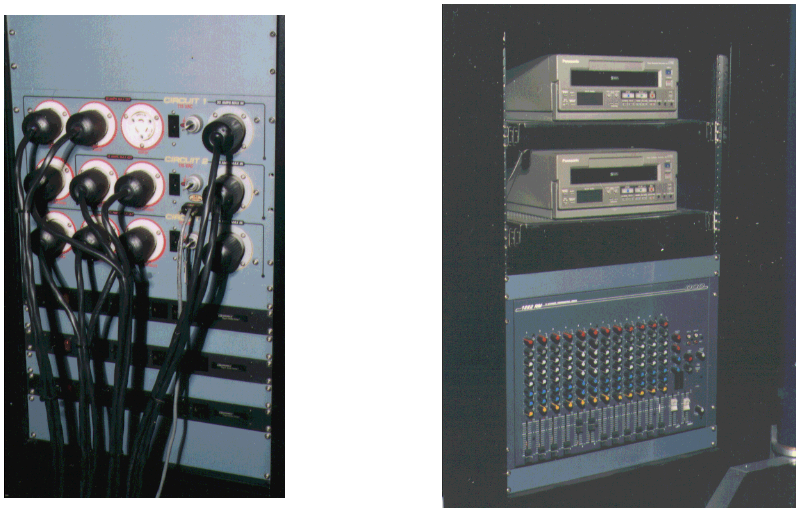

Figure 10: Power rack interface patch-panels

• **Structural Systems**

The racks and displays, as assembled without the painted shrouding, are depicted in Figure 11::

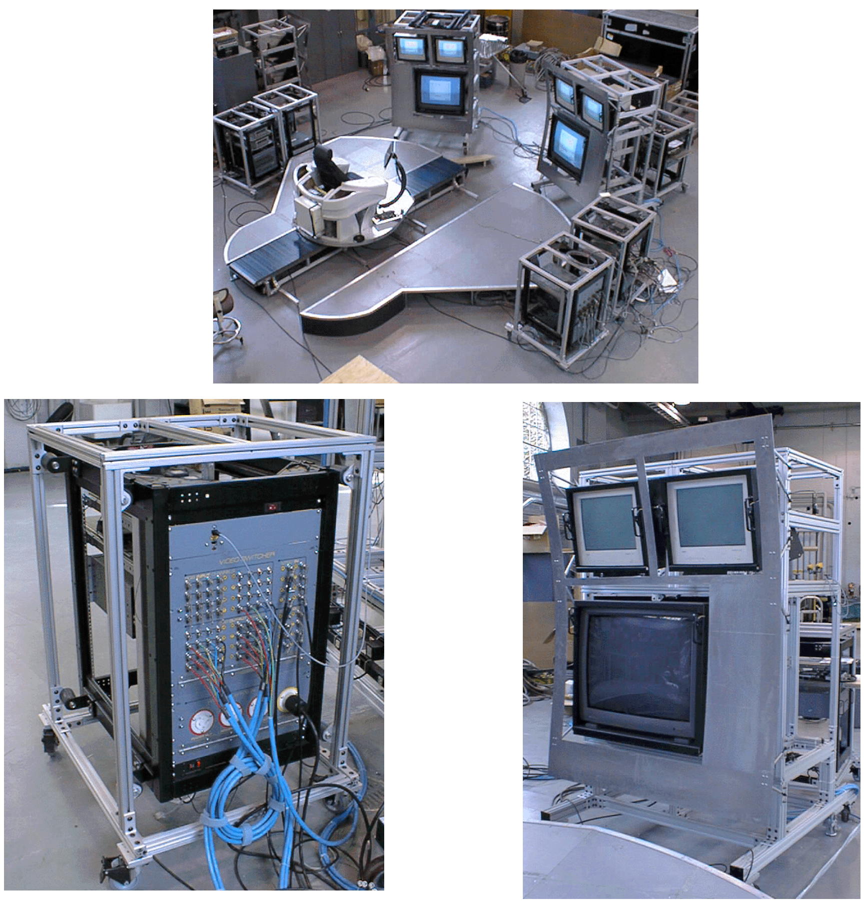

Figure 11: Skeleton rack systems

4.2 Experimental Results

The system was tested on a reconfigurable robot dubbed *Houdini* shown in Figure 12:,

Figure 12: CMU's *Houdini* pre-prototype system undergoing testing

and delivered to the International Union of Operating Engineers (IUOE) in Beckley, WV, in April 1998, for their own follow-on testing, training and evaluation under separate government programs. The IUOE is currently in the process of performing several testing programs, which they intend to report on separately.

5. RECOMMENDATIONS

Based upon the conclusions delineated in the previous chapter, the data collected during the experimental phase of the project, and the feedback from seasoned operators and trainers that have used the *RoboCon* system, the following recommendations can be made:

- **Utilization of RoboCon in realistic operational & training settings**
  The current prototype system should be used in continued LSDs within the DoE, in order to test its efficacy while doing productive and useful work in the D&D agenda. In addition, the system should also be used as a training tool for remote/robotic equipment operators to gather and hone their individual operator skills. Use of the system as an ergonomic and psychological testbed is also desirable but not as critical at this point (depends on the audience of course).
- **Expansion of control interfaces for foot- and manipulation controllers**
  Additional foot- and kinematic master-controller systems should be added to the control platform, allowing seated operators to control earthmoving equipment, as well as manipulation systems currently in use within the DoE.
- **Display upgrade for HDTV and flat-screen systems**
  Within the next three to five years, the display systems should be upgrade to the evolving HDTV standards and flat-screen technologies should replace the projection-screen and CRT-systems currently in use.

- **System interface computing system inclusion**
  As a final upgrade, the robot interface rack should be outfitted with a graphically-programmable computer-interface, to allow even faster and simpler interfacing to a host of different robotic/remote systems, by using software-switchable pre-wired panel assemblies.

6. ACKNOWLEDGMENTS

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