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The JPL Telerobot Operator Control Station: Part I - Hardware

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ABSTRACT

The Operator Control Station of the JPL/NASA Telerobot Demonstrator System provides the man-machine interface between the operator and the System. It provides all the hardware and software for accepting human input for the direct and indirect (supervised) manipulation of the robot arms and tools for task execution. Hardware and software are also provided for the display and feedback of information and control data for the operator's consumption and interaction with the task being executed. This paper, Part I, addresses the hardware design, system architecture, its integration and interface with the rest of the Telerobot Demonstrator System.

1.0 INTRODUCTION

The JPL/NASA (Jet Propulsion Laboratory / National Aeronautics and Space Administration) Telerobot Demonstrator System is a research testbed for the development, integration and testing of advanced robot control technologies [ref.1]. The component technologies and system-wide design experiences derived from such a system development and technology demonstration are targeted for use in future space programs, including the NASA's Flight Telerobot Servicer project [2].

Being a complex system involving many disciplines and technologies, the Telerobot Demonstrator System is designed as a hierarchical system, consisting of an Operator Control Station (OCS), a Reasoning and Planning Subsystem (TPR, also known as the Artificial Intelligence Planner, AIP), a Run-Time Control Subsystem (RTC), a Manipulator Control and Mechanization Subsystem (MCM), a Sensing and Perception Subsystem (S&P), and a System Executive (SE) Subsystem. Implicit in this architecture is the Human Operator, who is the 'commander' of the System, located within the OCS.

This telerobot system is a hybrid between teleoperated and robotic (autonomous) system. It is designed to operate where either pure teleoperated or pure autonomous operation is too complex, too inefficient or simply infeasible. Design performance goals for a telerobot system are primarily targeted for space applications in construction, assembly/disassembly, and servicing/maintenance. Telerobotic capabilities are to be demonstrated by performing laboratory tasks simulating those encountered in servicing satellites in orbit. Typically, they include coordinated two-arm manipulation of a large module, an ORU (Orbit Replacement Unit), and include the grappling/halting of a rotating satellite. Dexterous operations in terms of removal of panels, bolts, electrical connectors, tool exchange, object manipulation with precisely defined or loosely defined data bases, are in the list of demonstrations.

Special hardware and software have to been designed into the OCS. It contains state-of-the-art hardware, both mechanical and computing, for providing control input to the System. It contains software, in controls as well as human operator interface, for real-time and user-friendly interaction. Video displays for text, graphics and camera images are provided for operator consumption; where appropriate, voice input/output is provided to reduce operator work-load. Data manipulation such as object designation capability is provided for efficient task definition and execution. Access to all Telerobot subsystems is provided for software development and on-line monitoring.

There is a critical need for efficient and effective interaction between the Operator and the System. The hybrid characteristics of this telerobot system are such that teleoperated control and autonomous control are frequently traded and/or shared, in a continuum fashion. This mode of control is sometimes referred to as 'supervised control'. Thus, human factors issues are very demanding in the design of the OCS.

This paper, Part I, addresses the hardware design, system architecture, and its integration and interface with the rest of the Telerobot Demonstrator System. Description of the software is included in Part II of this paper [3].

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2.0 OPERATOR CONTROL STATION (OCS)

Figure 1 is the functional block diagram of the OCS, showing all its functional components and its interface with the other subsystems, namely the S&P, TELEOP, TPR (AIP), SE, RTC and MCM.

Implicit in the OCS is the human Operator, who uses the OCS to command and interface with the System. The Operator manages system configuration, transmits system information and receives feedback from the System. The OCS provides capability for the Operator to coordinate and monitor all other subsystems, permits the Operator to direct, supervise, and execute robotic and teleoperation control. In the JPL Telerobot Demonstrator System, OCS is designed for two operators, the Main Operator and Auxiliary Operator (also known as the Test Conductor). The Main Operator has the capability to execute all functions regradless of the absence or presence of the Auxiliary Operator.

The OCS hardware is a station, in a 'controlled' room environment where lighting, sound and sight are controllable, and stations the Main Operator and Auxiliary Operator. The station is equipped with multiple monitors for video and graphics displays and mixing. Audio and voice input/output systems are provided for operator command inputs in addition to keyboard inputs. Mechanical input devices for teleoperation and shared robotic/teleoperation control are provided. Multiple processors and computer networking is provided for OCS functions, planning functions and system management functions. And, the OCS is designed to ergonomic guidelines and standards.

Interface to the other subsystems is mainly via the ethernet network. A custom Network Interface Package (NIP) [ref. 4] software has been developed to standardize NIP network communication transactions between the different subsystems. These transactions can include commands, macros, statuses, messages, and combinations thereof. In such a way, the subsystems can be kept independent and cleanly separated from one another, as dictated in the hierarchical architecture.

In addition to this NIP interface, the Operator can log on to all the subsystems via the OCS computer terminal, via a terminal emulation mode. This is foreseen to be mostly used in system debugging, system setup, and certain detailed analysis operations, rather than for normal telerobot operations during task execution.

The present OCS design is based on experiences and evaluation of different systems, including the Los Alamos Scientific Laboratory, Fermi National Laboratory, Argonne National Laboratory, Oakridge National Laboratory M-2 and ASM systems [ref.5,6], and in-house research work. Human engineering factors are considered in this design [ref.7]. Other functional specifications and interface designs are based on the performance goals of the telerobot system and the architecture/data flow of the entire System. For further details on the functional requirements of the System and of the OCS, refer to [ref. 8,9].

Before describing the hardware design details, it is to be noted that the present OCS design is an evolutionary design which will evolve and change as the telerobot technology matures, both in system design and in component design. The present design is believed to have the necessary 'hooks and scars' for future system expansion. Despite its flexibility, certain architectural features are recognized to be suboptimal because of project constraints. Among the suboptimal design features is the sharing of certain OCS and TPR functions, even though they are distinctly separate subsystems. The Operator now inputs to the System via the OCS terminal as well as via the TPR terminal. The TPR high resolution graphics terminal is actually located at the OCS, used for operator input during autonomous and supervised control operations. This input process is independent of the use of the OCS SUN computer terminal during teleoperation and system mode operations. Otherwise, the OCS communicates with the TPR in the same fashion as the other subsystems, i.e. through the ethernet network using the NIP. One future approach to unify the design is to subsume the TPR functions into the OCS, at least in the operator interface features; in that case, the Operator will have only one terminal to interface with all the subsystems.

3.0 THE OCS HARDWARE

The physical layout of the OCS is shown in Figures 2 and 3. The OCS has an L-configuration, composed of six racks. Racks A, B, C, and D constitute the Main Operator station. The remaining racks E and F constitute the Auxiliary Operator station. The main station has all the controls necessary for the primary Operator to operate and execute telerobotic operations alone and independent of the auxiliary station. In fact, the auxilliary station has only a subset of the capabilities at the main station, to be used primarily by a Test Conductor-type secondary operator for monitoring purposes.

The primary station houses the right and left Force Reflecting Hand Controllers (FRHC) and their electronics, and the video monitors that the operation requires for teleoperation [ref.10]. The station also provides a keyboard for programmed control and user interface to the OCS computer, and to the other telerobot subsystems. The main Operator also has the OCS primary computer monitor and the TPR computer monitor in front of him for man-machine interface. For future expansion, a slot has been allocated in this main station for a real-time high-speed graphics machine, such as the Silicon Graphics IRIS system. At the present configuration, this station has two other graphics processes: (i) force-torque sensor displays, from the left robot sensor and from the right robot sensor; (ii) graphic overlays for the "object designation" process (see Section 3.5.3). The Main Operator has control over a voice recognition and synthesizer system, while he wears a head-gear consisting of a microphone and earphone. Direct commands can be issued by voice as well as through the keyboard, while more commands and parameter specifications can be input to the System via menu input processes at the OCS computer terminal.

The secondary station houses two additional video monitors and the OCS secondary computer monitor. While the secondary Operator does not have any voice input capability, he can always enter all the commands via the OCS secondary computer terminal, via direct command inputs using the keyboard or via the menu selection process, displayed to him on the OCS secondary computer monitor. Here, the Operator cannot provide the teleoperation inputs because of the absence of the FRHC's. All graphics, overlays and video images can be displayed to his two monitors, as routed by an OCS process of video switching.

Common to both stations are the video switcher, which is now configured to route a maximum of 16 RGB color channels to a maximum of 16 RGB color output monitors. Multiple views of the same input channel are possible with the present switcher. Other audio mixing, amplifier, video recording equipments are installed for the use by both Operators. Both stations have their own individual emergency kill button, which can also be used for a special halt-retract function.

The OCS computer is configured by a SUN 3/160 workstation as the primary computer, and with a SUN 3/60 workstation as the secondary computer. Each has a monochrome display monitor. The SUN system was selected for many reasons, including its wide-area ethernet networking capibility, efficient and extensive software development facilities, and general compatibility with the development environment and computers used by the other telerobot subsystems. The SUN View and SUN Tool facilities provide user friendly processes, including multi-window and multi-process capabilities that provide versatile terminal emulation communication between the OCS and the other subsystems.

3.1 The Force Reflecting Hand Controller (FRHC) Workstation

The central input device to the primary Operator is the set of two FRHC's, one right-handed and the other left-handed. (See Figure 8.) The Operator manipulates the controllers seated at the center of the workstation, while observing the arm responses on monitors providing multiple views of the robot work volume. As a safety and training measure, a direct viewing window, shown in the floor view diagram (Figure 2), is provided into the arm work area to verify his operations and to insure that the area is clear of personnel.

Mounting bases of the FRHC's can be adjusted to allow the hand grips of the controllers to be placed one above the other and rotated in a one foot circle. Figure 4 shows the range of adjustment for the FRHCs. Adjustment mechanisms can easily be reached and operated by the operator while seated.

3.2 The Operator Workstation Video Graphics

3.2.1 Wing and Overhead Monitors

To provide the operator with the necessary perspective to effectively and safely operate in the robot work space, multiple views are provided by two cameras located at either side of the work space (wing cameras), and one centered, forward looking camera somewhat above the work space (overhead camera). These views will generally be global, presenting the operator with an overall picture of the work space from different perspectives. The OCS also provides a stereo view from a camera pair mounted on a third robotic arm which can be positioned by the operator for an optimum view. Past experience on teleoperation using stereo views has shown that stereo vision provides additional depth cueing necessary to perform tasks efficiently.

3.2.2 Stereovision

The stereovision system, centrally located at the primary station, is a completely passive design. It has the advantage of not requiring any mechanism for synchronized switching to properly view the stereo images, and can maintain the stereo effect over a relatively wide latitude of head motion. Two orthogonally positioned monitors with cross-polarized face plates display views from the stereo pair cameras. The monitor views are superimposed onto a 45-degree beamsplitting screen having a 50% transmission/reflection ratio. Located at eye-level directly in front of the operator, images from the screen are directed to the appropriate eye by a pair of polarized glasses worn by the operator. Figure 5 shows the configuration and adjustment mounts of the stereo system. The left parallax is given by the bottom vertically positioned monitor, the right parallax by the horizontal monitor. To have the lines of the coincident images scanned in the same direction, the lower monitor is modified to have a reversed horizontal scan. The alignment of the images on the beamsplitter is critical to performance and positioning adjustments are provided. While the horizontal monitor is rigidly mounted within the OCS console, the vertically oriented monitor can be adjusted in many directions for precise alignment. The beamsplitter is also angularly adjustable. The adjustment ranges are indicated in the following table:

Stereo Vision Mount:	X	±1.50 in.
Range of Adjustments:	Y	±0.50 in.
(refer to Figure 5)	Z	±1.50 in.
	YR	±10°
	ZR	±10°
	Mirror	45°±5°
	Mirror X	±0.50 in.

The mirror is also removable, so that the Operator can use the 'right perspective' (i.e. the top horizontally mounted) monitor by itself; in this case, the Operator no longer needs to wear the polarized glasses.

3.2.3 Force/Torque Graphics

Information on the forces/torques experienced by the manipulators is useful in performing telerobot tasks with or without force reflection. Force/torque information is highly desirable to assure that excessive forces are not imparted to the work object in all modes of both teleoperations and programmed control. Wrist force/torque sensors provide this information. The OCS is equipped with two force/torque monitors which graphically display applied forces in the six-axes of each wrist in a readily interpreted manner. These monitors are placed side-by-side and are conveniently located directly above the stereo window.

3.2.4 OCS Monitors

The OCS monitor provides the user interface to the OCS software. The OCS user interface consists of a variety of predefined windows, pop-up menus, graphic buttons, and panels that are configured to provide a consistent command and message environment for the OCS operator. For details, refer to [ref.3]. The following table documents the full complement of monitors provided within the operator workstation:

Operator Station Monitors

	Designation	*Type*	*Manufacturer/Model#*
Primary Station:	Left Wing	19" RGB	Barco CD531
	Right Wing	19" RGB	Barco CD531
	Overhead	19" RGB	Barco CD531
	Left Stereo	19" RGB	Barco CDCT6351
	Right Stereo	19" RGB	Barco CDCT6351
	Left F/T	10" RGB	Barco MCD10B
	Right F/T	10" RGB	Barco MCD10B
	Primary OCS	19" Mono	Sun (3/160)
	TPR terminal	19" Mono	Symbolics (3640)
Secondary Station:	Secondary OCS	19" Mono	Sun (3/60)
	Aux. monitor (2)	13" RGB	Barco CD233

3.2.5 Graphic Generators

Two New Media Graphics 9000 graphic generators are installed in Rack E. These units permit color alphanumerics to be inserted onto selected video. They also serve in the object designation mode to generate wire-frame outlines of objects contained in a world model data base (see section 3.5.3). Using a mouse to designate vertices of identifiable objects contained in a video scene, the graphics generator output is superimposed on the video scene, automatically establishing correct relative orientations to redefine or update the world model. Future expansion to more than two graphic generators is forseen; spare slots on the racks are allocated for such expansion.

3.3 OCS Video Processing Elements

Much of the OCS rack space is devoted to video system requirements which include not only display monitors, but also a video router and video encoders and decoders.

Some clarification may be given to nomenclatures of the station monitors in prior discussions, since the video router allows any video to be displayed on any monitor. Suffice it to say that under normal operating conditions, an operator would use these nominal designations as described, i.e., the left wing camera would be displayed on the left wing monitor, etc., to maintain his correct orientation with the robotic work space.

The OCS video monitors, with noted exceptions, are all configured to accept Red-Green-Blue (RGB), video inputs. The video matrix switcher, supplied by BSM Systems, is capable of accepting and routing sixteen sets of RGB video signals to any or all of sixteen sets of output lines. Switcher control is via a RS-232 link between the OCS processor workstations and the switcher processor/controller. Configurational control of the switcher can be exercised either by keyboard or, as previously discussed, by voice command by the operator. The switcher will initially be configured to connect any of eleven inputs to any of twelve outputs, as shown in Figure 6, leaving provision for future expansion of the video system.

This figure also shows the RGB-to-NTSC encoding for input to the graphic overlay generators and VCR. While the graphic generators output RGB and can be routed directly to the switcher for monitor display, the VCR outputs NTSC video which must be decoded into RGB prior to display. A sync generator is included as part of the video subsystem, as shown, allowing OCS video to be slaved to the system master video clock. The encoders, decoders, and sync generator are Grass Valley Group components, and are also identified in Figure 6.

The video system described places at the disposal of the operator and test conductor complete and independent flexibility in selection of video source viewing monitors, graphics insertion capability, with provision for future system expansion.

3.4 Power Panel and Switches

3.4.1 Station Control Panel

The OCS power control panel in Rack D contains the OCS rack power switches. Main power is supplied via a keyswitch, with panel indicators to verify that each rack is energized.

Three arm power switches are located on the panel for energizing the arms; switches for deactivating the arms in emergencies are independent assemblies which are discussed below. One of the assemblies is located on the primary station desk top convenient to the Main Operator, while the second unit is located at the secondary station convenient to the Auxiliary Operator.

Also, to eliminate excessive number of mouse(s) connected to the different computers, namely the OCS primary computer, the OCS secondary computer, the TPR computer, and the two graphics generators, the OCS primary computer mouse and the two graphics generator mouse(s) are combined into one. Software is designed in the OCS to share the use of one mouse for these three machines. Mouse jacks are also provided on the front panel for the detachment and attachment of the mouse(s).

3.4.2 Emergency Stop Switch Assemblies

As a safety measure, the Main and Auxiliary Operators are each provided with a movable switch assembly which can abort arm activity in emergencies. These assemblies can be placed at any location convenient to the reach of the operator and the test observer. They are designed to be instantly recognized, having an indicator light, and have momentary push-to-stop mushroom-cap switches.

One more feature exists in the Main Operator's emergency stop switch assembly. It has the added switch for the selection of one of two available stop modes - (i) emergency stop mode, which immediately removes arm power and applies brakes; and (ii) a reflex stop mode, which causes the arms to retract to default locations out of the work zone. Selection of the reflex stop mode is indicated by the switch indicator lights.

3.5 Man-Machine Interfaces, Operator Aids, Human Factors

Space teleoperation places substantial demands on the human Operator. During the course of an exercise the Operator may be required to simultaneously:

- control, interpret, and respond to feedback from the remote manipulators;
- visually concentrate on task performance on various TV monitors;
- select and control camera positions for optimal views;
- interpret alphanumeric and graphic information which may be displayed;
- acknowledge and tend to visual and audible warnings.

To further tax the Operator, it may be necessary to continue these operations for extended periods of time. Under these conditions, the human factors issue becomes a critical area of research attention.

3.5.1 Some General Design Features

The locations of controls and displays to be made available at the operator station and the auxiliary station were a subject of design study, and resulted in incorporating the following features in the design of the OCS, some of which were noted earlier:

- angled vodeo monitors for viewing ease;
- primary head-on stereo display;
- adjustable arm controllers;
- contiguous left and right F/T displays;
- direct view window;
- relocatable, easily identified stop switches;
- stowable, adjustable position keyboards;
- desk-top workspace.

None of these general design features materially lessens the human stresses imposed during teleoperations. While they may add to comfort, convenience, and efficiency, they do not actively participate to reduce human stress. To reduce operator work load and attendant stress, operator aids have been incorporated in the OCS design.

3.5.2 Operator Aids

3.5.2.1 Voice Control Operator Aid

Experience has shown that substantial improvements in teleoperator performance are gained when voice commands are used to control auxiliary functions such as the camera system. During an exercise, the Operator's attention is expected to be focused on the control of the manipulators. Concentration on the task is particularly demanding when both arms are being used in a cooperative manner in manipulating a common work piece. Any distraction from the task should be prevented. It may be necessary for the Operator, however, to change camera angles as the work scene becomes obstructed or when objects leave the field-of-view. Voice control of cameras offers a natural, non-disruptive method for commanding the most useful views. It places minimal demands on the Operators' attention and allows the Operator to control the arms without interruption.

In the OCS, voice control is designed to control the camera pan and tilt motions; in this case, the stereo vision arm is placed on the 'vision arm'. Voice control is also extended to the control of the video router/switcher, allowing the operator to direct specific camera views for display on any desired station monitor. The video switcher, and video processing systems, have been described in Section 3.3.

Implementation of voice control requires a speech recognition system. Two competing speech recognition systems were considered for the OCS; Verbex S5000 and ITT 1280VME. Both are state-of-the-art, continuous speech, speaker dependent systems having efficient recognition algorithms which result in low error rates. The final selection is the Verbex S5000 system.

The Verbex S5000 system provides a >98% recognition accuracy and a very good (>95%) out-of-vocabulary rejection performance. The system can accomodate up to 80 active vocabulary words at any instance, and can include on-line storage of up to 500 vocabulary words, subsets of which can be swapped into active memory rapidly (within one second). Careful pruning and partitioning of vocabulary words into subsets can provide error detection and correction strategies, which will further enhance the Type I and Type II accuracies of the recognition system. Other niceties of the system include well developed application development and user training software/procedures. The Verbex also provides on-board audio input/output capabilities that are needed to integrate the speech recognizer into the OCS racks. Lastly, for application development, i.e. pre-programming the vocabulary and grammer, an IBM PC is needed to run the Verbex high-level software. (Verbex is presently converting their software into VMS and UNIX host machines.) The OCS is designed to communicate with the Verbex via a serial RS-232 line.

3.5.2.2 Voice Synthesis as an Operator Aid

During operation, the telerobot Operator is barraged by visual information by way of camera video, graphics, and alphanumerics. While most information is supplied to the Operator via display monitors, certain types of information, such as status reports and warnings, can be more efficiently and more effectively conveyed by voice. A voice generator has also been shown to aid the Operator by providing operational cues in telerobotic systems which can share control between manual and supervisory modes.

A DECtalk DTC01-AA text-to-voice generator is used in the OCS as an operator aid. DECtalk is considered to be one of the most advanced speech generators commercially available. It can produce natural, human-quality voice messages with a vocabulary of greater than 20,000 words. In addition to this general common-word dictionary, DECtalk also contains a user-definable dictionary for specialized vocabularies used in specific applications. Standard ASCII messages from the computer workstation transmitted through an RS232 port are converted to voice messages at a controllable synthesizing output rate of 120 to 350 words per minute.

The OCS audio subsystem provides a standard commercial audio mixer/amplifier and speaker for combining audio sources from the speech synthesizer, microphone, and from audible warning devices.

3.5.3 Object Designation: Operator-Machine Interface

Developed for the Telerobot Demonstrator System is an interactive graphic overlay technique, better known as the "Object Designation and Verification" process [ref.10]. This process permits the Operator to interactively update the position and orientation data of known objects by a mouse point-and-designate sequence. Thus, any discrepancy, error, or unintentional displacement of objects - as represented in the initial data base - could be reconciled. Future evolution of the same technique will provide an interactive CAD-type creation of new object models and data bases, which can be further used for robot manipulation under telerobotic control.

The "Object Designation" process, of e.g. designating a box, is initiated by OCS requesting the object model of the box from TPR, where the data base of all concerned objects resides (or at least, TPR can access to). The object model basically contains a name list of all the vertices and edges of the model, a base frame of the model (e.g. of the centroid of the object), and the list of transformations of the vertices relative to the base frame. Along with the object model, the OCS obtains the camera model from TPR, including the focal length, optical axis pointing vector, and the transformations that convert world coordinates into camera image coordinates.

The OCS Object Designation software then computes the pixel coordinates of the box (i.e. the vertices and edges of the box) so as to overlay its wire frame properly in location and orientation onto the selected camera image. If the object does not fall in the present field of view of the camera, OCS software will conjure the object model on the camera image as presented.

The Operator now verifies that the object model, as represented in the data base, is or is not correctly placed, by examining the model's wire frame overlay relative to what is shown in the camera image corresponding to the same object. If the two do not coincide, the Operator will start an interactive mouse point-and-designate process to associate vertices in the wire frame to those of the real image. After successively associating three or more vertices, and repeating the same on more than one camera view of the object, the Operator can call a best-fit procedure. This will cause the computation of the object transformation, containing the actual object location and orientation (relative to the world). Upon acceptance by the Operator, this now updated position of the object will be sent to and stored in the telerobot data base. Telerobot task execution can then proceed using this updated data base.

Figure 7 shows the wire frame of a box, which is being overlayed and designated onto the image of the box, as seen by the camera. The top of the figure shows the menu options for various image operations.

The hardware that performs this process is the New Media Graphics Generators discussed in Section 3.2.5 and shown in Figure 6. The OCS SUN computer contains all the computing software.

4.0 FUTURE RESEARCH AND DEVELOPMENT

In its present state of completion, the OCS is shown in Figure 8. The completed system is now planned for integration and installation at JPL's Telerobot Demonstrator Testbed laboratory in Spring, 1989. After its successful integration with the rest of the Telerobot System in Summer, 1989, the OCS will serve as the focal point of the Telerobot Demonstrator System. Real hands-on operational flow analysis and workload analysis will be conducted, so as to evaluate the effectiveness of the OCS design, and of the integrated telerobot system.

More research and development items, improvements on point-designs, alterations of physical layout, addition of vocabulary, etc. will undoubtedly surface when more experience is gained from OCS and telerobot experiments. Other already forseen technology development items include: interactive model/data base building; the use of CAD-type data base techniques for object trajectories planning and verification; faster and better algorithms in object designation process, including hidden line removal, incorporation of perspective cues etc.; smoother and more unified operator-machine interface; more powerful display, iconic representations and graphics. As more powerful computers become available, and as the understanding of a telerobot system matures, the state-of-the-art OCS technology will evolve.

5.0 Acknowledgements

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to the National Aeronautical and Space Administration. GE Aerospace (formerly RCA) / Advanced Technology Laboratory was subcontractor to JPL, responsible for the development of the Operator Control Station and part of the Manipulator Control Subsystem.

Figure 1. TELEROBOT OPERATOR CONTROL STATION FUNCTIONAL BLOCK DIAGRAM

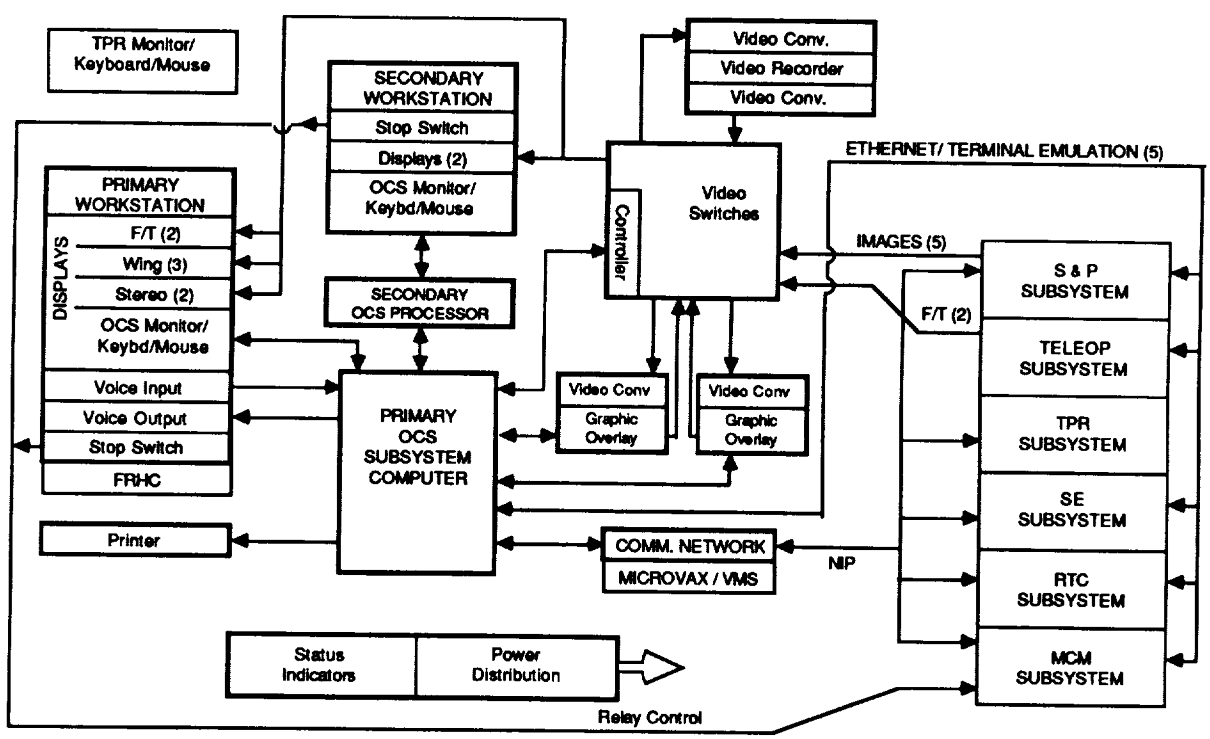


Figure 2. THE OCS - PLAN VIEW

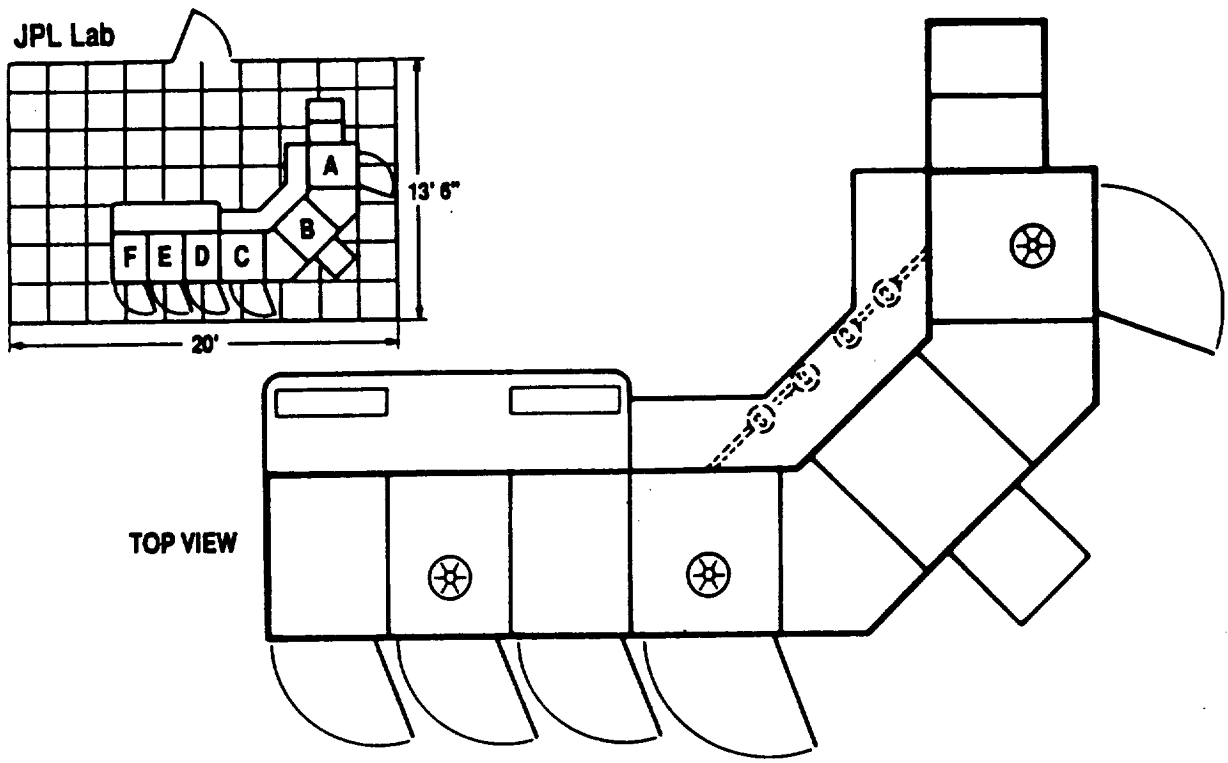
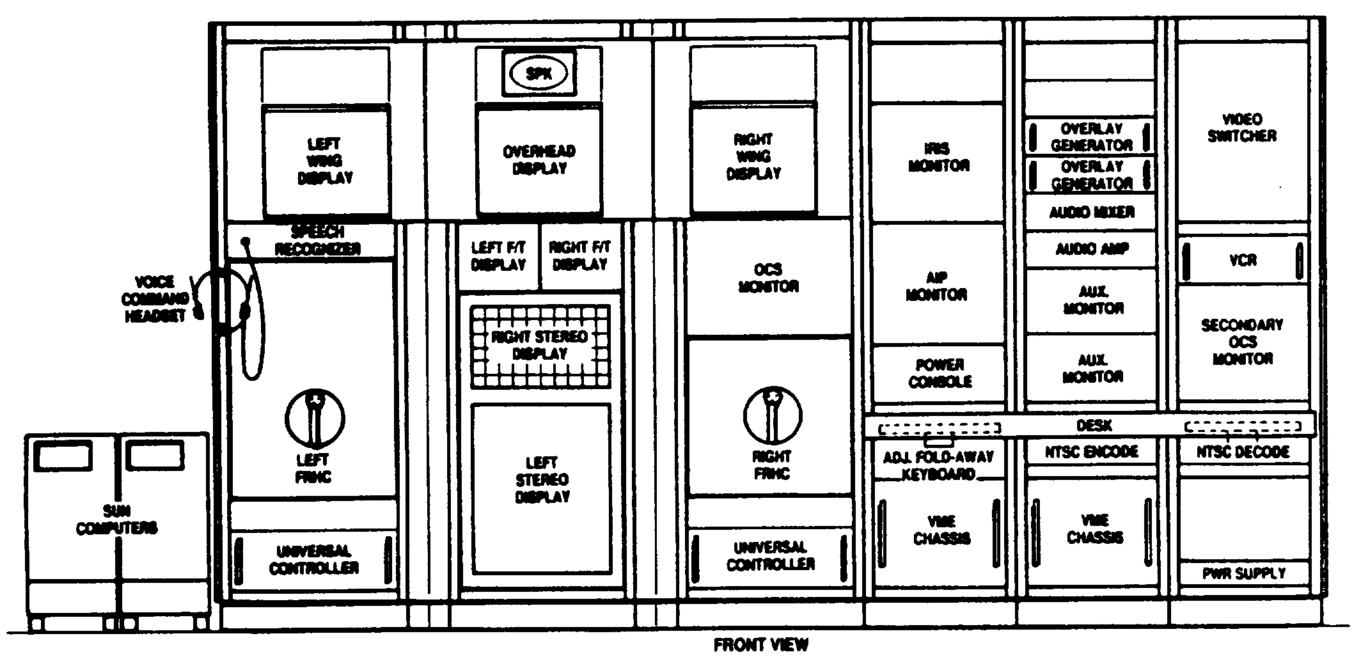


Figure 3. THE OCS - ELEVATION VIEW



Operator Control Station

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Figure 4. HAND CONTROLLER RANGE OF ADJUSTMENTS

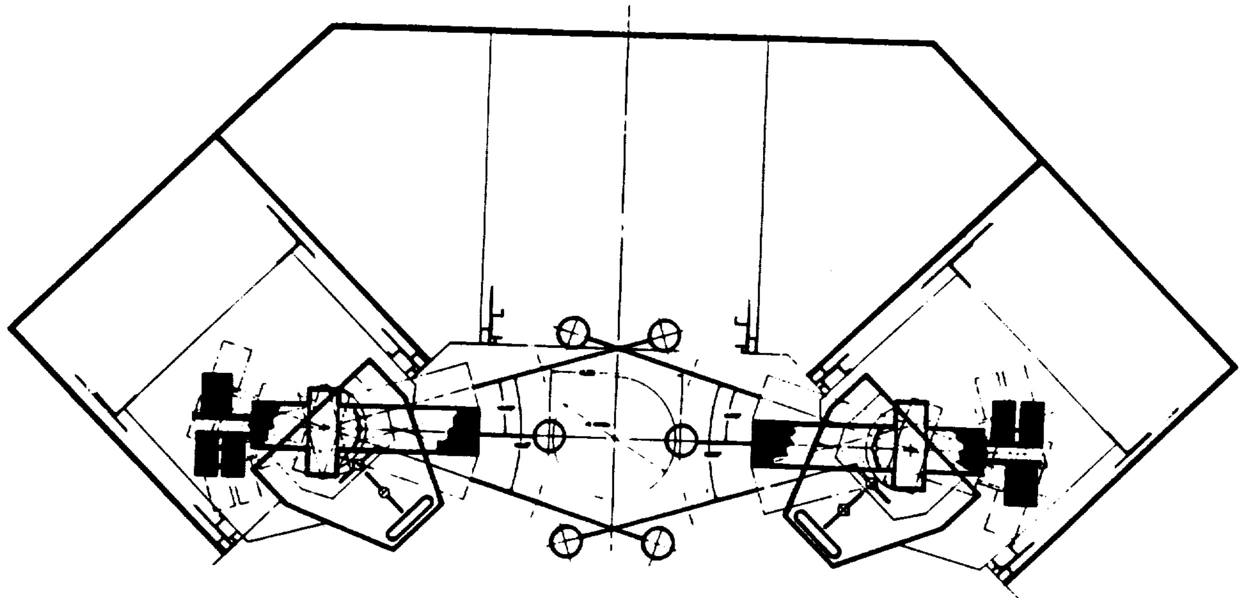

Figure 5. STEREO DISPLAY MONITOR ARRANGEMENT

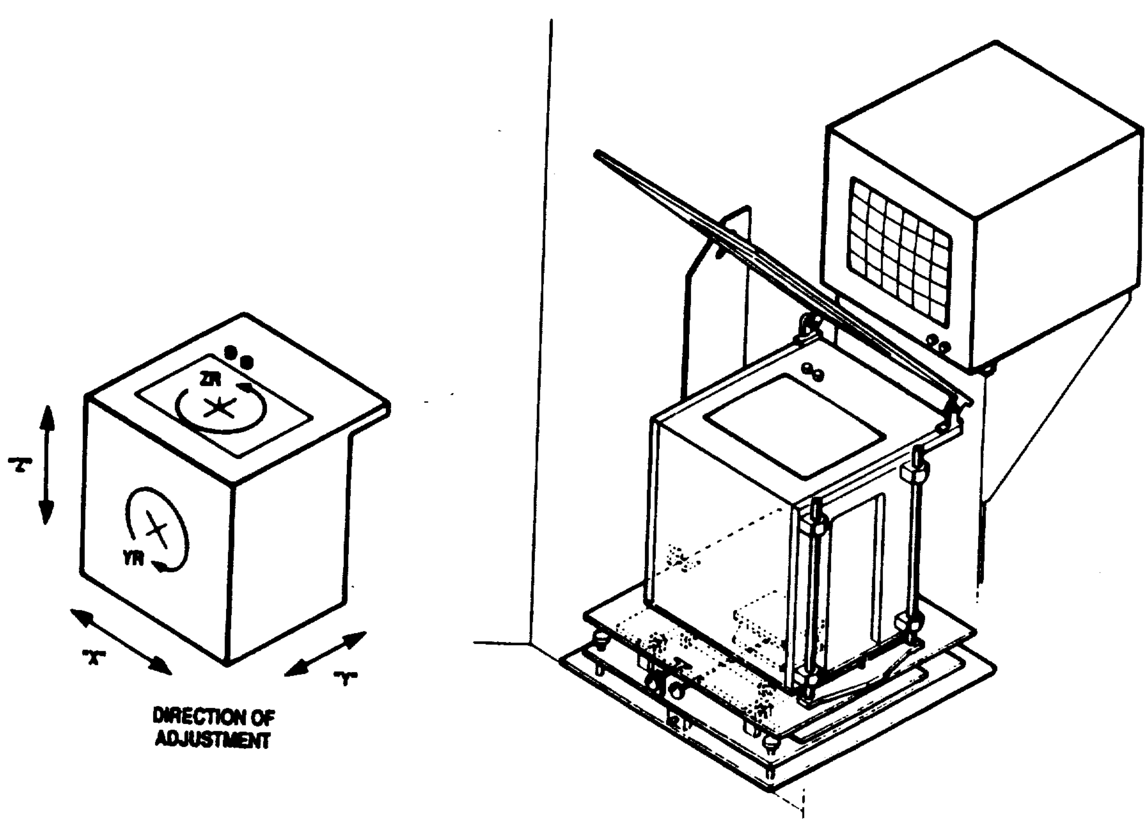

Figure 6. OCS VIDEO SUBSYSTEM ELEMENTS

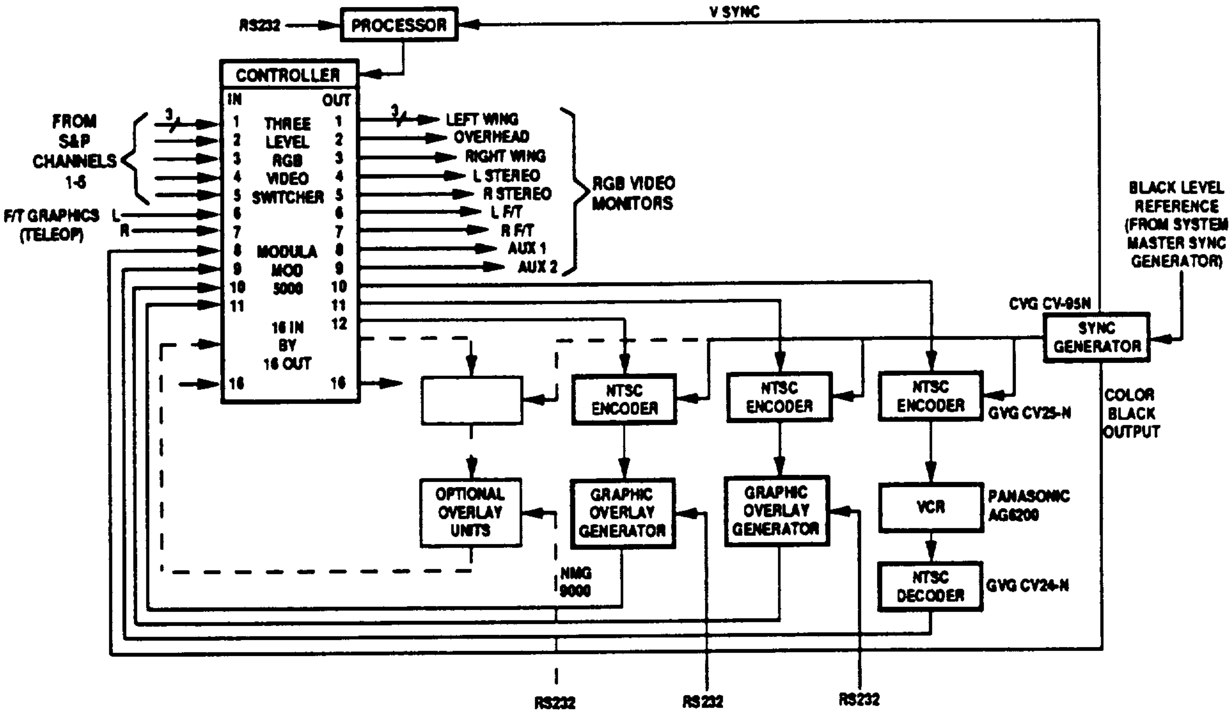

Figure 7. OBJECT DESIGNATION - WIRE FRAME OVERLAY

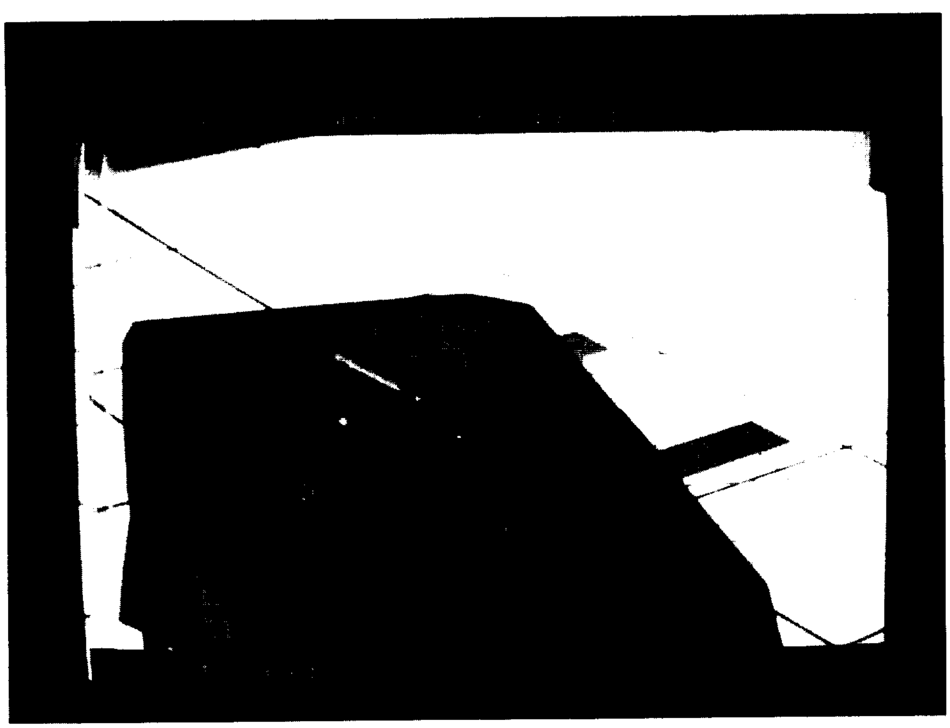

Figure 8. THE OPERATOR CONTROL STATION

(Status as of 1/89. For complete layout of elements, refer to Figure 3.)

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