TELEROBOT OPERATOR CONTROL STATION REQUIREMENTS

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ABSTRACT

The Operator Control Station of a Telerobot System has unique functional and human factors requirements. It has to satisfy the needs of a truly interactive and user-friendly complex system; a telerobot system being a hybrid between teleoperated and autonomous system. These functional, hardware and software requirements are discussed in this paper, with explicit reference to the design objectives and constraints of the JPL/NASA Telerobot Demonstrator System.

INTRODUCTION

A telerobot system is a hybrid system between a teleoperated system and an autonomous (robotic) system. It is capable of being teleoperated such as a master-slave manipulator system used widely in the nuclear industry. It is capable of being operated autonomously under preprogrammed control or under real-time intelligent, sensor-based and knowledge-based control, such as in various forms of automated factory systems.

More importantly, a telerobot system is capable of being operated in a continuum mode, where teleoperated control and autonomous control can be traded or shared, as the circumstance requires. That is, when it is more natural and easier to do human teleoperated control, the telerobot system will be configured to do so. When it is more efficient to perform the task autonomously, the telerobot system will be configured to do so. And, when certain degrees of freedom are more readily achieved by autonomous control while other degrees of freedom are naturally achieved by teleoperated control, the overall control is shared between the two control modes. In all cases, the human operator provides the guidance, direction, high-level decision, supervision and execution of the task.

It is thus apparent that human factors issues are very demanding in the design of the operator control station of this telerobot system. Design requirements are very unique. Based on past experience of operational and research teleoperated and robotic systems, the Jet Propulsion Laboratory (JPL) is now developing a state-of-the-art Operator Control Station (OCS) as part of the NASA (National Aeronautics and Space Administration) Telerobot Demonstrator Project [1]. This paper will present the functional, hardware and software requirements of the OCS of this Telerobot Demonstrator System.

TELEROBOT SYSTEM REQUIREMENTS

The system requirements are driven by the tasks to be performed by the telerobot system; and also driven by the state of the technology. The telerobot system must be able to perform tasks equally as well, and hopefully better, than a straightforward teleoperated system and than a straightforward robotic system. For space applications, the telerobot system must offer advantages over expensive and hazardous EVA (extra-vehicular activities) and IVA (intra-vehicular activities) where astronauts actively participate in the performance of construction, servicing and repair.

In the context of the JPL/NASA Telerobot Demonstrator System, the system is designed as a laboratory testbed for developing, testing and integrating multi-disciplinary technologies. The system is designed within certain overall

constraints of the space environment, while not limited by near-term technology specifics regarding maturity in hardware and software designs.

Overall telerobot system capabilities [2] are targeted as follows:

1. Force reflection in teleoperation.
2. Hybrid position/force control in robotic and advanced teleoperation.
3. Dual arm coordinated control in robotic and teleoperation.
4. Collision prediction, detection and avoidance in robotic operation; use of virtual force field in teleoperation.
5. Supervision by human operator to perform robotic operation and to trade/share between robotic operation and teleoperation.
6. Automatic task planning and command generation: a must for robotic operation, and as a suggestive direction for teleoperation.
7. On-line manipulator path planning: a must for robotic operation, and as an aide for teleoperation.
8. Automatic tracking of labelled and unlabelled objects.
9. Operator initiated object designation and subsequent automatic verification of modeled objects.
10. Simulation of a delay of up to 500 milliseconds (round trip) between the (local) operator's station and the (remote) manipulators.
11. Integrated system operation; ease of operator-machine interaction.

These 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.

OCS AS PART OF THE TELEROBOT SYSTEM

Figure 1 shows the current JPL Telerobot Demonstrator System. It is shown with a generic OCS which is to be replaced by a state-of-the-art OCS in mid-1989.

The Telerobot System has the following subsystems:

1. Operator Control Station (OCS)
2. Artificial Intelligence Planner (AIP)
3. Run-Time Control (RTC)
4. Sensing and Perception (S&P)
5. Manipulators and Control Mechanization (MCM), including Teleop components
6. System Executive (SE)

This above partitioning is driven by the identification and separation of system functions, specific technology, hardware and software. (For more specifics, refer to [2]).

For a user-friendly and machine-interactive operation, the OCS discussed in this paper actually crosses some boundaries in the above system partition. The crossed boundaries include AIP, SE and MCM/Teleoperation components. It will be clear in the following sections that the user interface now placed in AIP, the system management in SE and the hand controller hardware in Teleoperation subsystems are truly part of an overall Operator Control Station; but for reasons of subsystem maturity, component availability/compatibility, and for working group partitioning efficiency, these AIP, SE, and Teleop functions have been allocated outside the OCS.

OCS's OPERATOR REQUIREMENTS

The human Operator uses the OCS to interface with the system. The Operator manages system configuration, transmits system information and recieves feedback from the System. The OCS provides capability for the Operator to coordinate and monitor all other subsystems, permits the Operator to direct/supervise/ execute robotic and teleoperation control. In the JPL Telerobot Demonstrator System, OCS is designed for two operators, the Main Operator and the Auxiliary Operator (also known as the Test Conductor). The Main Operator has the capability to execute all functions regardless of the absence/presence of the Auxiliary Operator. The Operator's functions include the following:
-   System management functions: system startup/shutdown, setup, software configuration, other monitoring/diagnostics functions;
-   System operation functions: mode transitions, setting system parameters, system calibration, video switching, emergency halt (and other modes of halting), object data

manipulation;

- Teleoperation functions: hand motion for input to hand controllers, setting subsystem parameters, establishing telepresence via visual, kinesthetic and proprioceptive feeback;

- Robotic control functions: instantiate, monitor, supervise, direct, confirm and give permission to proceed all actions generated under autonomous planning;

- Trading and sharing teleoperated and robotic controls;

- Initiating and executing data logging functions for off-line analysis and system performance evaluation.

OCS HARDWARE REQUIREMENT

The OCS hardware is a station, in a "controlled" room environment where lighting, sound and sight are controllable, and houses the Operator and Test Conductor. 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 are provided. Multiple processors and computer networking is provided for OCS functions, planning functions, and system management functions. The OCS is designed with due consideration in anthropometric and ergonomic constraints. Specifically, the requirements are:

1. Be configured with workstations for an Operator and a Test Conductor;

2. The main workstation to have all necessary control inputs and feedback;

3. At the main workstation, to provide the following devices for display, record and transmit data:

(a) mono, stereo video monitors for camera and buffer images

(b) video switcher and mixer(s)

(c) indicator lights, aural signals

(d) synthesized voice

(e) video recorder(s), audio mixer

(f) high resolution bit-mapped video display monitors;

4. At the main workstation, to provide the following devices to accept Operator requests and commands:

(a) keyboard(s), function switches

(b) one left and one right bilateral force reflecting 6-dof hand controllers; the mechanisms and electronics

(c) voice input/recognizer

(d) mouse(s) and joystick(s);

5. At the auxiliary workstation (of the Test Conductor), to provide:

(a) all data/views available at the main workstation except the stereo view

(b) peripheral data collection hardware for off-line data analysis

(c) keyboard function switches independent of main workstation;

6. To provide the following physical and electrical support:

(a) regulated electrical power

(b) VCR recorder

(c) terminal/keyboard interface to the AIP (for autonomous and shared control instantiation, for object designation process)

(d) terminal/keyboard interface to the SE (for executing system management functions);

7. To provide display system to permit:

(a) terminal emulation through windowing to allow the Operator to access each subsystem

(b) switching of video images onto designated monitors;

8. At both the main and auxiliary workstations, to provide a "Panic Button" for emergency halt and other mode(s) of halt;

9. To provide networking capability to all subsystems;

10. To provide electronics, hardware, switches to permit teleoperation mode changes, indexing, triggering for robot end-effector opening and closing, force reflection, and other control processing for the hand controllers;

11. In support of Operator-assisted object designation and verification, to provide:

(a) mouse/keyboard/voice input for selection of objects

(b) graphics generation, mixing capability to overlay wire frame models of objects onto video images;

12. To provide the OCS computer(s) to perform OCS internal and interface functions.

Figures 2 and 3 show the control station configuration of the JPL Telerobot Demonstrator System. Figure 4 show the functional block diagram of the OCS, illustrating the interface with all the subsystems.

OCS SOFTWARE REQUIREMENTS

Software required in OCS includes the processing of OCS input/output data; interface software with other subsystems; the system management software (currently allocated to SE); and the system mode switching/

supervision, object-data-manipulation, man-machine-interface (currently allocated to AIP); and hand controller teleoperation software (currently allocated to MCM/Teleop). Specific software requirements are to provide:

1. Command interpreter to process Operator generated commands via the keyboard, mouse, and voice; hence, to parse, translate and generate inter- and intra-OCS commands;

2. Message processor for translating, generating and displaying messages on OCS monitor; for messages initiated from within or outside OCS;

3. Status monitoring process, to monitor OCS health and parameter-setting status; in addition to the overall system and subsystem status monitoring process performed by the SE;

4. RS-232 controllers for graphics overlay/mixer controller, voice display controller, and video switch controller;

5. Gateway computer interface via an ethernet network;

6. NIP (a custom Network Interface Package) gateway interface software for processing NIP transactions [3].

7. Object designation/definition software to create wire-frame models, overlay on camera images, manipulate using mouse cursors, perform best-fit, and update/augment data bases; to interface with the AIP for model/data;

8. Interface software between the primary and auxiliary OCS workstations;

9. Terminal emulation to all subsystems via multiple windows on OCS monitor;

10. Pull-down menus for system and subsystem commands;

11. Continuous speech voice recognition and multi-voice (gender/person) speech synthesis for direct input and feedback;

12. Graphics generation and overlay software for object designation/verification process;

13. Graphics and simulation software for special displays including predictive displays, scenario simulation, sequence playback displays;

14. Software to accept keyboard/mouse/symbolic/graphics input, instantiate processes, specify goals and task sequences, as specified by Operator;

15. Software to allow operator to display/supervise/update/modify/cancel task sequences and parameters;

16. Software and displays for smooth transition between system modes, including teleoperation mode to and from robotic mode;

17. Data base maintenance, management, and creation of world models, object location, camera models, and calibration settings;

18. Support software for interpreting and transmitting Operator generated (voice or keyboard) manipulator control commands; maintain command context and monitor status of commands;

19. System configuration, startup/shutdown/halt, statusing, health monitoring, data traffic monitoring of all subsystems;

20. Control processing and data acquistion software to process Teleoperation hand controller joint data, special switches, triggers, force feedback, coordinate transformation and communciation;

21. Graphics processing/generation of Teleoperation related displays including force/torque data and predictive data.

Requirements #1-13 are currently allocated to the OCS of the JPL Telerobot Demonstrator System, while #14-18 are allocated to the AIP, #19 to SE, and #20-21 to the MCM/Teleop for reasons mentioned in an earlier Section of this paper.

OCS in the NASREM ARCHITECTURE

The NASA/NBS Standard Reference Model (NASREM) [4] for telerobot systems functionally partitions the telerobot process into six levels, where each level has its sensory processing, world modelling and task decomposition subprocesses. Levels interconnect with the level below and the level above it. All levels connect with a 'global data base' and an 'operator interface'.

The OCS described in this paper, i.e. the physical station and its functions, map right into the 'operator interface' block in the NASREM architecture. A few of the functions, particularly those now allocated to AIP, SE, and MCM, but considered above to be OCS functions, overflow out of the NASREM 'operator interface' block. Figure 5 (excerpted from [5)] shows the mapping of the JPL Telerobot Demonstrator System into the NASREM.

FUTURE RESEARCH and DEVELOPMENT

Upon its completion, installation and integration in mid 1989 with the rest of the System, the OCS will serve as the focal point of the Telerobot Demonstration System. Real hands-on operational flow analysis and workload analysis could actually conducted, to evaluate the

effectiveness of the OCS design.

More research and development items, improvements on point-deisgns, alterations of physical layout, addition of vocabulary, etc. will undoubtedly surface when more experience is gained from OCS 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/verification; faster and better algorithms in obect designation process, including hidden line removal, incorporation of perspective, cues etc.; smoother and more unified oprator-machine interface; more powerful display/graphics systems. As more powerful computers become available, and as understanding of a telerobot system matures, the state-of-the-art OCS technology will evolve.

ACKNOWLEDGEMENT

REFERENCES

[1] P. Schenker, "Telerobot Program Objectives and Technology Outreach," Proceedings of the Workshop on Space Telerobotics, Pasadena, CA, Jan. 1987 (also JPL Publication 87-13, Vol. 1, pp. 3-17, July 1987).

[2] J. Matijevic, et.al., "Functional Requirements for the Telerobotic Testbed," Jet Propulsion Laboratory Document, #JPL D-3693, May 1988.

[3] R. Cain, et.al., "Network Interface Package (NIP) User's Guide," SRI International, Contract #957908 Report to JPL, also SRI Project #3528, Nov. 1987.

[4] J. Albus, H. McCain, R. Lumia, "NASA/NBS Standard Reference Model for Telerobot Control System Architecture (NASREM)," National Bureau of Standards, NBS Technical Note 1235, Jun. 1987.

[5] W. Keksz and J. Matijevic, "NASREM and JPL Telerobotic Testbed," Jet Propulsion Laboratory Internal Publication 347-88-319, May 1988.

Figure 1. The JPL Telerobot Laboratory
with a Generic Operator Control Station

FRONT VIEW

Figure 2. The OCS - Elevation View
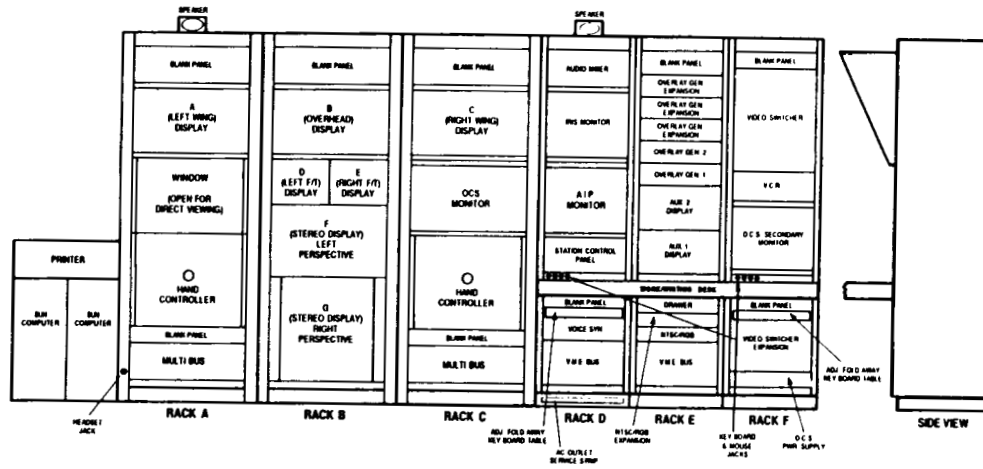
TOP VIEW

JPL LAB
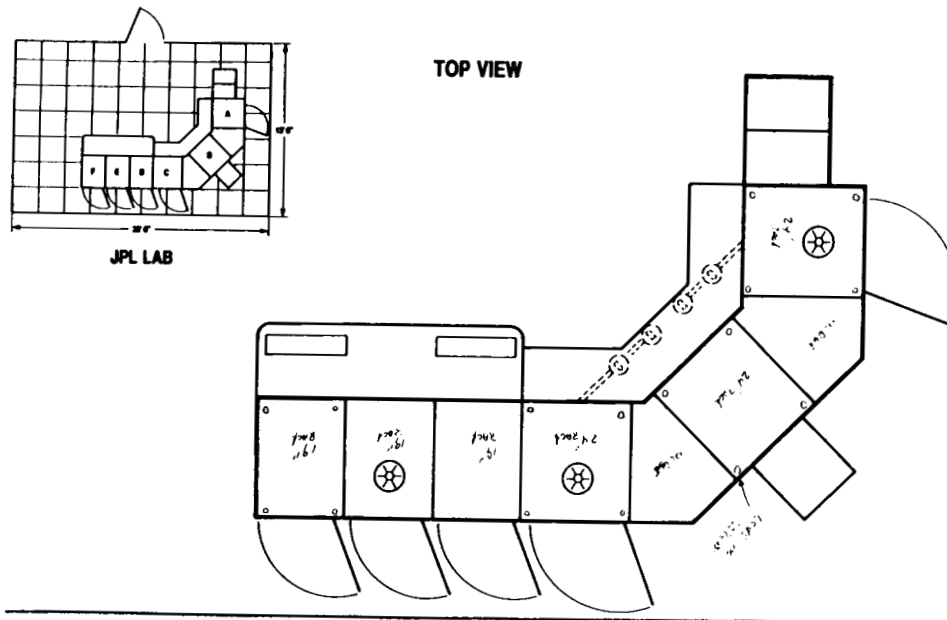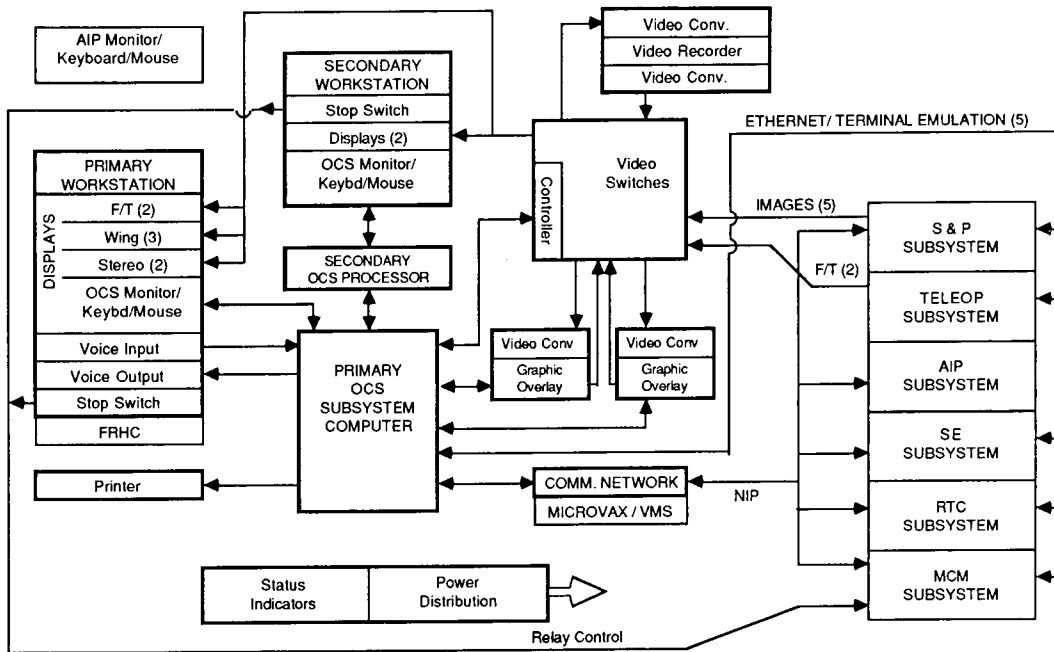

Figure 3. The OCS - Plan View

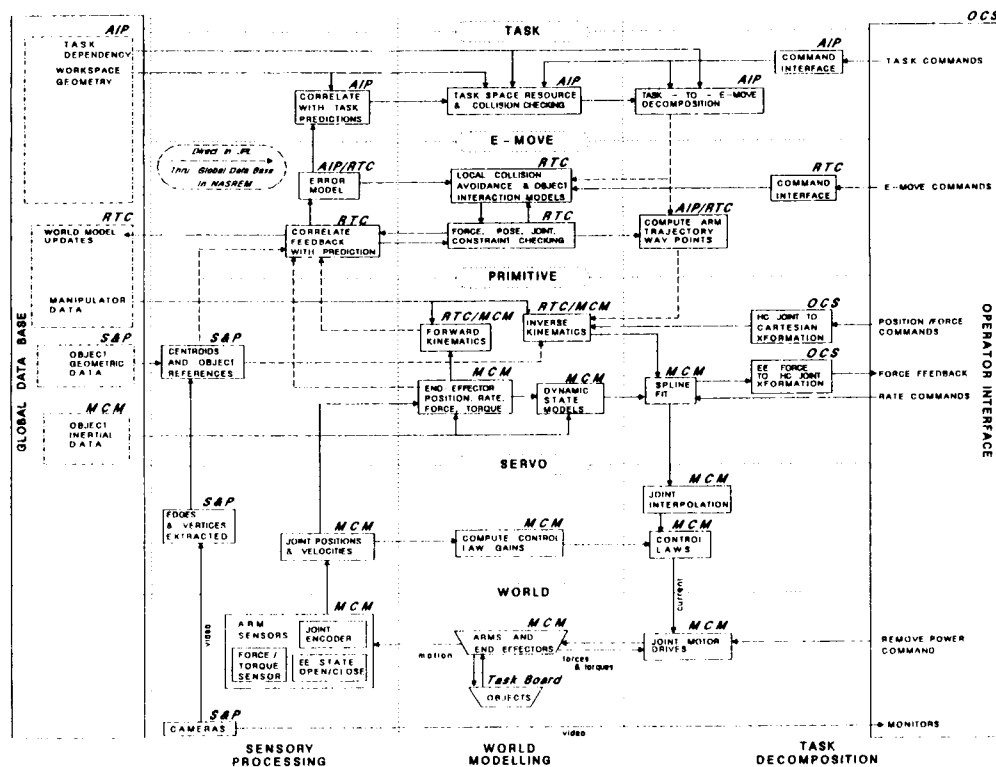Figure 4. TELEROBOT OPERATOR CONTROL STATION
FUNCTIONAL BLOCK DIAGRAM

Figure 5. JPL Telerobot System Mapped into NASREM

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