

CREW INTERFACE WITH A TELEROBOTIC CONTROL STATION

By

Eva Mok
Rockwell International Corporation
Space Station Systems Division
12214 Lakewood Blvd.
Department 590—Mail Code AE91
Downey, CA 90241
(213) 922-0912

ABSTRACT

A method for apportioning crew-telerobot tasks has been derived to facilitate the design of a crew-friendly telerobot control station. To identify the most appropriate state-of-the-art hardware for the control station, task apportionment must first be conducted to identify if an astronaut or a telerobot is best to execute the task and which displays and controls are required for monitoring and performance. Basic steps that comprise the task analysis process are (1) identify Space Station tasks, (2) define tasks, (3) define task performance criteria and perform task apportionment, (4) verify task apportionment, (5) generate control station requirements, (6) develop design concepts to meet requirements, and (7) test and verify design concepts.

INTRODUCTION

Designing an efficient man-machine interface is of high importance to Space Station telerobotic operations. It is estimated that the cost ratio of astronaut time spent on extravehicular activity (EVA) versus intravehicular activity (IVA) is 4 to 1. Therefore, means to increase the productivity of a crew member are important. The use of telerobotics presents a feasible way to reduce crew EVA hours. Tasks best performed by telerobots must first be identified to achieve an efficient man-machine interface. Requirements are then generated to guide the design of the control station, which provides the interface between the crew person and telerobot. This paper discusses a method and verification techniques for apportioning crew and robot tasks in the most effective way. Figure 1 is a flow diagram of our task apportionment and verification process.

Space-based crews will be working with highly automated and sophisticated telerobot systems. Interfaces between the crew and the system will have to be crew-friendly, whereby productivity and flexibility are increased, reliability is improved, and little or no recurrent training is required. The ideal design for a teleoperator control station provides displays and controls that are transparent to the operators to simulate their presence at the remote site. The operators can then pay full attention to the task without being distracted by remoteness. To create this type of environment, tasks must be apportioned between the crew and telerobot relative to their capabilities and limitations.

IDENTIFY SPACE STATION TASKS

The first step is to identify the types of tasks that will be performed on the Space Station. We are supplementing our data base on future Space Station tasks with expert opinion from astronaut consultation; data from Soviet missions; and our past experience in the Shuttle, Space Lab, and Sky Lab programs.

Define Task

This step defines a task in terms of how it is performed (Reference 1):

- Are tools required?
- Where is the task performed?
- Is it time critical?
- Does it require more than one operator?
- How complex is it?
- How frequently is it performed?
- Is the operator required to make frequent decisions?
- Is it concurrent with other tasks?

To identify the subtasks required to complete the task, we first develop scenarios of the step-by-step process by which the task is performed. A comprehensive literature review is conducted to aid in deriving the steps involved in performing the task. The literature reviewed comes from such resources as NASA requirements and procedures documents, as well as related literature from military and academic sources and from nuclear and other industries that use telerobots.

Define Performance Alternative

This step defines the limitations and capabilities of each performance alternative. The possible alternatives, or combinations of alternatives, for performing Space Station tasks include crew IVA, crew EVA, telerobotics, automated systems, and ground control. The following paragraphs give a more detailed discussion of these alternatives.

IVA crew performance is preferred with tasks that require supervisory control, learning, critical and quick decision making, and memorization (References 2, 3, and 4). Crew effectiveness is limited when tasks are tedious, have time constraints, and require extensive and immediate information processing. For instance, scheduled subsystem monitoring or subsystem checkouts do not make good use of the crew. Crew time is critical because of the small number of crew members available on the Space Station and the heavy work schedules they must meet every day. It is neither efficient nor pleasant to have the crew perform time consuming, repetitive, and unstimulating tasks. In such cases, it is better to have an expert system monitor and control subsystems and then interact conversationally with the crew. System status and anomalous situations should be reported to the crew through a conversational natural language interface, i.e., voice communication and graphic displays (Reference 4). Then the crew members can use their expertise to decide which action should be taken next.

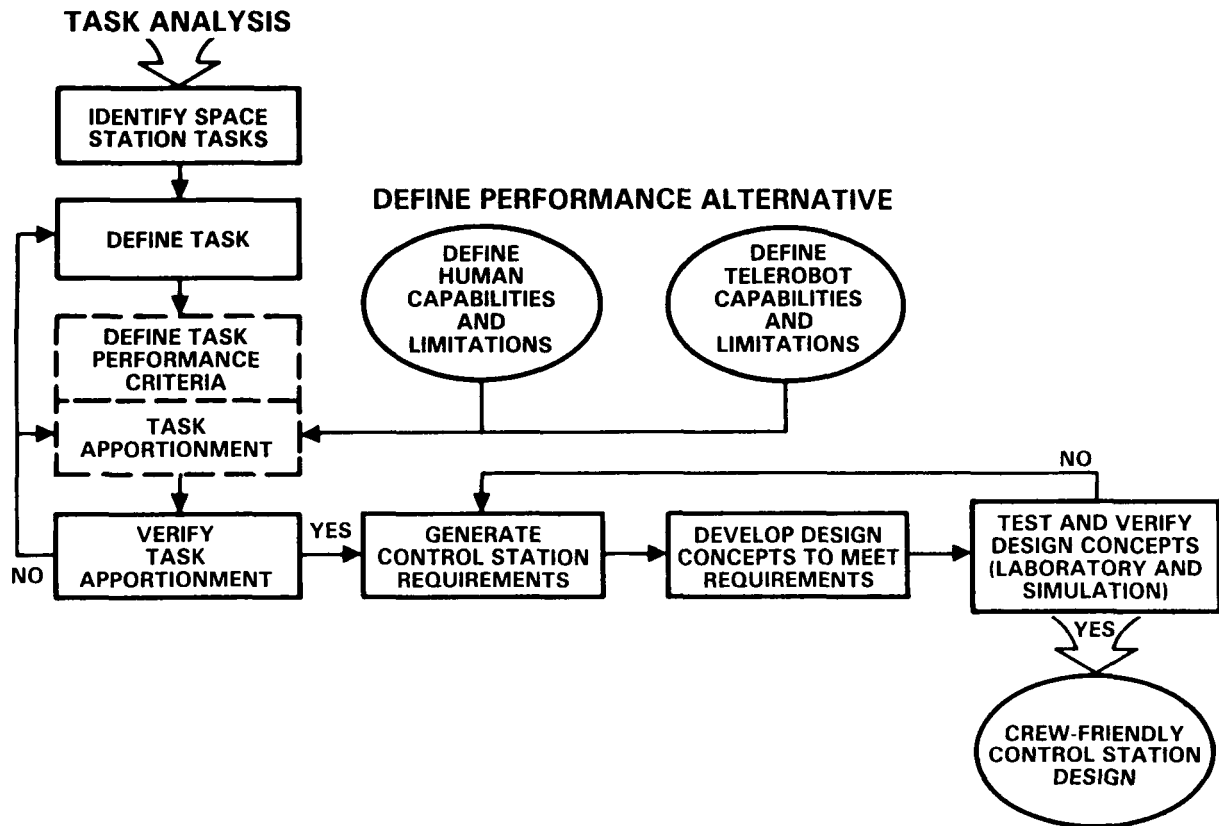


Figure 1. Method for Apportioning Space Station Tasks to Ensure Crew-Friendly Telerobotic Control Station Design

EVA crew performance capabilities are more limited than are those of the IVA crew. EVA is inherently more stressful than IVA because of the novelty and danger of the space environment and the limited duration of the space suit life support system. The physical difference between IVA and EVA is that the EVA crew wears the extravehicular mobility unit (EMU) or space suit. The constraints imposed by the EMU are time constraints, reach envelope, and dexterity limitations. Safety is one of our key drivers for reducing crew EVA. An EVA task that is a good candidate for telerobotic operations is the exchange of an orbital replacement unit (ORU) (Reference 3). Space Station apparatus is designed in a modular fashion. An ORU is the minimum-sized unit; if any part of an ORU fails, the entire unit is replaced. When the ORU can be located for easy access, and its removal and replacement involve simple standardized procedures, a robot can be used to perform the changeout. However, if an ORU is located where access is complicated, such as inside a housing requiring access through a panel opening, an EVA astronaut must perform the task.

Telerobot performance limitations and capabilities are related to end effector access, precision of movement, degrees of freedom, and effectiveness of IVA remote control. An outline of telerobot characteristics and requirements is shown in Table I. Robots and their associated computer systems tend to be more efficient than humans at continuous monitoring, repetitive tasks, storing and recalling large amounts of data in a short period of time, ignoring distraction, and resisting tedium or boredom. On the other hand, humans are best at using their intelligence at perceiving, understanding, continually refining what needs to be done on the basis of what has been learned, and solving unforeseen problems. Robots, however, can be given perceptual abilities outside the range of human capabilities, such as responding to radiant signals beyond the limits of human vision. They can work in the

Table I. Summary of Space Station Telerobot Manipulator Characteristics and Requirements

Characteristics	Requirements
Degrees of freedom	<ul style="list-style-type: none"> • Operating arm = 7 • Stabilizing arm = 3
End effectors	Several types, interchangeable
Maximum tip force	225 N (50 lb)
Maximum tip speed	1 m/s (40 in./s)
Force sensitivity	2.5 N (0.5 lb)
Stiffness/compliance	<ul style="list-style-type: none"> • Adjustable by software control • Maximum 90 N/cm (50 lb/in.) • Minimum 2 N/cm (1 lb/in.)
Modes of control	<ul style="list-style-type: none"> • Full master-slave • Robotic control • Autonomous or supervisory control
Slave power required	300-W peak, 25-W standby
Arm length/reach	~ 1.5 m (60 in.)
Typical arm motion angles	± 45 deg
Typical wrist motion angles	Up to ± 180 deg, except wrist roll continuous
Master-slave signal transmission rate	200 kBd

dangerous space environment and handle substances that pose unacceptable hazards for humans (References 3 and 4).

Automation will play a major role in the success of the Space Station. The primary rationale for implementing automation on the Space Station is that it will increase crew productivity

(Reference 4). However, there are limitations to automating the Space Station. For instance, automated equipment cannot detect changes that lie just outside its programmed range, cannot make unusual decisions, and cannot correct mistakes. Automation will be implemented to relieve the crew from knowledge of detailed procedures for setting up and operating special equipment. Automation in the form of expert systems can provide higher order intelligence for assistance with planning, scheduling, monitoring, control, and fault management (References 3 and 4).

Ground control and support of the Space Station will always be essential, especially in the early stage of the program. As the space program matures, the goal is to minimize ground involvement with day-to-day operations. Initial ground control and support will consist of flight and system monitoring and assistance during the deployment, assembly, activation, check out, and verification of each new Space Station element (Reference 4).

DEFINE TASK PERFORMANCE CRITERIA AND PERFORM TASK APPORTIONMENT

The next step is to establish a set of weighted criteria describing the relative importance of task parameters. For example, reliability might be more important and, therefore, weighted higher than time to perform the task. Task analysis data, alternative definitions, and performance criteria are combined and entered into the Rockwell-developed analytical hierarchical process (AHP) for a hierarchical ranking of how each alternative satisfies the performance criteria. For instance, the robot may be the most reliable alternative, but also the slowest; the EVA crew might perform the task quickly, but at high risk.

Verify Task Apportionment

The identified tasks are simulated in our laboratories and test beds to verify apportionment decisions. Rockwell's Simulation and Systems Test Laboratory was outfitted to verify the optimal hardware to create an efficient crew-friendly control station. Rockwell's software has been used extensively for preliminary design of control stations, hardware placement verification, and crew integration. Table II is a list of control station prototype hardware used to perform station operations analyses in the laboratory. The scenarios developed for the task analysis steps are simulated and displayed at the simulator control station. Astronaut consultants, in-house and team member experts, and data from past programs augment this analytic process. Trade studies are performed to evaluate hardware cost effectiveness.

Generate Control Station Requirements

Data obtained from the task analyses will help derive man-machine interface requirements for the control station design so the crew can effectively control robotic and automated systems and monitor the tasks. Such requirements must refer to the following (Reference 2):

- Displays for performing a task
- Kinds of information for processing while the crew performs or supports the task
- Controls for executing the task
- Equipment (e.g., reliable, maintainable, and safe to operate)
- Control station surroundings (e.g., lighting, noise, traffic flow) that must enhance productivity
- Demands imposed by the control station on other systems

Figure 2 shows a requirements tree for the control station outfitting. For example, the requirements state that the station must provide controls from moving a telerobot around, operating the 6-degree-of-freedom (DOF) arms, end effectors, all displays, cameras, lights, other remote sensors, alarm acknowledgement,

Table II. Prototype Hardware Is Used To Perform Control Station Operations Analyses

Hardware	Components
Work station local area network (LAN)	PC/AT processor with gateway to lab LAN
CRT displays	Color (digital-analog) and monochrome (B/W-green-amber)
Flat panel displays	Plasma (24 in.-17 in.-10 in.), TFEL (10 in.), liquid crystal display (10 in.)
Control devices	Keyboards, touch pads, touch screens, trackballs, joysticks, mouse, digitizer tablets, hand controls
Voice systems	Recognition/synthesis
Data storage	Tape, VCR, optical disc
Purchased software (S/W)	Operator system, compilers, graphics devices, utilities, S/W drivers, data bases
Video equipment	Color cameras, video switchers, converters, frame grabbers, stereo TV systems
Miscellaneous	Projection TV system (6-ft screen), portable computers (grid, panasonic), printers and plotters (color and black/white), image scanners

and all communication (References 5 and 6). The requirements generation is continued to a sufficient level of detail that individual pieces of equipment, with specific volumes and weights, can be stated as meeting the detailed requirements.

Develop Design Concepts

Two types of control station concepts have been selected from the above analysis. One concept houses the control station in a cylindrical module called a resource node (Reference 6). Because direct viewing is not possible from within this structure, the crew will have to rely on television viewing of telerobotic tasks. This is not necessarily a disadvantage, because direct viewing may be confusing when orientation of the telerobot is different from the operator's.

The second concept has the control station housed in the cupola, a glass dome-like structure with 360 deg direct viewing of external activities and telerobot activities (Reference 6). The crew uses displays and controls located inside the cupola to interface with the telerobot. In addition, the cupola allows the operator the option of relying not only on electronic displays (i.e., TV, graphics), but on his or her own advanced and versatile viewing and control system—the human eye/brain network. The cupola is preferred by most astronauts because it allows them to manage a task by direct view and to observe the solar system and Earth.

Test and Verify Design Concepts

As concepts are developed, they are subjected to the same test and verification procedures as those used in verifying task apportionment. Thus, by continually refining the design concepts, we move by successive approximation to the evolution of a final design.

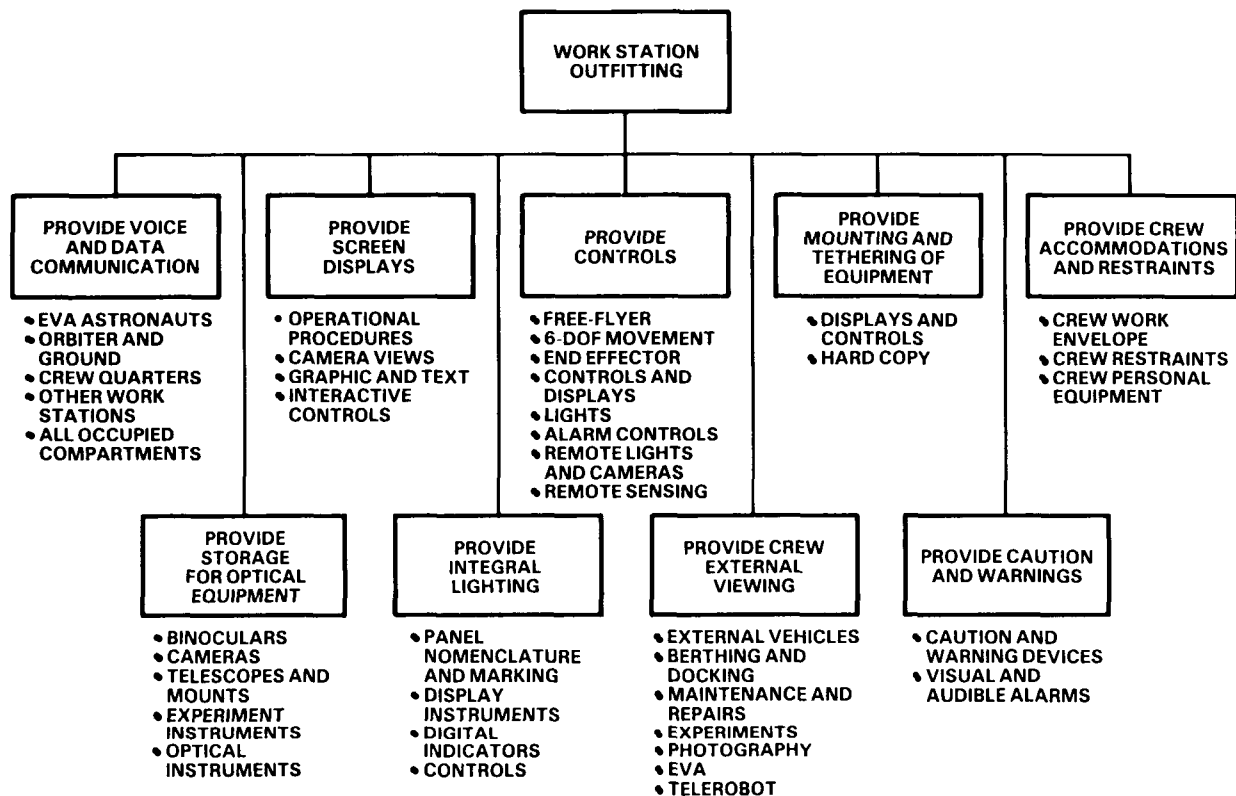


Figure 2. Telerobotic Control Station Requirement Tree

CONCLUSION

The Space Station is a complex and sophisticated structure filled with highly advanced and intricate devices. For humans to interact efficiently with these devices, the interfaces must be natural and direct. The development of crew-friendly control stations assists in accomplishing these goals. We believe the apportioning and verification procedures described above will allow us to design integrated and consolidated electronic controls and displays, permitting humans to effectively monitor and control events on board the Space Station.

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