N90-25527

TELEPRESENCE AND SPACE STATION FREEDOM WORKSTATION OPERATIONS

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ABSTRACT

The Space Station Freedom workstation system is a distributed network of computer based workstations that provides the man-machine interfaces for controlling space station systems. This includes control of external manipulator, robotic and free flyer devices by crewmembers in the space station's pressurized shirt-sleeve environment. These remotely controlled devices help minimize the requirement for costly crew EVA time for such tasks as station assembly and payload support. Direct window views may be used for controlling some of the systems, but many activities will be remote or require levels of detail not possible by direct observation. Since controlling remote devices becomes more difficult when direct views are inadequate or unavailable, many performance enhancing techniques have been considered for representing information about remote activities to the operator. This paper describes the telepresence techniques under consideration to support operations and training. This includes video enhancements (e.g. graphic and text overlays and stereo viewing), machine vision systems, remote activity animation, and force reflection representation.

INTRODUCTION

The space station workstations will be distant from many of the devices they control. This is unlike the Shuttle manipulator workstation which is an optimally located workstation dedicated to providing an operator the necessary controls and displays for the Shuttle remote manipulator system. Because this workstation is close to the manipulator system, most tasks controlled from it can be observed directly through windows in the aft flight deck. Direct observation of remotely controlled equipment makes a task easier and assists an operator in maintaining an overall orientation even when camera views are available. Although some devices controlled from the space station workstations will be observed through windows, many tasks done by operators at space station workstations will involve controlling devices for which direct views are either inadequate or unavailable because of distances or obstructions. As can be seen in Figure 1, direct observation of remote truss activities controlled from the forward node workstations will be difficult. Operators at these workstations will require additional information about external events to control the devices safely and productively. This paper briefly describes the space station workstation system, the devices that will be controlled from the workstations, and the different techniques that have been considered for providing space station operators external event information (or telepresence).

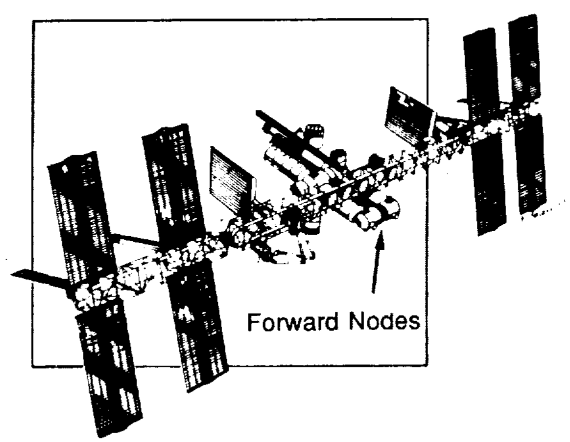

Figure 1. Space Station Freedom

SPACE STATION WORKSTATION SYSTEM

The workstations in the space station will be distributed throughout the habitable areas. A key characteristic of this system is that access to systems control is accomplished through the distributed computer system. In this respect each of the individual workstations is like a terminal on a large centralized system. However, each workstation will contain local processing abilities so that unlike a centralized system, activities at each workstation will have the capacity for independent activity. By using the distributed computer system each workstation will have the capacity to access control of space station systems (such as the Electrical Power, Data Management, Thermal Control, and Guidance, Navigation, and Control Systems) and many of the workstations will be able to control the devices outside the pressurized volumes.

There are three main categories of workstations: Cupola, fixed, and portable. The Cupola workstations, which are primarily configured to control devices outside the pressurized volumes (robots and free flyers), provide direct views of external activities through windows. One cupola is positioned on the nadir of one forward node and the other is positioned on the zenith of the other forward node (see Figure 2). Each cupola will provide viewing for the upper or lower (±Z axes) areas of the space station. These cupolas are small dome shaped structures that contain windows all around the sides (±X and ±Y axes) and in the top (or bottom for the nadir cupola) and are large enough for two side-by-side crewmembers to work. The workstations in the cupolas will have access to systems control through the space station distributed computer system but are expected to be used primarily for controlling external space station devices that require direct observation. The cupola displays and controls are reconfigurable within the cupola so that operations can be performed in either the forward, aft, starboard, or port directions. They differ from the fixed workstations in that they are reconfigurable and they differ from the portables in that they cannot be removed and used remotely from the cupolas.

The second category of workstation is the fixed workstation. These are workstations that fit in the standard 40" wide x 80" high (approx.) space station racks. Within the fixed category are two types: Command & control and standard workstations. The command & control workstations are required to have the capabilities of the cupola as well as the capabilities of any other fixed workstation. The command and control workstations are expected to be used for general station flight management and for controlling external devices which require video views rather than direct views (e.g. controlling a dexterous manipulator at the end of the space station truss).

Each of the space station laboratory modules will have a fixed workstation that will be used primarily to support the laboratory activities. These include the U. S. Laboratory Module, the ESA APM (Attached Pressurized Module), and the NASDA JEM (Japanese Experiment Module). The aft end of the JEM will also house a fixed workstation for operating the JEM's external robots. This workstation will not be part of the distributed workstation system. The devices that it will control can only be controlled from this workstation and this workstation will not control distributed systems. It services the adjacent external exposed facility that is observed through a window in the aft bulkhead of the JEM.

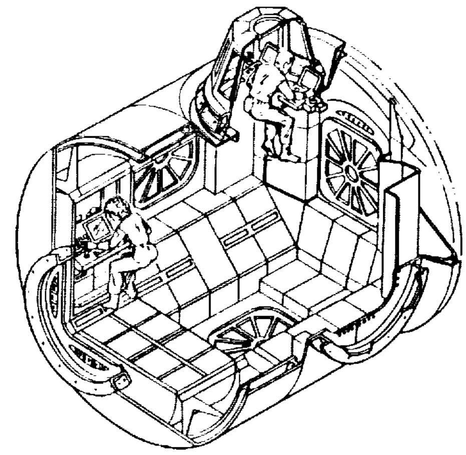

Figure 2. Forward Node Command & Control and Cupola Workstation Concepts

The third category of workstation is the portable. The portable workstations may be the size of large "lap-tops" and will provide access to the distributed computer system to support such activities as crew health care, crew operations, airlock and hyperbaric airlock activities, logistics, and payload support in areas remote from fixed workstations. They will also be used to supplement fixed workstation operations when extra processing, controls, or displays are required.

The workstations involved in operations requiring telepresence are primarily the cupola, command & control, and the JEM's workstation for controlling external robots.

FREE FLYERS AND ROBOTS

There are three categories of devices controlled from the cupola, command & control, and the JEM workstations that will use telepresence. These are free flyers, large manipulators, and dexterous manipulators.

The free flyers include the ESA MTFF (Man Tended Free Flyer), the CERS (Crew and Equipment Retrieval System), and the OMV (Orbital Maneuvering Vehicle). The MTFF will operate as a space laboratory with a number of experiments. This will be mostly unattended or automatically attended by on-board tele-control or ground tele-supervision. Periodically the MTFF will dock at the space station for servicing and parts replacement. The CERS is required to retrieve incapacitated EVA crew-members or equipment separated from the space station. The OMV is required to posit or retrieve payloads (ranging from 3,500 to 7,500 lbs.) in other orbits and then return to the space station.

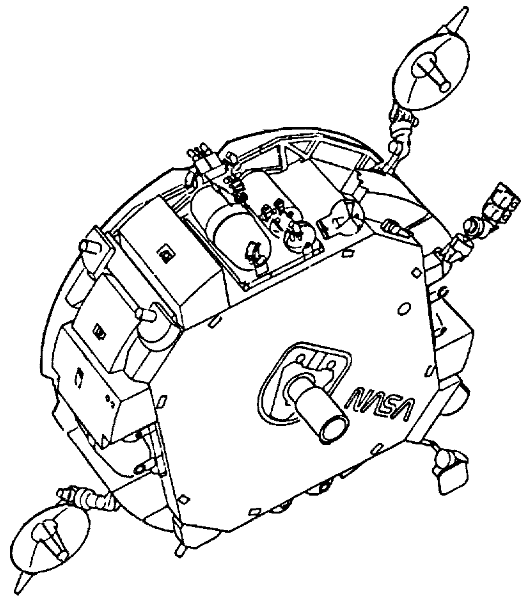

Figure 3. Orbital Maneuvering Vehicle

The large manipulators include the SSRMS (Space Station Remote Manipulator System, as shown in Figure 3) and the JEM RMS (Remote Manipulator System). These arms will be used much like the Shuttle RMS for moving grappled objects from one location to another. The objects moved will range from modules delivered by the Shuttle that will form the habitable volumes to the dexterous robots that are moved to and from work locations. The SSRMS (as well as dexterous manipulators, payloads, and orbital replacement units) can be moved about the station truss by the mobile transporter. The JEM RMS is dedicated to JEM exposed facility operations (as is the JEM small fine arm).

The dexterous manipulators include the FTS (Flight Telerobotic Servicer), the SPDM (Special Purpose Dexterous Manipulator), and the JEM small fine arm (the FTS and JEM small fine arm are shown in Figure 4). These are robots that will be used for assembly, maintenance, and payload tasks of the type that currently require an EVA astronaut. These have arms that are approximately six feet long with end effectors that accept different tools for removing, installing, manipulating, and servicing equipment. These are similar to robots currently used in environments that are hostile to humans such as in undersea and nuclear industries.

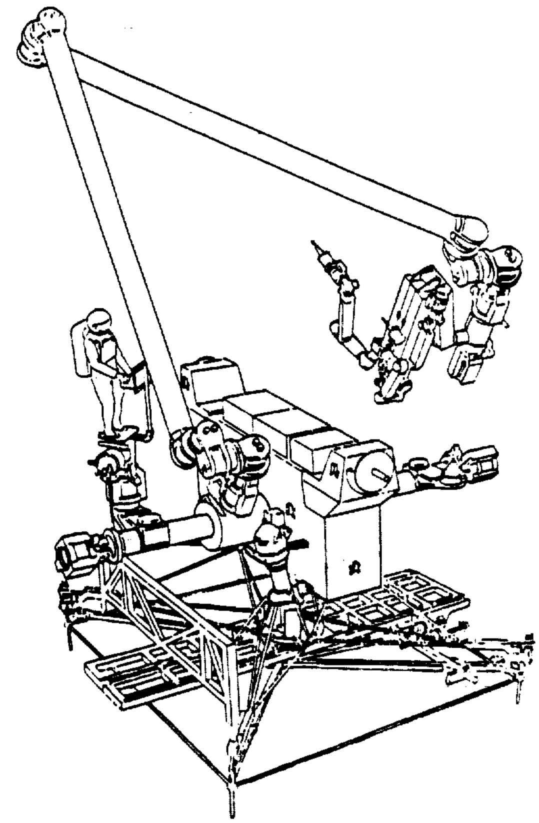

Figure 4. Space Station RMS on the Mobile Transporter shown with the SPDM Attached

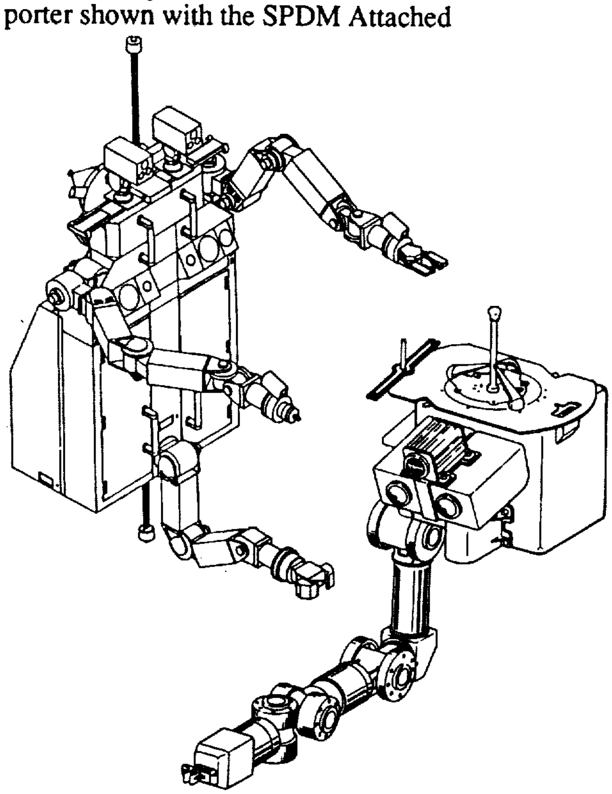

Figure 5. FTS (Top) and Japanese Small Fine Arm (Bottom) Dexterous Manipulators

TELEPRESENCE TECHNIQUES

The telepresence techniques that have been considered for operating the free flyers and robots from space station workstations include video systems and enhancements, machine vision systems, animation, and force reflection.

VIDEO

The most commonly used telepresence technique is video. This often involves the use of multiple video views to provide orthogonal views of the task area. The proper use of lighting to assist depth perception (e.g. with shadows and light patterns) can also facilitate tasks that must be accomplished from camera views. The SSRMS and the JEM RMS will have cameras at the joints as well as at the grapples for viewing operations and targets. The dexterous manipulators will have cameras at the base of the arms (or at the body of the robots) as well as at the end effectors for viewing the manipulations. The space station truss will also have cameras and lights positioned along it to provide general viewing to support these operations.

Enhancement techniques have been developed for video systems. These include stereo viewing and graphics and text overlays on live video. Stereo viewing allows an operator at a workstation to perceive a three-dimensional image which facilitates depth perception in remotely viewed tasks[3]. Some of the systems require the use of glasses much like those used in the 3-D movies to achieve the effect. Other systems are able to achieve the effect without requiring the operator wear any devices but this requires precise eye positioning and small movements of the head may result in the loss of the three-dimensional perception. Another type of three-dimensional display is the head or helmet mounted display which can have individual displays for each eye[5]. The three dimensional systems are only effective for remotely observed events that are within about six feet of the cameras. Consequently, stereo vision systems are considered primarily for dexterous manipulators.

Graphics and text overlays on video are used to aid operators in alignment tasks. For example, the OMV must be grappled by the SSRMS as it approaches the space station and then it must be docked. This requires two operators to work cooperatively. One operator flies the OMV while the other operates the SSRMS. Simulations have indicated that graphic circles overlayed on the live video of the mating structures have been useful in assisting the operator in aligning the devices as they are brought together. Text presented overlayed on the video can provide information on how far apart the objects are and how quickly they are coming together.

MACHINE VISION SYSTEMS

Machine or automatic vision systems use optical or laser systems that respond to targets to calculate positions and rates. Optical systems use high contrast targets arranged in a pattern on an object that is in an unknown orientation at an unknown distance. The pattern of light that is reflected is processed to give information about the object's orientation and distance[6]. This information can then be displayed at a workstation in either graphic or text form to assist the operator. This has been considered as an augmentation to video to assist an operator in docking procedures or to provide the data for automated orientation sequences performed by a robot.

Laser systems have the advantage of not being sensitive to the dramatic lighting and shadow conditions found in space. The SPDM is expected to contain a computer vision processor and a laser scanning sensor that will produce high-resolution three-dimensional maps of the worksite[7]. Current research is addressing such questions as using model-based camera and laser-scanner machine vision techniques that may be appropriate for space applications[1].

ANIMATION

Animation involves representing external events in the form of graphic presentations. These can range from two points in the screen that indicate relative distances and closing rates to near-fidelity representations of three dimensional objects.

In its simplest form, animation may be used to present information acquired from a machine vision system in graphic rather than text format. Rather than seeing numbers presented on the screen that represent the distances and rates between two closing objects an operator could see two simple graphic forms coming together. The movements between the forms on the screen represent the distances, directions of movement, and relative rates between the real objects being manipulated outside the space station.

In its most complex form, animations could be derived from the models of the space station kept in databases. One technique being considered for collision detection and avoidance is the use of a database that contains information about all the space station components. This database would contain all the data about dimensions and locations and would be used to generate a three-dimensional dynamic graphical model of the space station. Any movement by an RMS, free flyer, or dexterous manipulator could then be modeled with the rest of the space station and provide information about conflicts that could result in collisions. This model would then be used to restrict movements of devices that would result in collisions.

If this database is developed and used for collision detection and avoidance, it has been suggested that it could also be used to provide operator aids at the workstations. The database could then be used to generate "birds-eye" views from points where there are no cameras. These types of global views have been shown to be useful in preventing disorientation when operators have no direct view of remotely controlled events. It could also be used to generate views that are behind objects or otherwise obscured from the real cameras.

FORCE REFLECTION

Force reflection is giving information to the operator or the system about forces that are experienced by a device. The information may be felt, seen, or heard by the operator. Force reflection may also be part of a closed loop system in a robot to prevent it from exceeding certain forces. In this mode, the operator may receive no force information at all and the robot will be prevented from exerting forces that will damage equipment. The force reflection that is instrumental in telepresence is the force reflection that provides information to the operator and that is the type that will be described.

Force reflection that is felt (hand-controller force reflection) can allow the operator to "feel" when the end effector has made contact and the amount of force being exerted. This mode, sometimes referred to as bilateral force reflection, is one in which the forces exerted on the device being controlled are reflected or conveyed to the device (e.g. hand controller) that is controlling the robot. In this manner the controller and the robot are tightly coupled so that forces on one are reflected in the other. For master type of controls, this means motions that force movement in the robot also can force movement in the controller and the operator. These types of controllers often have force limitations at the controller to prevent an operator from being injured by accidental events at the end effector.

This type of force reflection offers several advantages. It has been shown to facilitate inexperienced operators or operators that are doing unscheduled or novel dexterous manipulator tasks[4]. It can be useful for providing information about objects that cannot be seen. In a limited fashion, the end effector can reach behind something and "find" a protrusion or a hole by providing limited topological information to the operator. In addition, operators performing representative remote handling tasks using force reflection can have lower error rates, lower peak forces, and more consistent application of forces than without force reflection[2].

There are also several disadvantages. Force reflecting hand controllers used at a space station workstation will require the operator to be restrained against the forces exerted by the hand controllers. Since the operator will be in a weightless environment, even the smallest forces will cause the operator to move. This type of force reflection can also be fatiguing since the operator has to work against the force reflection. Also, typical force reflection systems are more expensive in mass, volume, and individual unit prices than systems without force reflecting capabilities[2].

Aural force reflection provides auditory displays so that information about forces at the end effector are perceived by sound rather than by feel. In this manner, force reflection may be perceived as sound that varies in intensity or pitch in proportion to the forces exerted at the end effectors. Simpler versions of aural force reflection include alarms that sound when certain forces have been exceeded.

Visual force reflection provides visual cues rather than forces that are felt or sounds that are heard. This information may be presented on a computer display as text that indicates forces and force vector information or as graphics with lengths or areas that are displayed in proportion to the forces at the end effector. These displays may use light intensity, color, or on/off status to indicate forces. This form of force feedback has a disadvantage in that the information will not be perceived unless the operator is actively attending to it.

SUMMARY

This paper has given an overview of the space station workstations, the devices the workstations will control, and the telepresence techniques that have been considered to support the control of those devices from the workstations. The telepresence techniques used at space station workstations will likely involve combinations of some of the concepts described above. Given the variety of the devices controlled from the workstations it is possible that different techniques will be chosen for different operations. The crew may have the option of choosing between techniques for some operations. Facilities that support the development of space station systems are currently evaluating these techniques to determine the appropriate applications for each of the space station devices and their respective tasks.

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