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Telerobotic Space Station Applications

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ABSTRACT

This paper presents telerobotic space station applications, important issues in telerobotics and work at the University of Alabama in Huntsville in the area of telerobotics.

INTRODUCTION

NASA's recent award of over $5 billion in space station contracts begins the transition of the U.S. space program from brief space visits to space habitation and industrialization. The end result of the space station project will be a 400,000 lb. structure of modules, trusses and solar arrays in orbit above the earth.

While many space station sections will arrive completed structurally, others will require assembly in space. Assembly in space will be done manually by extravehicular activity (EVA), by some application of automation or by a hybrid of the two. Planning of space station assembly in orbit is primarily the responsiblity of the McDonnell Douglas Astronautics Co.

The two largest factors which drive all space station assembly discussion are safety and cost. With recent cuts into space station funding, it is important that remaining funds be spent wisely.

The cost of EVA is high; training, support, equipment and safety measures all contribute to a high price tag. A 40 minute prebreathing exercise is required before each EVA; the astronaut's space suit constrains motions, produces loss of dexterity and eliminates tactile sensing. While the cost of assembling the space station cannot be eliminated, it can be reduced significantly by the application of telerobotics.

In a recent study by Boeing Aerospace, it was estimated that automation of satellite servicing would cut the repair time required in half from the amount needed for EVA during four servicing reference missions (Meyer, 1985). It is not possible to automate space in the way we automate earth factories. Space is not known for its highly repititve nature. However, through robotics we can effectively extend the astronauts arm to remote locations while allowing the astronaut to remain in a more suitable "shirt sleeve" environment.

TELEROBOTIC ISSUES

There are several established issues of telerobotics including those associated with cameras, lighting, displays, end effectors and robot arms. Brief discussions of the issues and work to date at the University of Alabama in Huntsville are presented.

Number of Cameras. The number of camera views to be provided for a telerobotic task in space is a trade between operator convenience and the cost of putting needless cameras and equipment in orbit. Current cost to orbit is approximately $3600/lb.

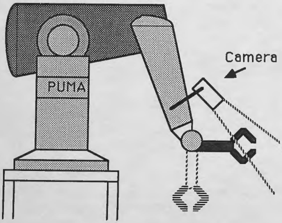
Recent research at UAH in this area has concluded that no more than two views are necessary to perform a telerobotic task. When more views are presented, subjects tend to depend only on two views. Fewer cameras also allow console design simplicity.

View Color. The issue of black and white vs. color views has been investigated heavily by the telerobotics community. All have concluded that view color does not effect task time. However, it is obvious that in a servicing or assembly task with color components, color views will be necessary. Cost will not rise significantly by providing color views.

Camera Position. The placement of cameras for telerobotic tasks is an issue of angle to the task board and distance from the task board. Fixed cameras may become inefficient as task area orientation changes in space.

UAH research has shown that a manipulator arm view and an orthogonal arm view are preferred by most subjects although not statistically substantiated. There is also a strong feeling (an area of further investigation) that one movable camera could be substituted for 2 or more fixed cameras. Near term experimentation at UAH will look at this area.

One example of this is the situation that occurs when a camera is mounted on a robot arm. If the camera is fixed, the task area may not be visible due to robot arm movement in both the horizontal and vertical directions. Figure 1 depicts the vertical view degradation scenario.



Vertical View Degradation
Figure 1

Lighting Intensity. Light intensity is a critical factor. A task in space can go from a situation of total brightness to one of shadows and darkness. However, cameras that adjust for light can overcome this handicap. It would seem obvious that these cameras must be provided on the space station and should be as they are readily available today.

Lighting Position. Lighting position determines some of the shadows on the task area and the amount of light available for cameras. The most recent work at UAH is in this area and is presented later in this paper.

Feedback Delays. Time delays are inherent in any teleoperation system. Sending and receiving transmissions from space or space vehicles can result in time delays up to 8.0 seconds. The length of delay depends on the number of switching satellite and data processing times.

Studies at UAH have shown this interaction to increase task time 20-40% for each additional second of time delay with the percentage increasing as the time delay increases. Move and wait strategies are generally adopted by subjects, and even learning and confidence fail to eliminate the effect of time delays.

Predictive Displays. One way to eliminate some of the effects of time delays is to use predictive displays. The operator can observe a wireframe drawing of the robot manipulator in real time overlaying the camera view of the robot. An MIT study (Sheridan, 1984) concluded that predictive displays reduce task time 50-150%.

End Effector. Various types of grippers, end effectors and tools will be necessary for space tasks. Near term research at UAH will investigate relationships between gripper size and fastener size and study electrical vs. pneumatic grippers.

Number of Robot Arms. While increasing the number of robot arms may increase the range of possible tasks, it also increases the likelyhood of work envelope violation. Telerobotic research at UAH has centered around a one armed robot but graphical simulation of two and three armed robots has been conducted.

Research at the Jet Propulsion Laboratory (JPL) has been conducted using up to three robots (single arm) in the same work envelope.

Reach Considerations. Not all space telerobotic tasks will fall within the work envelope of robots being researched today. Attach point separations range from 2 to 20 feet (Fischer, 1985). Rather than increase the arm length of telerobots, it seems feasible to design interfaces to the Remote Manipulator Servicer (RMS) and Flight Telerobotic Servicer (FTS) which would allow the robot to be moved from place to place and platform to platform.

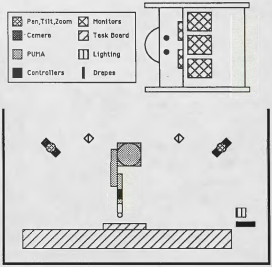
Design for Space Automation. The growing trend for earth-bound applications is to "design for automation". The same holds true for space-based tasks. Space station structures, arrays and interfaces should be designed with robotic construction and servicing in mind. For example, fasteners should be developed to aid robotic end effectors in performing tasks. Protuberences should be minimized as much as possible (while maintaining mission requirements). Design for automation has shown decreases in cost and the number of parts,and increases in part simplicity.

TELEROBOTICS RESEARCH

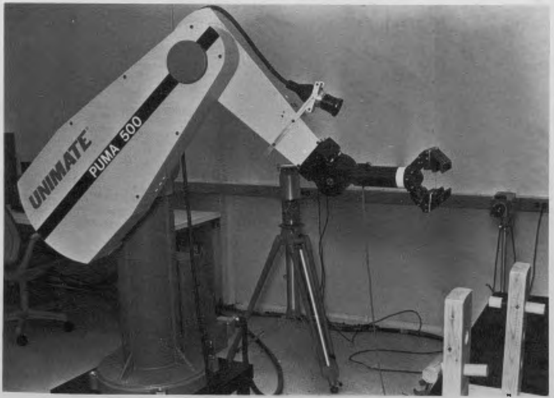
A space telerobotics laboratory has

been developed at the University of Alabama in Huntsville. Support in the form of effort, funding and equipment is being provided by Boeing Aerospace Company, NASA/ Marshall Space Flight Center, SRS Technologies, the State of Alabama and United Technologies-Space Flight Systems.

The goal of the UAH telerobotics laboratory is to understand man's role in telerobotics technology. The laboratory layout is shown in Figure 2. The laboratory is centered around a PUMA 562 (6 DOF) robot arm. Mounted on the arm is a high resolution black and white CCD camera. The Puma (shown in Figure 3) is remotely controlled with two 3 DOF hand controllers at the control console. Other scene cameras (both B/W and color) are available in the lab. All video feedback is sent to the operator's console which allows up to five monitors (B/W and color). The robot gripper is also remotely controlled from the console along with up to two pan/tilt/zoom units. Three 600W high intensity lights and a NASA task board complete the laboratory hardware. The robot work envelope is covered on three sides by light suppression drapes.



Laboratory Layout
Figure 2



Puma 562
Figure 3

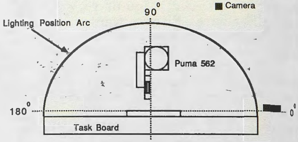
EXPERIMENTS

A number of baseline experiments were conducted in 1987 in the telerobotics laboratory. The objectives of these experiments were to check out the lab hardware and software and to become familiar with the operational characteristics of the facility. A more important objective was to conduct several baseline experiments for which the experimental results could be compared with previously published results.

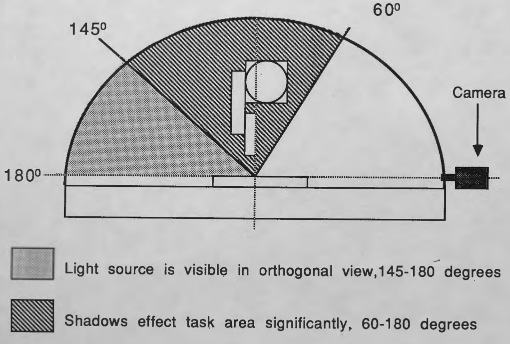
These initial experiments have provided insight into lighting position and camera position interaction. As a result, an experiment was designed to study lighting position effects on the orthogonal and arm camera views.

For this latest experiment, the laboratory was set up as shown in Figure 4. To study light postion effects, a 600W high intensity lamp was moved along in arc with its focus held on a central task point. Both the orthogonal and arm views were provided. Three subjects were asked to perform simple tasks on the board for different lighting positions on the arc. The task consisted of removing a wooden cylinder from a hole and placing it in a another hole vertically above the removal point. The subject's comments and light position preferences were recorded after each session. As a baseline, the monitor brightness was set comfortably at the 0^0 position and held constant throughout all trials. The light source was kept 5' (arc radius) from the central task point and level at 3'-6" from the floor. Two 9" black and white monitors were provided at the operators console.

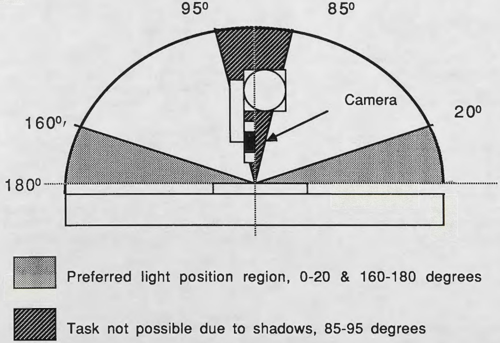
Results considering the orthogonal view are shown in Figure 5. These results



Experimental Layout
Figure 4



Orthogonal View
Figure 5



Arm View
Figure 6

indicate a problem when the light source directly shines into the camera view (from 145^0 to 180^0). Shadows are a significant factor for the orthogonal view from 60^0 to 180^0.

The results considering the arm view are shown in Figure 6. The results indicate that the best lighting position with respect to the arm view is between 0^0 to 20^0 from either side of the task board. In the region from 20^0 to 85^0 on either side of the task board, the light intensity becomes greater and affects depth perception. In reality this can be handled by light adjusting cameras. However, when the light is behind the robot arm and directly facing the task area, the trial became impossible to do since the view was obliterated by shadows. With a fixed camera and light source in space, this will become an unfortunate reality.

TELROBOTIC APPLICATIONS

Space station servicing missions and assembly tasks include:

Truss assembly

Solar array deployment

Module alignment

Space shuttle cargo loading/unloading

Platform drive mechanism replacement

GRO subsystem module replacement

Radiator panel replacement

OMV propellant transfer

AXAF tank replacement

Large satellite assembly

Communication platform/stage assembly

Logistics module installation

Platform battery replacement

Platform payload servicing

Some servicing or assembly tasks may be attached to the space station or shuttle; others however, may be free flying and require capture by the RMS or FTS before servicing.

TELEROBOTICS REQUIREMENTS

The current list of telerobotic space application requiremets includes:

Cameras that adjust for light intensity

Optimal positioning of camera(s)

Automatic focusing camera(s) with pan, zoom and tilt capabilities

Ergonomic display consoles that optimize operator comfort

Versatile robot arms that can perform the majority of tasks that would be done by EVA

A human in the telerobotic loop due to the unrepetitive nature of space tasks

RMS and FTS interfaces for moving a telerobotic servicer to remote task areas

End of arm interface and multiple end effector capability

Design for space automation to allow for maximized telerobotic applications

Control from space shuttle during early stages of space station assembly

Control from space station after operator's console is integrated

Telepresence capablities

Orientation referencing

CONCLUSIONS

The use of telerobotics is necessary for space station assembly and servicing; research must proceed in this area to reduce expenditures. A single telerobotic servicer that can perform a variety of tasks will be the most cost effective approach to space station servicing and assembly.

Near term experimentation in the UAH telerobotics laboratory includes voice control applications, time delay effect study on complex tasks, single view capability and preliminary investigation into a single operator controllable camera/light source.

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