EVA AND TELEROBOT INTERACTION

Kelli F. Willshire
NASA Langley Research Center

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INTRODUCTION

We are about to enter into a new era - that of astronauts working hand in hand with telerobots in space. This has been done to some degree with astronauts and the Space Shuttle's Remote Manipulator Arm. However, for the Space Station Freedom, not only will astronauts be working with the RMS type system but also with smaller, more dexterous systems such as the Flight Telerobotic Servicer (FTS). Because EVA time is a premium resource, the most effective use of the astronauts and the telerobot will be required. There may be some tasks for which it is most efficient to have both the EVA astronaut and the telerobot working together. This type of close interaction has not occurred before and brings up many issues. Most of these issues are related to technology: communication must be infallible, new control systems and devices may be required, enhanced telerobot safety systems may be necessary. IVA operations may also be affected by the combined EVA telerobot tasks. There is also the issue of how the EVA astronaut and the telerobot work on separate tasks but at the same time. For both situations, research and development of at least some new technology is required: enhanced communication both by voice and data, sophisticated collision detection systems, more responsive controls and displays. These new systems or system enhancements may require knowledge base systems for their operation. This paper will review some of the important issues, types of tasks, the FTS capabilities, the technology that is needed to address those issues, and the possible impact on Space Station Freedom.

OUTLINE

- ISSUES OF EVA - TELEROBOT INTERACTION
- TYPES OF TASKS
- FTS CAPABILITIES
- TECHNOLOGY REQUIRED FOR INTERACTIONS
- POSSIBLE IMPACT ON SPACE STATION FREEDOM

When astronauts and the telerobot work together or in close proximity, many issues become important. These issues are listed on this page, not necessarily in priority order.

The first issue is that of communication. Effective communication between the astronaut and telerobot will be critical for safe and successful task completion. Communication should be extremely reliable and noninterfering with the conduct of the task. That is, methods of communication should be as natural as possible so that voice is likely to be the best method to use. This will require more capable voice recognition and command systems.

Safety is the next issue and is related to communication. The entire scenario of astronauts and the telerobot working together or in close promixity is safety critical, not only for the astronaut, but also for the integrity of the Space Station and the mission success. Many subissues are involved in safety and include physical means of preventing the telerobot from harming itself, the astronauts, or the Station; effective work practices by the astronauts; adequate visibility and communication; and escape procedures should an accident happen.

Workload is another issue when the interaction of the telerobot and the astronaut is considered. How much work and of what level of difficulty, mental or physical, is optimum for the astronauts when working with telerobots? The astronaut would not likely be exclusively an observer, which could be boring and monotonous and create a situation where a critical event may be missed. On the other hand, the astronaut should not have to continually manipulate the telerobot which would be physically fatiguing and possibly result in an unsafe situation.

Task allocation is related to workload. Which tasks are best suited for the astronaut to do and which are best for the telerobot is already being examined. This area will need to be extended to consider the IVA astronaut in the loop with the EVA astronaut and telerobot.

Control should be considered in at least two ways. The first is that of who has authority for a task and how does that authority get changed when necessary. The second, but related, way is that of control from the ground. This brings up the additional problems of time delay.

Symbiosis, a term used by the investigators at Oak Ridge National Laboratories among others, is the issue of how the astronaut works with the telerobot or separately but in close proximity. This is a broader issue which is made up of components of all the above issues.

Mobility is the last issue to be discussed. What is the best way to move both the telerobot and the astronaut when both are exterior to the Station? What are safe modes and speeds of travel? What procedures should be followed for moving about the Station?

ISSUES

- COMMUNICATION
- SAFETY
- WORKLOAD
- TASK ALLOCATION
- CONTROL
- SYMBIOSIS
- MOBILITY

Fatigue was mentioned with respect to workload. Ocean Systems Engineering has identified some possible problems for IVA astronauts based upon their experience with underwater teleoperated systems. They list several physical and environmental fatigue factors. Operational stress can be generated by task difficulty, operational time limitations, or extended durations of concentration. Eye strain can be caused by improperly sized video monitors, video flicker, distortion, or improper restraints monitoring. Body fatigue can be created by large scale masters, miniature joysticks, or the relationship between the restraint and console. Boredom is caused by repetitive work tasks, excessive time on operations, lack of sleep, or minimal time off from work. IVA lighting can create glare on video monitors which can adversely affect eyesight during operations. Background noise interferes with communication and concentration. These problems can be avoided by proper human factors design and operational procedures.

POSSIBLE PROBLEMS FOR IVA ASTRONAUTS

O PHYSICAL AND ENVIRONMENTAL FATIGUE FACTORS

- OPERATIONAL STRESS : GENERATED BY TASK DIFFICULTY, OPERATIONAL TIME LIMITATIONS, EXTENDED DURATIONS OF CONCENTRATION

- EYE STRAIN: IMPROPERLY SIZED VIDEO MONITORS, VIDEO FLICKER, DISTORTION, AND IMPROPER RESTRAINT FOR MONITORING

- BODY FATIGUE: CREATED BY LARGE SCALE MASTERS, MINIATURE JOYSTICKS, AND RESTRAINT TO CONSOLE RELATIONSHIP

- BOREDOM: CAUSED BY REPETITIVE WORK TASKS, EXCESSIVE TIME ON OPERATIONS, LACK OF SLEEP, MINIMAL TIME OFF SHIFT

- IVA LIGHTING: GLARE ON VIDEO MONITORS, ADVERSELY AFFECT OPERATION EYESIGHT,

- NOISE: BACKGROUND INTERFERES WITH COMMUNICATION, CONCENTRATION

There will be several types of Space Station tasks that can be done by either EVA astronauts or telerobots or both. Assembly of the Station and large space structures has received quite a bit of attention since it is one of the first tasks required by the Station. Assembly by telerobot is feasible, although it may take longer with a telerobot. On the other hand, the telerobot can be operated almost 24 hours a day, whereas the EVA astronaut is limited to 6 hours per day, and no EVAs are permitted until the third day in space. Since assembly of a truss structure involves a series of repetitious steps, it is amenable to automation or robotic operations by which most steps can be done autonomously. However, it may prove optimal to have both the EVA astronaut and the telerobot working together during assembly.

Similarly, inspection and check-out tasks can be fairly routine and repetitious and so amenable to automation or at least supervised teleoperation. Making sure that utilities are in place, secure, and operational is an example of an inspection and check-out task.

Repair is a more complicated task depending upon the type and extent of repair required. There may be groups of steps which can be automated, but more than likely, supervision will be required and decisions made by astronauts.

Replacing orbital replacement units (OURs) should be routine in most cases if the ORUs are designed properly and no extenuating circumstances exist.

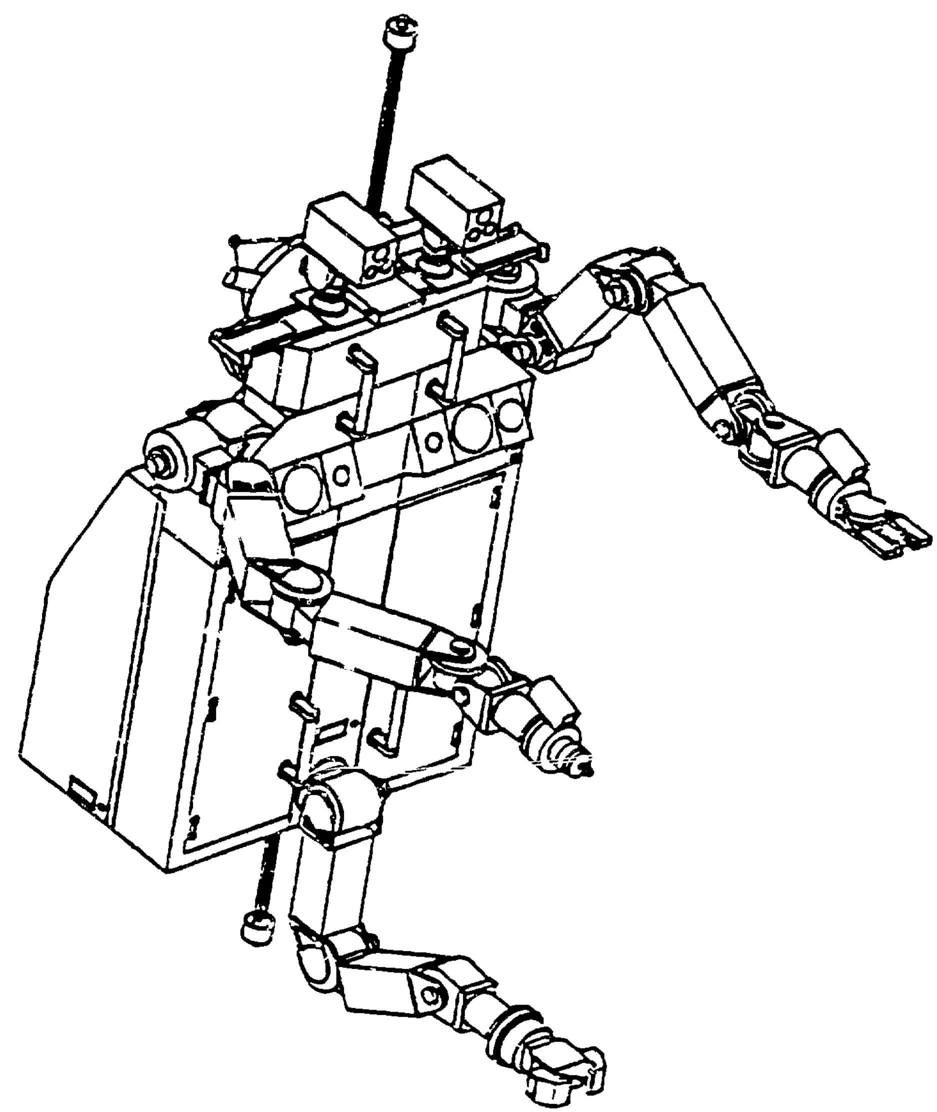
Servicing implies a variety of tasks from resupplying fuel, cleaning, refurbishment, and routine replacement of worn parts. Individually, these tasks should be able to be automated or at least conducted via supervised teleoperation.

TYPES OF EVA OR TELEROBOT TASKS

- ASSEMBLY
- INSPECTION AND CHECK OUT
- REPAIR
- ORU REPLACEMENT
- SERVICING

This is the Martin Marietta Astronautics concept of the Flight Telerobotic Servicer being developed under contract with NASA Goddard Space Flight Center. Its characteristics are described on the following pages.

FLIGHT TELEROBOTIC SERVICER



These are the Flight Telerobotic Servicer (FTS) characteristics projected by the FTS project office to be available by assembly complete. The FTS consists of three main parts: the telerobot, the workstation, and a distributed data management system. The telerobot will have two 7 degree-of- freedom manipulator arms, which are each 5 feet in length. It will also have an attachment, stabilizing, and positioning subsystem which is similar to a leg in function. There will be four cameras; one on each wrist, and two on the head, with a lighting system. End-of-arm tooling will be provided which allows switching to one of several end effector tools on a caddy.

The workstation will be an enhanced multipurpose application console or MPAC. There will be an operator restaint system inside the space vehicle. Two 6 degree-of-freedom mini-master force reflecting handcontrollers will be used for operating the manipulators. Three video images will be able to be presented simultaneously, or one can be used for computer graphics. There will be voice control of the cameras. Video and data recorders will be included.

The FTS data management processing system (DMPS) will be fault tolerant, redundant, distributed, and modular so that it can be more easily repaired and upgraded as more capabilty is needed.

PROJECTED FTS CHARACTERISTICS

O TELEROBOT

- TWO 7 DOF MANIPULATOR ARMS (5FT)
- ATTACHMENT, STABILIZING AND POSITIONING SUBSYSTEM
- FOUR CAMERAS: TWO ON WRISTS, TWO ON HEAD
- LIGHTS
- END-OF-ARM TOOLING

O WORKSTATION

- ENHANCED MPAC
- OPERATOR RESTRAINT SYSTEM
- TWO 6 DOF MINI-MASTER FORCE REFLECTING HANDCONTROLLERS
- VIDEO DISPLAY: THREE IMAGES SIMULTANEOUSLY OR ONE FOR GRAPHICS
- VOICE CONTROL OF CAMERAS
- VIDEO AND DATA RECORDERS

O DMPS

- FAULT TOLERANT, REDUNDANT, DISTRIBUTED, MODULAR

The FTS has three modes of operation. The first listed is the fixed base dependent mode in which the FTS is attached and stabilized at the worksite by the Shuttle RMS or Station (Mobile Remote Manipulator System) MRMS. It obtains its power, data, and communication resources via an umbilical to the host, e.g., the Shuttle or Station. The second mode is that of fixed base independent. For this mode, the FTS is attached and stabilized at the worksite, but uses power from internal batteries and wireless communication. The third mode is transporter attached. The FTS stays attached to the Shuttle RMS or the Station MRMS for mobility during a task and receives its resources from the host transporter. Regardless of the operation mode, the FTS is designed and sized so that it can be taken inside the Shuttle or Station for servicing.

FTS OPERATIONS

- O FIXED BASE DEPENDENT
  - ATTACHED AND STABILIZED AT WORKSITE
  - RESOURCES VIA UMBILICAL
- O FIXED BASE INDEPENDENT
  - ATTACHED AND STABILIZED AT WORKSITE
  - POWER FROM INTERNAL BATTERIES
  - WIRELESS COMMUNICATION
- O TRANSPORTER ATTACHED
  - SHUTTLE RMS OR STATION MRMS FOR MOBILITY
  - RESOURCES FROM HOST TRANSPORTER
- O IVA SERVICED

The FTS is projected to use the following amounts of resources. The telerobot and workstation together will weigh under 1500 pounds. The stowed telerobot will require 7 ft X 3.5 ft X 3 ft volume. The power requirements will be less than 2000 watts peak, or 1000 watts average, and 350 watts for standby.

FTS RESOURCES

- O WEIGHT
  - TELEROBOT AND WORKSTATION < 1500 LBS
- O VOLUME
  - 7 FT x 3.5 FT x 3 FT FOR STOWED TELEROBOT
- O POWER
  - LESS THAN 2000 WATTS PEAK
  - 1000 WATTS AVERAGE
  - 350 WATTS STANDBY

The question is not whether telerobots, such as the FTS, or astronauts should always perform certain tasks, rather the problem is to find the optimum mix of astronauts, IVA and EVA, and telerobot operations. This optimum depends upon proper human factors design of the human-machine systems, including designing for robot-friendliness. The latter usually makes things more human friendly, also. In addition, technology enchancements are necessary to reach the complete optimum. The required technologies include a more rugged EVA suit for longer, more comfortable operations; sophisticated collision detection and avoidance systems; responsive controls and displays so that time delays are not apparent to the user; automatic control delegation so that control is switched when necessary to the proper agent; enhanced communciation systems which are more reliable and understandable, especially in the area of voice recognition and commmand; and finally, enhanced knowledge bases and knowlege base methodology to support the proper level of automation and supervision.

Supporting these technologies on the Space Station Freedom may require more data, communication, and power resources. However, the investment of these resources will be outweighed by the increased productivity of the Station overall and its mission success.

REQUIRED TECHNOLOGY

- MORE RUGGED EVA SUIT
- SOPHISTICATED COLLISION DETECTION AND AVOIDANCE
- RESPONSIVE CONTROLS AND DISPLAYS
- AUTOMATIC CONTROL DELEGATION
- COMMUNICATION ENHANCEMENTS
- ENHANCED KNOWLEDGE BASES