

TELEROBOTIC WORK SYSTEM-SPACE ROBOTICS APPLICATION

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ABSTRACT

The need to increase astronaut productivity for assembly, servicing, and maintenance missions has led to the definition of a concept for remote operations called the telerobotic work system. Dexterous manipulator arms are controlled from the Space Shuttle Orbiter cabin or a Space Station module. Concepts for the telerobotic work system have been developed by the Lyndon B. Johnson Space Center through contracts with the Grumman Aerospace Corporation and Martin Marietta Aerospace. An evolutionary development of the system is proposed as a means of incorporating technology advances. Early flight testing is seen as needed to address the uncertainties of robotic manipulation in space. Space robotics can be expected to spin off technology to terrestrial robots, particularly in hazardous and unstructured applications.

INTRODUCTION

The role of the space crew is changing, with more missions recognizing the benefits of servicing and maintenance as a cost-effective mode of operating satellites. The size of the Space Station mandates assembly in space. Recent Space Shuttle missions have demonstrated the effectiveness of the extra-vehicular activity (EVA) crew in many of the tasks needed. As the magnitude of mission requirements grows, the productivity of the astronaut must be increased. For EVA, a buddy system as well as an observer in the cabin are required. Preparations add to nonproductive time. Remote operating systems are a means of amplifying space crew output.¹ One concept for remote operations is the telerobotic work system (TWS).

The basic concept of a telerobotic work system consists of two dexterous manipulator arms controlled from a remote station. The operator is provided with sensory feedback of the environment and conditions at the work site. His control of the arms may be supplemented by interaction with a computer to perform certain tasks or portions of tasks. The tasks to be performed range from changing modules and components in the repair of satellites to the construction of large space systems like the Space Station. An objective of the system development approach is to increase the productivity of the operator through more robotic modes exhibiting a higher degree of autonomy.²

The TWS concept is viewed as a means of unifying technology for autonomous robots. A robot operating in the environment of space has analogies to a robot operating in hazardous or unstructured terrestrial situations such as toxic materials handling, nuclear plant service, undersea operations, construction, agriculture, and police and firefighting work. A smart, adaptive robot can also perform a variety of service functions for the disabled and aged. The development of a robot with the capability to operate in space can meet many of the requirements of terrestrial applications.

SYSTEM REQUIREMENTS

The functions of the TWS will be the servicing of satellites; satellite repair, assembly, and construction; payload handling; and contingency repair of spacecraft. These functions may be further broken down into a variety of generic tasks. Examples of the tasks are removing and installing fasteners, connection of umbilicals and fluid lines, module replacement, and adjustment of thermal blankets. The performance of these tasks will be greatly affected by the environment. The lack of gravity forces is the most significant effect on manipulative functions. Zero g is beneficial in allowing large masses to be handled. The effect of gravity in changing mechanism joint slop and stabilizing parts retention creates a challenge in design of manipulators and end effectors and also influences task requirements. The human factors that are impacted by the space-flight environment include interaction with displays and controls. Posture is different in zero g, restraints will be needed for force-reflecting controllers, and visual perceptions may be distorted.

One approach to system development that also accommodates the need to evaluate the effects of the environment is a protoflight testbed that would be flown on the Space Shuttle.³ The testbed supports research and technology experiments, validates ground simulations, and demonstrates the utility of a dexterous manipulation capability for remote operations in space.

CONCEPTUAL DESIGNS OF TWS

The TWS has been studied at the Lyndon B. Johnson Space Center through contracts with Grumman Aerospace Corporation⁴ and Martin Marietta Aerospace.⁵

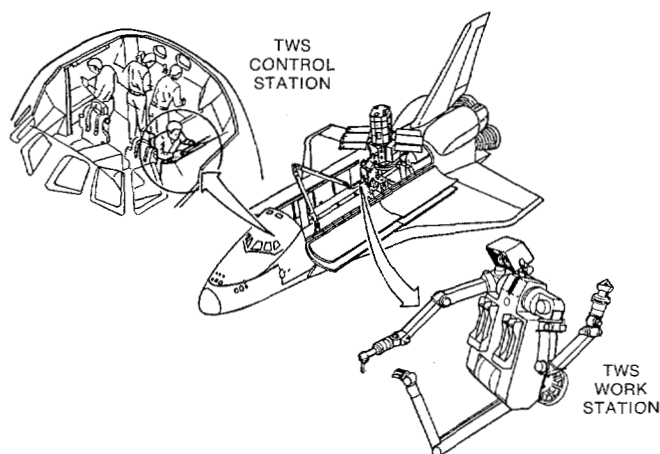


Fig. 1. Telerobotic work system.

Figure 1 illustrates the system arrangement and major components for the initial application on the Space Shuttle Orbiter. The system elements logically divide into the robot work station where the physical tasks are to be accomplished, the control station with the operator's displays and controls, and the system processor that provides the computer power and logic to make the system function. Mobility to reach the work site is achieved with the Shuttle remote manipulator system (SRMS). Later applications may achieve mobility by using a free-flying module similar to the manned maneuvering unit (MMU).

The robot work station has manipulators and end effectors to perform physical tasks. Sensor suites monitor and measure conditions at the work site. Although work-site conditions in space are more structured than in many terrestrial situations, the configuration cannot be as well controlled as in most robotic uses in industry. The ability to determine the state of the task components is critical because of the inaccessibility in space; thus, the need for a preceptive and adaptive system. The concept of EVA equivalency is a strong driver in development of the configuration. The capability of the EVA astronauts to perform dexterous tasks in the servicing and repair of satellites has been well demonstrated in recent Space Shuttle missions. Satellite designs are now being implemented in response to the demonstrated EVA capability. If the TWS can perform tasks equivalent to those of the suited astronaut, there will be satellites to work on. The use of EVA as a backup to the remote operating TWS is an added benefit of the equivalency approach.

Extravehicular activity equivalency has resulted in strongly anthropomorphic configurations in the contractor concepts. Grumman has carried the human analogy one step further by using the acronym "SAM" for Surrogate Astronaut Machine shown in Fig. 2. The principal camera location responds to the operator's eye-to-hand relationship. Other cameras on the arms provide additional views of the task. Proximity, force feedback, and tactile sensing supplement the visual aids. A third arm functions

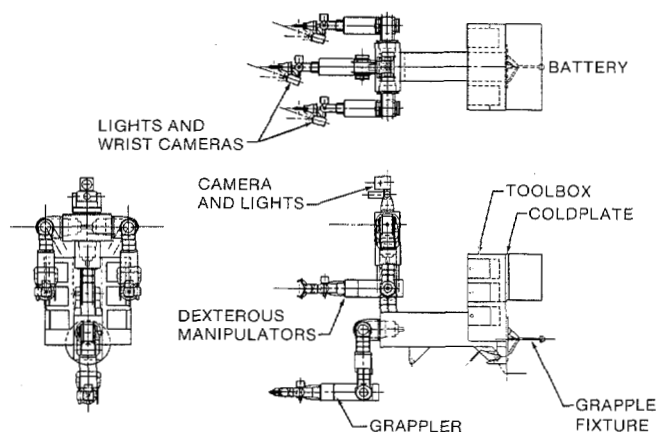


Fig. 2. Grumman work station concept.

to stabilize the TWS at the work site. A dexterous arm similar to the other arms is proposed that would give some redundancy. The adequacy of a flexible arm to perform the stabilization function may require flight testing. The most useful approach to end effectors for accomplishing tasks is the attachment of tools to the dexterous arms. Tool stowage is behind "SAM's" torso to reduce the volume of the manipulative system.

Martin's concept particularly differs from Grumman's in the location of the tool stowage in the torso as shown in Fig. 3. The dexterous arms are seven-degree-of-freedom (7-DOF) electric drive manipulator arms. The stabilizer arm is proposed to be a stiffer 5-DOF arm. The dexterous arms have a force-sensing wrist with an interchangeable tool device. This configuration allows use of special-purpose tools or a general-purpose gripper. Cameras and lights are mounted in a head with a 3-DOF neck.

The operator interface at the control station is critical for effective interaction with the robot. Interior space is at a premium in orbit, particularly on the Space Shuttle. For example, the

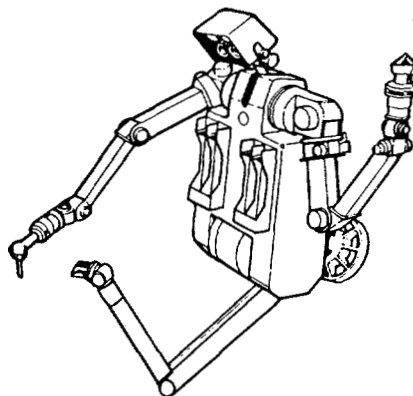


Fig. 3. Martin work station concept.

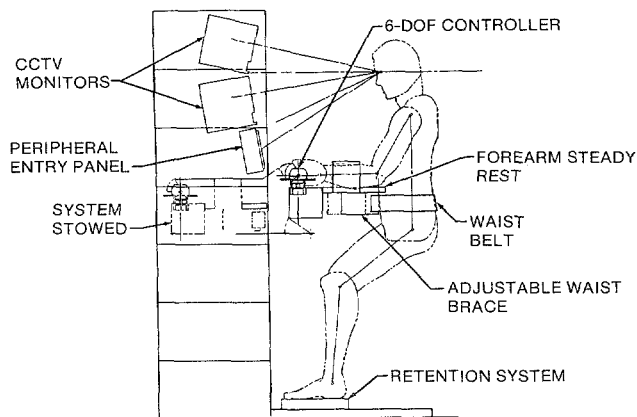


Fig. 4. Grumman TWS control station concept.

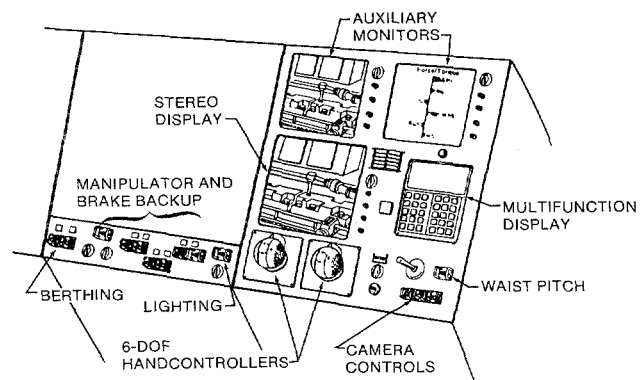


Fig. 5. Martin TWS control station concept.

Shuttle remote manipulator system (SRMS) was driven to a resolved-rate control system because of the swept volume of a replica master controller for such a long arm. Replica controllers to position the smaller dexterous arms represent a potential tradeoff for TWS application. Six-DOF rate controllers are proposed by Grumman (Fig. 4) and Martin (Fig. 5). Martin has suggested a hybrid control system that uses rate or position depending on the task.

PROGRAM DEVELOPMENT

The development of the TWS is planned to be evolutionary from the beginning. The development logic is based on an evolutionary pattern with capability of the TWS design to incorporate technology advances as they become available. This approach will depend on modular subsystems and precise definition of interfaces to enable the adoption of newer innovations. Another feature of the logic is the evolutionary route of teleoperation to telepresence to supervisory control to supervised adaptive robotics.² The implications of this approach are evident in the selection of feedback sensors that will be compatible with expert systems and artificial intelligence. The anticipated result would be a system that will have application on the Space Station, but will have been developed and demonstrated on the Space Shuttle.

SUMMARY

The development of a space telerobotic work system represents a valuable resource for performing a variety of tasks in the unstructured and hazardous

environment of space. Development and demonstration in flight test on the Space Shuttle can lead to applications on the Space Station for the mobile remote manipulator system, the satellite servicer, and the orbital maneuvering vehicle. A system meeting these requirements can be of great use in developing the technology needed for many terrestrial applications of telerobots. Telerobots will find uses in hazardous situations, in construction, in agriculture, and in personal service functions for disabled and aged.

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