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Space Telerobotic Systems: Applications and Concepts

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1. Abstract

The definition of a variety of assembly, servicing, and maintenance missions has led to the generation of a number of space telerobot concepts. The remote operation of a space telerobot is seen as a means to increase astronaut productivity. 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 Corporation. These studies defined a concept for a telerobot with extravehicular activity (EVA) astronaut equivalent capability that would be controlled from the Space Shuttle. 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.

2. Introduction

Increased operations in space with the Space Station and the Strategic Defense Initiative define a need for remote operating systems to assist the space crews in accomplishing a variety of new functions. 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 its assembly in space. Other large space systems will require assembly on orbit. Recent Space Shuttle missions have demonstrated the effectiveness of the extravehicular activity (EVA) crew in many of the tasks needed for future space construction, assembly, and maintenance. As the magnitude of mission requirements grows, the productivity of the astronaut must be increased. The use of EVA is crew time intensive; it requires a buddy system as well as an observer in the cabin. Time spent preparing to leave the cabin, prebreathing oxygen, and maintaining equipment add to nonproductive time. Remote operating systems are a means of amplifying space crew output [1]. One concept for remote operations that has been defined in some detail is the telerobotic work system (TWS).

The basic concept of the telerobotic work system consists of two dexterous manipulator arms controlled from a remote station (Figure 1). The direct 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. The operator is provided with sensory feedback of the environment and conditions at the work site. This approach is reflected in the term "telerobotics," which implies a combination of teleoperating and robotics. An objective of the system development approach is to increase the productivity of the operator through more robotic modes having a higher degree of autonomy [2].

A robot operating in the environment of space has analogies to a robot operating in hazardous or unstructured terrestrial situations. The development of a robot with the capability to operate in space can meet many of the requirements of terrestrial applications. Current NASA activities in telerobotics consist of studies and technology development at all centers. The Jet Propulsion Laboratory has a ground-based demonstrator, and Goddard Space Flight Center is the lead center for the flight telerobotic servicer for Space Station.

3. System Requirements

The functional requirements for the telerobot will be derived from 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. An operational consideration in the requirements is EVA equivalency. Space systems are being designed to interface with the proven capability of the astronaut in the extravehicular mobility unit. A telerobot with EVA equivalent capability can interface with the space system and also has an operational backup in the EVA astronaut.

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. Other zero-g

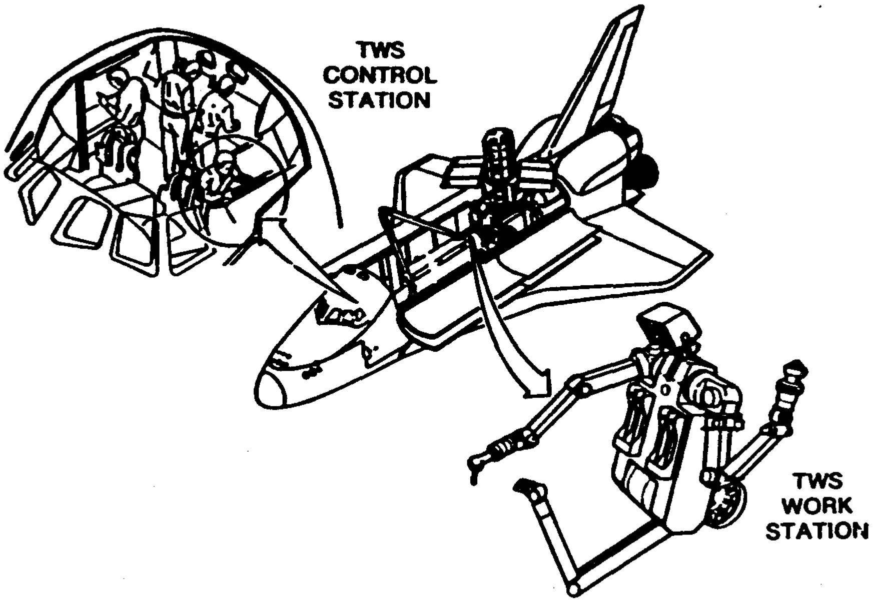

Figure 1. Telerobotic work system

effects are less beneficial. Parts being handled are not positioned and oriented by gravity forces, and the free play in the joints of mechanisms becomes an uncertainty. The human factors that are impacted by the space-flight environment relate to the 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.

4. System Architecture

The major elements of the TWS concept are the telerobot, the control station, and the system processor. This configuration corresponds to the architecture for an automated system as defined by Holcomb and others [2] and shown in Figure 2. The robot interfaces with the remote site at which the mission functions or the state changes are to be accomplished. The control station is the operator's interface with the system through controls and displays. The system processor implements the operator's commands and directs feedback of the results. The potential of the architecture is illustrated in Figure 3 as an example of the relationships of functional components of the system. Those relationships may be defined as operator interface, task planning and reasoning, control execution, and sensing and perception. Effectively, there is an operator control loop, an executive control loop, and a local control loop at the remote site. These control loops provide feedback and interaction to enable accomplishing tasks in an effective and productive manner.

5. Conceptual Designs of TWS

The Lyndon B. Johnson Space Center has studied the TWS through contracts with Grumman Aerospace Corporation and Martin Marietta Corporation. 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). Stabilizer arms hold the TWS in position at the work site. Later applications of the TWS may achieve greater mobility by using a free-flying module similar to the manned maneuvering unit.

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 [3]. 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 EVA equivalency requirement has resulted in strongly anthropomorphic configurations in the contractor concepts [4 and 5]. Grumman has carried the human analogy one step further by using the acronym "SAM" for the Surrogate Astronaut Machine shown in Figure 4. 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 to stabilize the TWS at the work site. A dexterous arm similar to the other arms is

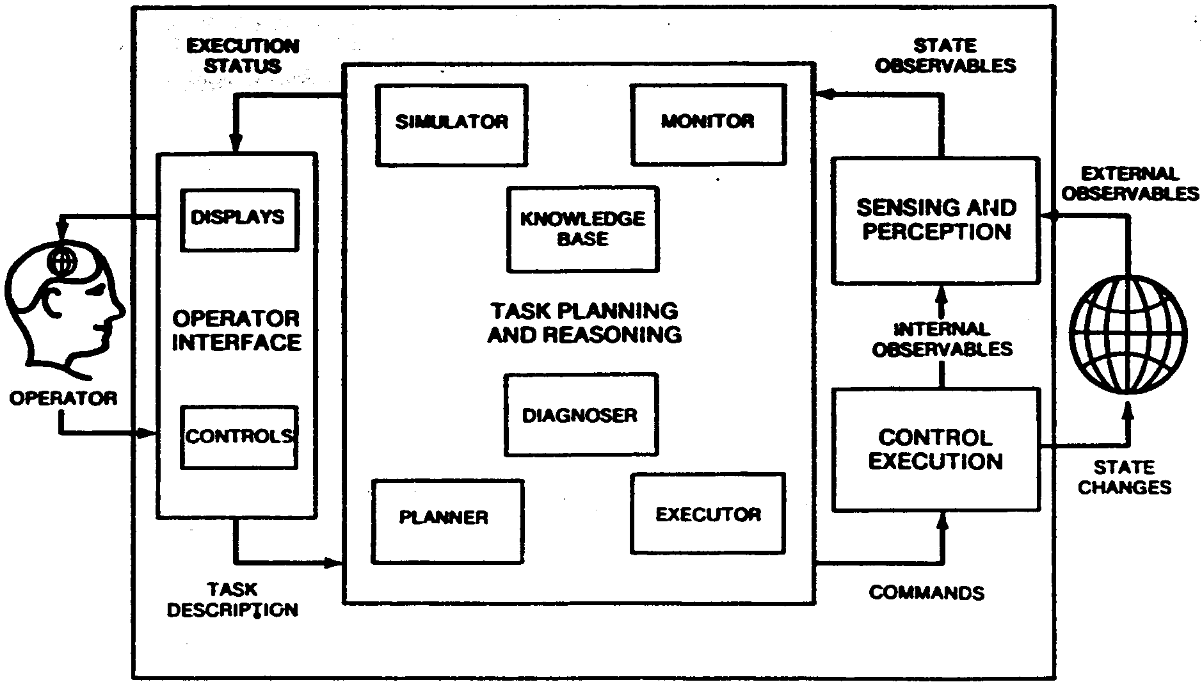

Figure 2. Architecture for an automated system

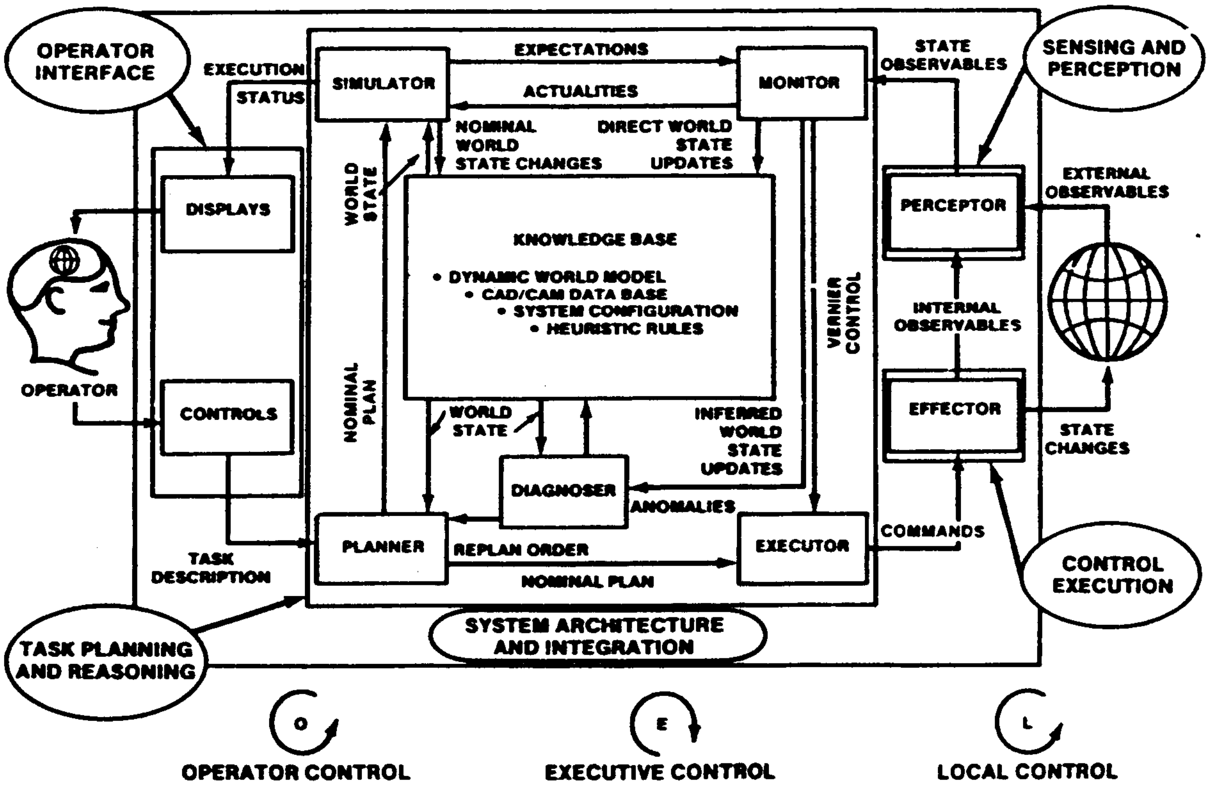

Figure 3. Automated system - control architecture

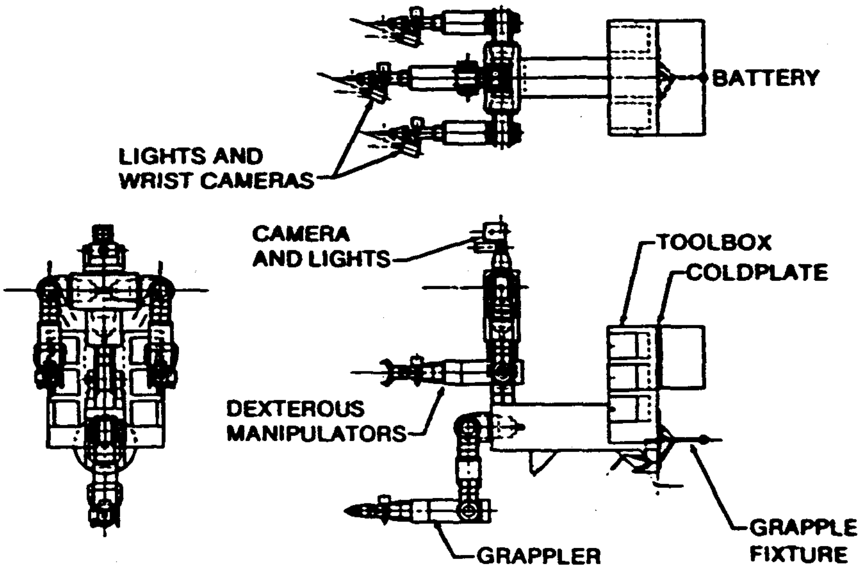

Figure 4. Grumman work station concept

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 Figure 5. 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 volume is at a premium in space, particularly on the Space Shuttle. For example, the design of the SRMS was driven to a resolved-rate control system because the swept volume to operate a replica master controller for such a long arm was difficult to accommodate in the Orbiter cabin. Six-DOF rate controllers are proposed by Grumman (Figure 6) and Martin (Figure 7). Technique for controlling a 7-DOF arm is a technology development issue. Martin has suggested a hybrid control system that uses rate or position depending on the task. Replica controllers to position the smaller dexterous arms are a potential tradeoff for TWS application.

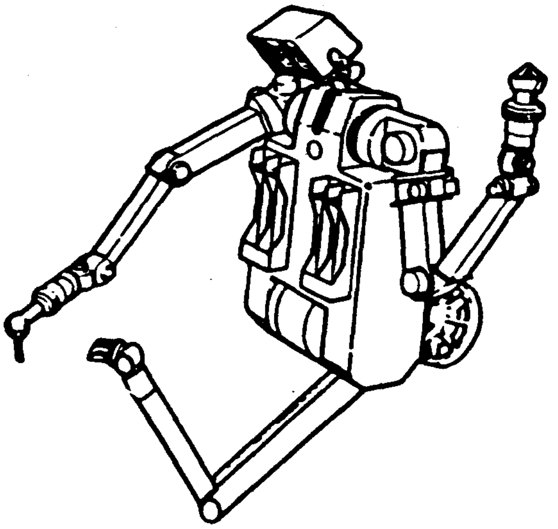

Figure 5. Martin work station concept

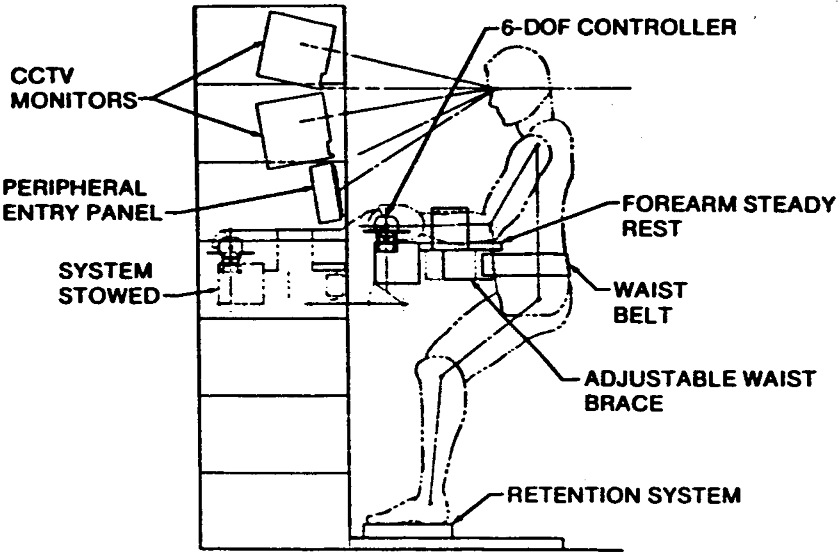

Figure 6. Grumman TWS control station concept

6. Program Development

The development plan for the TWS is predicated on the need to increase the productivity of the crew; therefore, the plan is evolutionary in nature. In this logic, the TWS design must be capable of incorporating 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 needed for adaptive robotics. The telerobot technology program of the NASA Office of Aeronautics and Space Technology is consistent with this development approach. In addition to the ground demonstration telerobot at the NASA Jet Propulsion Laboratory, a protoflight testbed has been proposed to support research and technology experiments, to validate ground simulations, and to demonstrate the utility of a dexterous manipulation capability for remote operations in space. The flight telerobotic servicer program for Space Station is currently being defined. The anticipated result is a telerobotic system that will have application on the Space Station, but will have been developed and demonstrated on the Space Shuttle.

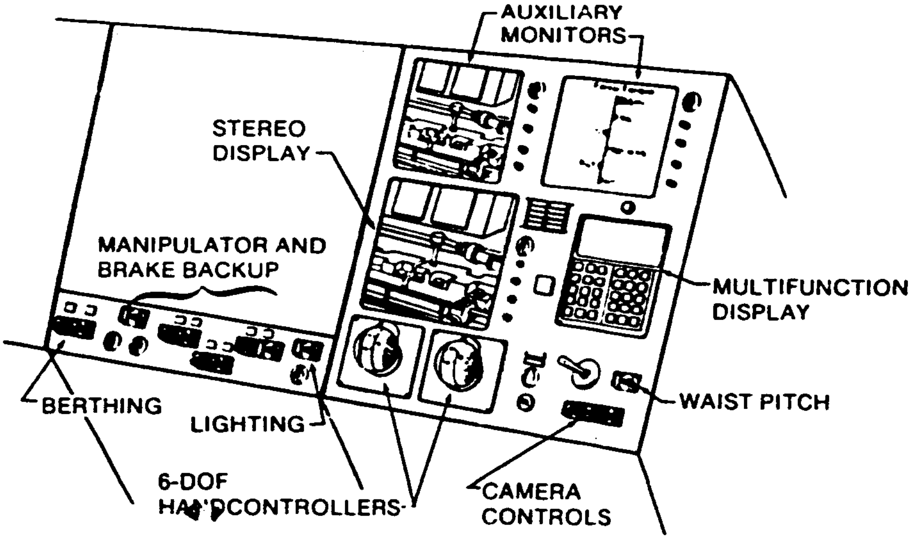

Figure 7. Martin TWS control station concept

7. Summary

The development of a telerobotic work system or a similar concept 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 personal service functions for disabled and aged people and in hazardous situations such as are found in construction and agriculture.

8. References

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[4] "Telepresence Work System Definition Study," Grumman Aerospace Corporation, Contract NAS 9-17229, October 3, 1985.

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