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7.0 AN OVERVIEW OF THE PROGRAM TO PLACE ADVANCED AUTOMATION AND ROBOTICS ON THE SPACE STATION

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7.1 Introduction

To stimulate the development of new technologies related to automation and robotics (A&R) Congress has given NASA a mandate to advance the state of art in A&R for the benefit of the Space Station and the U.S. economy as a whole. Presumably A&R developments for space could carry over, at least in concept, to terrestrial applications. Congress further stated in Public Law 98-371, July 18, 1984 that:

"The Administrator shall establish an Advanced Technology Advisory Committee in conjunction with NASA's Space Station program and that the committee shall prepare a report by April 1, 1985 identifying specific Space Station systems which advance automation and robotics technologies, not in use in existing spacecraft, and that the development of such systems shall be estimated to cost no less than 10 per centum of the total Space Station cost."

An Advanced Technology Advisory Committee, known as the ATAC, was established and did publish a two volume technical report [1] as required and, in addition, has published two subsequent progress reports [2],[3]. These reports have guided contractor studies that are currently in progress and they have been a source of information for Congress and the general public.

In addition to the ATAC, NASA also created the Automation and Robotics Panel (ARP) to conduct an independent study to provide guidance on major considerations for incorporating A&R into the Space Station design. Their findings were also published [4].

Following the ATAC and ARP studies, NASA entered into a preliminary Space Station design phase (called Phase B) to develop a conceptual design and estimate the cost of that design. As part of this effort A&R managers were appointed at each participating NASA center (JSC, MSFC, GSFC, and LeRC) to guide the Phase B contractors in developing A&R concepts for the Station. This paper will discuss some of the results of the contractor A&R effort and will also discuss NASA plans to develop a telerobotic system.

7.2 What are automation and robotics?

Before discussing automation and robotics for the Space Station, it would be helpful to distinguish these concepts from automation applications that have been employed by NASA in designing existing spacecraft. Indeed, it was the intent of Congress that NASA advance the state-of-the-art. Unfortunately, however, many of these concepts have been discussed in the engineering and computer science literature by citing specific applications

rather than developing mathematical definitions of the concepts. However, Volume II of the March 1985 ATAC Report [1] offers some working definitions which are summarized here.

Artificial intelligence - This is a field of computer science dealing with inference and knowledge representation with the purpose of programming a computer to "behave" in ways that humans recognize as intelligent behavior.

Expert system - A computer program which is designed to emulate the decision-making a human expert would employ to solve a given problem.

Robotics - The study and use of machines capable of manipulation and/or mobility with some degree of autonomy.

Teleoperation - The study and use of manipulators which receive instructions from a human operator and perform some action based on those instructions at a location that is remote from the operator.

Telepresence - This describes a teleoperation situation in which the operator has sufficient cues to simulate the sensations that would be experienced in performing the operations manually, i.e., without any teleoperation device.

Automation - Use of machines which rely on artificial intelligence, robotics, or teleoperation.

7.3 Preliminary design phase studies in A&R

As part of the Phase B design studies, each of the participating contractors was asked to identify functions to be performed on Space Station that could be automated and to propose an A&R technology for implementing the automation concept. Goals such as minimize Station cost, maximize crew time savings, build in a high degree of maintainability to avoid high design risk situations, enhance safety in operating and maintaining the Station, and to the extent possible consider automation alternatives which could lead to new or advanced terrestrial applications were considered by the contractors. Initially, Space Station functions were considered individually, but as the studies progressed groupings were considered that permitted the conceptualization of generic A&R technologies. For example, generic robotic concepts were proposed that could do Station assembly, repair, maintenance, and inspection. Expert system configurations were also proposed that could coordinate and plan a number of Station activities.

In all there have been at least 400 Space Station functions that have been considered as candidate A&R applications. Table 1 lists some of the functions that could be automated through the use of expert systems or some form of robotics.

Table 7.1   Recommended Applications for the Initial Space Station

Knowledge-based (expert) systems

    Systems management-training and crew activity planning

    Space station coordinator

    Data base management-subsystem assessment, trend analysis, fault management

    Resource planning and scheduling

    Thermal curvature control

    Logistics

    Onboard personnel training

    Passive thermal monitoring

    Fault diagnosis for communication and tracking

    Power system control and management, including trend analysis and fault management

    Environmental control and life support subsystem-trend analysis, reconfiguration management, data base management, built-in testing, monitoring and recording, fault detection and identification, and assuring atmospheric integrity

    Guidance, navigation, and control-automated maneuver planning and control

    Platform applications, including power system control, distributed data processing, and planners for guidance, navigation, and control

    Laboratory module applications, including data management system and life support for experimental subject

    Experiment scheduling

Robotics

    Space station assembly

    Inspection and repair of trusses and structures

    Oru replacement

    Utility run inspection and repair

    Payload servicing -- exchange, transport, resupply, fluid transfer, and manipulation, including interfaces compatible with both robots and humans

    Laboratory functions -- care of plants and animals, analysis of biological samples, and centrifuge access

A&R was considered for the assembly, initial operating capability (IOC), and evolutionary phases of the Station. Based on constraints implied by factors such as cost or design risk, only a portion of the possible A&R will be operating by IOC. The bulk of the A&R would probably be realized in some evolutionary phase of the Station. However, to insure that this type of evolutionary development would not be too costly, contractors were asked to appropriately "hook" and "scar" the IOC design. That is, for example, they were asked to design the computer software for the data management system that could easily accommodate additional expert systems or other artificial intelligence software. Such a provision in the software is known as a "hook". Also, they were asked to have the Station be "robot friendly" by, for example, including some form labeling that could be easily recognized by a computer vision system or by including robot grappling devices that would stabilize a robot when it was performing some manipulation function. Modifying hardware in this fashion is referred to as "scarring".

7.4 Set-aside for a telerobotic system

Congress has directed NASA to set a portion of the Space Station funding aside for a flight telerobotic system (FTS). Phased over several years, the total funding of such a system is expected to be approximately 100 million dollars. The prime responsibility for its development will reside at the Goddard Space Flight Center but several of the other NASA centers will participate in the program.

It is envisioned that the FTS could perform a number of functions on the Space Station relating to assembly, maintenance, and servicing which in the absence of the telerobot would be performed manually by the crew. Characteristics of a FTS that would be needed are believed to include the following:

Mobility. The FTS could be attached to either the remote manipulator arm in the Shuttle, the mobile remote manipulator system that will travel along the truss (and is to be developed by the Canadians), the orbital maneuvering vehicle (OMV), or the service bay

gantry. The OMV is a small space craft that will travel in an orbit close to that of the Space Station and be available for servicing satellites.

EVA Equivalency. The reach and strength of the FTS should be roughly equivalent to that of a suited astronaut in case the FTS fails.

Control. The FTS should be controllable from the Shuttle or the Space Station. If suitable predictive control mechanisms can be developed, it could also be controlled from the ground. The problem with control from the ground is that the operator will experience a time delay in the telemetry.

Telepresence. The operator will be able to see the object being manipulated on displays at the control station and should also have displays or some sensory feedback that will indicate the forces being applied by the system.

Evolution. The FTS will be initially designed as a teleoperation device and evolve into a device that has robotic, i.e., autonomous, capabilities.

Since the conceptual design studies for the FTS are just now being done, the specific configuration is still not known. However, it is expected that it will initially incorporate a number of features which may include multiple light sources, multiple stereoscopic cameras, and force, torque, and position sensors. To stimulate the incorporation of more advanced features at a later time, OAST is sponsoring (mainly at JPL) research into end effectors, advanced sensors, computer vision, human/machine interfaces and evolvable architectures. In addition, there are a number of contractor studies that will effect both the IOC and the evolutionary designs of the FTS.

7.5 Conclusions

The preliminary design phase of the Space Station has uncovered a large number of potential uses of A&R, most of which deal with the assembly and operation of the Station. If NASA were to vigorously push A&R concepts in the design, the Station crew would presumably be free to spend a substantial portion of time on payload activities. However, at this point NASA has taken a conservative attitude toward A&R. For example, the belief

is that robotics should evolve through telerobotics and that uses of artificial intelligence should be initially used in an advisory capacity. This conservativeness is in part due to the new and untested nature of A&R; but, it is also due to emphasis placed on designing the Station to the so-called "upfront cost" without thoroughly understanding the life cycle cost. Presumably A&R has a tendency to increase the initial cost of Space Station but could substantially reduce the life cycle cost.

To insure that NASA will include some form of robotic capability, Congress directed the set-aside funding that was discussed above. While this stimulates the development of robotics, it does not necessarily stimulate uses of artificial intelligence. However, since the initial development costs of some forms of artificial intelligence, such as expert systems, are in general lower than they are for robotics one is likely to see several expert systems being used on the station.

7.6 References

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