

FUTURE USES OF MACHINE INTELLIGENCE AND ROBOTICS FOR THE SPACE STATION*

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ABSTRACT

This paper summarizes the exciting possibilities for using the advanced technologies of artificial intelligence, robotics, and automation on the NASA Space Station in the future. Formal adoption of the policies to turn some of these possibilities into plans is in process.

ADVANCING TECHNOLOGY FOR SPACE STATION AND THE U.S. ECONOMY

We are at the beginning of a new era in space which poses significant challenges as we move into the second 25 years of the U. S. space program. This era will see a major thrust in commercial uses of space and the achievement of a permanent presence with the Space Station Program.

A vital element needed to enable the Space Station Program to perform its missions successfully¹ is substantial use of automation and robotics (A & R). This will require helping to create a new generation of machine intelligence and robotics technology building on recent advances in artificial intelligence, robotics, computer science and microelectronics.

The advances in A & R stimulated by the Space Station Program will benefit the U. S. in several ways, notably:

- o Increased productivity in space
 - New knowledge
 - Commercial applications
- o Increased productivity throughout the U. S. economy as the new technology is transferred back to earth-based industries.
- o Preservation of U. S. leadership both in space and at the cutting edge of technology in general.

There are difficult challenges to meet if this goal of helping to create a new generation of technology is to be realized. However, NASA believes that the goal is achievable. This paper summarizes a framework for this exciting venture.

NEW CHALLENGES

New challenges for the U. S. space program are: first, we must make use of the new technologies becoming available to assure effective use of our resources; second, we must meet the challenge of international competition in space; third, we must establish a permanent manned presence in space; fourth, we must move from an era centered primarily on space exploration to an era which also optimizes the commercial uses of space². These new challenges require that we initiate imaginative new ways of doing business.

An important reason for a permanent presence in space is the knowledge it will produce. Knowledge about many aspects of science and the applications of this knowledge in technology development and commerce will result from the enterprise of building a Space Station set of evolving multipurpose facilities in space. The functions envisioned for the Space Station, include on-orbit laboratories, permanent observatories, a transportation and communication node, servicing and repair facilities for spacecraft, manufacturing facilities, and assembly facilities. The Space Station is a means of acquiring and exploiting the unique knowledge and products which are made available through continuous access to the benefits of space, including namely, microgravity, high vacuum and being outside the atmosphere in low Earth orbit.

What are the future roles of humans in space? The human role should be based on what humans do best which is use their intelligence to perceive, to understand, to redefine continually what needs to be done on the basis of what has been learned, to take advantage of unforeseen opportunities, to solve unforeseen problems, to save a mission (occasionally), to supervise machines, to adapt with minimal reprogramming, and to acquire, integrate, and interpret multisensory data.

The fundamental challenge is to meet the needs of the customers and users of space with facilities enabling maximum productivity and having low start-up costs, and low annual operating costs. An effective way to meet this challenge may be with a man-machine mix where artificial intelligence, robotics, and advanced automation are integrated into high reliability systems.

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The need for automation in space is thus seen not only to meet increased productivity requirements, but also to lower costs, improve reliability, achieve autonomy, perform tasks unsuited to humans alone, and increase safety.

NASA STRATEGY FOR ADVANCING AUTOMATION AND ROBOTICS TECHNOLOGY

NASA supports strongly the goal of advancing Automation and Robotics (A & R) technology--a goal necessary to both the success of future space activities and the general well-being of U. S. technology.

Present space activities would not be possible without automation. The NASA Space Station Program, specifically designed along the lines of this paper with objectives carefully chosen and expectations for success not placed unreasonably high, will effectively serve as a high-visibility focus for promoting research and development in all disciplines in the field of automation. Important advances in terrestrial applications of automation are expected to follow from a vigorous space automation program.

NASA will use the Space Station definition and preliminary design (Phase B) process to define the uses of A & R to achieve increased human-machine productivity and the advances needed as the Space Station evolves. An implementation plan for assuring that Phase B will address A & R needs adequately using a systems approach and progressive experimental demonstrations/evaluations is being prepared by the Office of Space Station.

Once this definition is available, NASA will be in a position to address the proportion of Space Station funding to be devoted to advanced A & R. It is clear even now, however, that the goal of a substantial portion (estimated at no less than 10%) is reasonable and will be met. Indeed, contributing studies³ indicate that significant resources will be required for building an adequate A & R technology base.

A Computer Aided Design (CAD) system augmented with relational data bases of reasons for design features is essential for achieving most of the goals of this effort for the design, development, and maintenance of the Space Station.

The NASA Space Station Program will be designed and implemented to utilize and advance A & R technologies. Since current technology cannot meet many of the needs of the Space Station, a vigorous program of research and technology development will be pursued. Success will be anticipated in these development efforts and, as they approach maturity, incorporation of the new technology into the Space Station Program will be planned. The schedule will, however, not be constrained to wait for "breakthroughs" in the technology.

NASA will use advanced A & R technology on the initial as well as on evolutionary versions of the Space Station. There will be some flexibility to optimize (not strictly maximize) applications of the A & R technology current at the time of the Preliminary Design Review for the initial station. However, the initial station will include artificial intelligence (AI) and robotics to ensure the design for accommodation of A & R evolution and growth process works with these requirements. Supporting this policy NASA is pursuing an initial set of progressive experimental demonstrations/evaluations to specifically define the initial station configuration by evaluating AI and robotics technology that is ready and relevant. Example demonstrations are a robot EVA orbital replaceable unit exchange, an IVA voice-controlled flying robot for inspecting or "go-fer" robot integrated with crew activity planning, and a subsystem controller with AI override or fallback from AI to traditional automatic control.

This use of A & R technology will promote the use of the crew more as supervisors of machines (higher on the functional hierarchy) and thus make more crew time available for customer and user mission operations.

Each Space Station function, element, and subsystem will be considered for automation and robotics technology application. NASA policy is to design for Space Station A & R evolution and growth by making provisions, in both hardware and software, for anticipated A & R technology advances.

Very extensive A & R technology activities currently exist in industry, academia and government agencies. Current and future technology from these activities will be considered and used, as applicable, in the Space Station Program to the maximum extent possible. This will include, for example:

- o Robots designed for terrestrial applications, modified as necessary for weightless space applications,
- o CAD/CAM Systems, and
- o Products from DARPA's Strategic Computing Program technologies.

Criteria for incorporation of Automation and Robotics technologies will be developed and promulgated. These will focus on measurable issues such as productivity and annual operating costs and on issues such as the merits of transferring space A & R technology back to terrestrial applications.

A major purpose of the ATAC policy report¹ (and the elaborating detail of its Appendix I) is to provide guidelines to Phase B Space Station contractors. These guidelines address A & R for both initial and evolutionary versions of the station.

Careful selection and implementation of each application will be exercised to minimize overall system risks and costs and improve system reliability.

Potential system interface issues exist in the integration of the diverse hardware and software A & R technologies. Rapidly-evolving A & R technologies are creating a dynamic and improving man-machine environment.

The NASA policy recognizes that the Space Station program will provide enhancement and advances in automation and robotics technology through developments on two fronts:

- o Research and development in systems which are not incorporated in existing spacecraft.
- o Implementation of automation in systems which are incorporated in existing spacecraft but have not previously been automated.

The former case above is the furtherance, through basic research and development, of the state of the art. The latter is the utilization of the state of the art of expert systems and artificial intelligence in applications that support the Space Station. It is felt that pursuance of knowledge engineering must be concentrated toward space station goals and that the expert system designs for the applications should begin immediately with Phase B.

The task of utilizing and advancing A & R technology is a challenging one and subject to many risks. There are many critical paths for which a "fall back" position must be maintained. This alternative position will vary for different applications. However, the primary considerations would be to minimize ground and crew involvement in fault isolation, redundancy management and repair of onboard systems and payloads.

Evaluation and tracking of the use of knowledge-based automatic programming systems will be carried out for software development and maintenance because of the possible very large cost savings to be derived from their use.

A commercial approach to A & R hardware/software will be utilized (as contrasted to a defense approach) with maximum accessibility obtained to defense-supported hardware and technology such as VHSIC and systolic arrays.

An A & R implementation plan will be developed and maintained to ensure logical insertion of A & R technologies based on indepth technical knowledge of performance and evolvability of end-item subsystem application, costs (both development and operations), and technology readiness. In making such plans, NASA recognizes that there are three levels of involvement for NASA. These are: areas in which NASA must lead in producing new technology; areas in which technology can be modified and adopted; and areas in which "off-the-shelf" technology can be utilized.

Both metrics such as productivity and quantitative goals will be established for various A & R technology in an urgent effort to start measuring how we are progressing and where we are going.

Space Station system architecture will be developed to accomodate evolving A & R technology through:

- o immediate use of CAD/CAM system for the space station design which permits direct access to the data bases by subsystems in space
- o defining and using a standard hardware and software environment
- o designing the Space Station Data System and Software Development Environment to be compatible with and supportive of artificial intelligence and robotics technologies
- o immediately developing, using in Phase B, and periodically updating a Space Station Design Manual for Space Station A & R Evolution and Growth.

Early experimental demonstrations of A & R applications, including flight experiments, will be planned and carried out before the end of Phase B.

A & R TECHNOLOGIES

Automation and Robotics, as applicable to space activities, span a wide spectrum of technologies. These are listed:

Robotics and Teleoperation Including Sensors
Expert Systems
Human Factors and Human-Machine Interfaces
Planning Systems
Voice Recognition and Natural Language Understanding
Computer Vision
Autonomous System Design and Verification
Relational Data Bases
Distributed Processing
Fault Tolerance
Computer Technology
Software Engineering and Verification

CANDIDATE SPACE STATION SYSTEMS

The potential for automation on the Space Station includes almost all systems and functions. Most likely, there will be an evolutionary progression towards realizing an autonomous Space Station. However, all initial designs must utilize as much mature automation as technologically feasible while not precluding eventual growth. The subsystem design should conceptionally be targeted for the mature, year 2000+ Space Station and retreat from that position to the initial station.

The major systems which are candidates for A & R applications are listed below:

- Co-orbiting and Polar Platforms
- Electrical Power
- Guidance, Navigation & Control
- Communications and Tracking System
- Information and Data Management
- Propulsion
- Environmental Control & Life Support System
- Thermal Control
- Structures & Mechanisms
- Habitability
- Extra Vehicular Activity
- Verification
- Operations--Ground and On-board
- Payloads and Experiments

MANAGEMENT APPROACH

NASA will use its present organization and management structure with an outside advisory committee to assure proper integration of A & R efforts into the Space Station. It is recognized, however, that new attitudes and ways of doing business will be required.

An A & R technology demonstration plan is being developed to validate readiness of technology transfer and minimize cost impact of implementation.

State-of-the-art expert system technology can be applied to certain space station functions; however, a significant lead time (3-5 yrs) is required to complete the needed knowledge engineering and programming activities. For the initial station applications, studies will begin very soon to define specific applications and expert system design should begin shortly thereafter. ATAC cautions against the overselling (or overbuying) of expert system state-of-the-art.

Several elements of AI are generic to a number of space station applications such as natural language understanding, image understanding, planning, etc. Space Station applications whose growth is highly dependent upon advancements in these AI areas will be defined and AI research programs that use these applications as major demonstration projects will be emphasized.

Expert system verification is still not well understood and therefore additional research may be required before any life critical application is space worthy.

NASA has adopted the ATAC report Glossary as a standard set of definitions because they are based on industry standard definitions.

NASA will solicit the involvement of entrepreneurs, especially in small business, for creative and innovative ideas to lower costs in commercializing space and space automation.

Methods will be sought to minimize the needed lead time from laboratory demonstration of A & R technology to Space Station operations, including much more efficient safety, reliability, and quality assurance testing for A & R such that a perceived impediment to technology transparency can be minimized while meeting the necessary standards. Maximum use will be made of automation technology in the management process itself.

Specifically:

- o Each NASA Center with responsibility for a major element of the program, will be encouraged to establish an A & R office with access to an ARPANET-like capability staffed with personnel competent in the field of A & R who will conduct research and stay abreast of developments in government, universities, and industries.
- o A Technical Management Information System is being developed to link all participating organizations. This will employ the most current office automation and CAD/CAM techniques.
- o Programs will be established to train design engineers in A & R concepts so that they can be utilized more effectively.
- o An A & R Design Manual is being developed and will be updated periodically for use by engineers and designers throughout the Space Station program.

CLOSING REMARKS

NASA now has a goal for action to address the significantly new challenges posed by a new competitive, commercial era in space as we move into the second 25 years of the U. S. space program. It is a goal of creating, adapting, and using a large array of machine intelligence and robotics technology that can be mixed in countless ways for diverse applications both on the space station complex and in the U. S. economy.

The challenging space station man-machine applications are "pulling" and defining the technology-generation process. These applications also provide the flight evaluations for demonstrating the reliability of the new technology and for demonstrating the feasibility of particular intelligent computing or robotics capabilities.

The timely, successful generation and application of intelligent machine and robotics technology will have profound effects. If the technology is widely dispersed in applications throughout our society, as the NASA technology transfer process makes possible, Americans will have a significantly improved capability to handle complex tasks and to codify, mechanize, and propagate knowledge. The new technology will improve the capability of our industrial and political leaders to tap the nation's pool of knowledge and effectively manage large enterprises, even in

times of great change, with greatly improved productivity.

Successful achievement of the objectives of the Space Station Automation and Robotics activity will lead to deployment of a new generation of space systems containing machine intelligence and robotics technology. These systems will provide the United States with important new methods of space knowledge generation and exploitation in commercial enterprises and thereby preserve the U. S. leadership in space.

There are difficult challenges to overcome in order to realize the goals of a national program of such scope and complexity. However, NASA believes that the goals are achievable. Given the policies and strategies set forth in this paper, we intend to seize the opportunity and undertake this effort.

It will yield a substantial return on invested resources in terms of increased space station productivity and increased economic strength.

ACKNOWLEDGEMENTS

This paper is based on the ATAC report¹ which was prepared for the NASA Advanced Technology Advisory Committee by an Intercenter Working Group and members of the NASA Johnson Space Center Artificial Intelligence Office. The ATAC report was based on the Space Station Automation Study. The Working Group provided guidance on the purpose, contents, and organization as well as making vital contributions to the draft material.

The congressionally-mandated Space Station Automation and Robotics Study was initiated in May, 1984, with the objective established as a report to Congress on or before April 1, 1985. The study was headed by Dr. Daniel Herman and Dr. Vic Anselmo of NASA Headquarters.

The California Space Institute (Cal Space) of the University of California formed an Automation and Robotics Panel (ARP) which consisted of representatives of industry, academia, and government. Their report³ was used in writing the ATAC report.

Various aerospace contractors were involved and studied automation and robotics issues in specific areas as follows:

Boeing	Man/Machine Interface ⁴
General Electric	Payload Automation ⁵
Hughes	Subsystem Automation ⁶
Martin-Marietta	Assembly and Subsystem Automation ⁷
TRW	Satellite Servicing ⁸

SRI International provided a technology assessment based on the contractors' studies and their knowledge of the state-of-the-art and the anticipated technology readiness.⁹

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