

# AI Applications for the Space Station

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## **Abstract**

NASA is currently developing a Space Station for long term usages of space. This Space Station presents NASA with numerous problems which may be best handled by effective use of expert systems. This paper outlines some of the benefits expert systems will provide, some of the issues involved in choosing appropriate applications, and the impact expert systems will have on the design of the Space Station.

## **Introduction**

In 1984, President Reagan committed the United States to a permanent manned presence in space through the development of a Space Station. The NASA Space Station Program is currently in the early stages of design. The extended life of the program (15 to 20 years) and the wide range of planned capabilities present NASA with a major challenge to make effective use of all available resources. Therefore, Automation and Robotics (A&R) plans are being included in all Space Station design activities. These A&R plans draw heavily upon the field of Artificial Intelligence (AI) to provide the core technologies needed to enable advanced automation.

AI will be applied to the Space Station in a number of ways. There are two primary types of applications anticipated early in the Space Station's life: telerobotics and expert systems. This paper will concentrate on expert system applications and technologies. Expert systems will be used to reduce crew workload by providing continuous monitoring of many onboard systems. Faults will be detected early and potential solutions to problems will be suggested to the crew, increasing overall onboard safety. Expert

systems will also be used to schedule and manage onboard resources and crew time. Expert systems can be applied to almost every subsystem onboard the Space Station and on the ground; in areas such as crew training systems, crew medical systems, mission planning, environmental systems, power systems, traffic control, communications and tracking, and many others.

Closely associated with expert system applications will be improved man-machine interfaces using voice synthesis, voice recognition, natural language, and advanced graphics. The increased use of automation in all functions will place a larger emphasis on the manner in which humans interact with the computer. The man-machine interface must become more flexible and less dependent upon the users learning specific procedures and peculiar syntaxes. The emphasis will be on allowing users to work with the computer tools in a manner that is comfortable for the user and not dependent on hardware/software limitations.

## **Benefits of Expert Systems**

Many Space Station tasks involve monitoring data for potential problems or recording information for analysis. Expert systems make excellent monitoring tools since they never get bored or tired, are always alert, react faster than humans, and can't retire or quit. Expert systems can provide a wide range of aid; from merely warning controllers of developing problems, to advising controllers on potential responses, to actually correcting problems as they occur. The use of expert systems for these kinds of tasks could potentially free large amounts of crew time.

Another potential benefit of expert systems is a reduction in the effort required to modify the system. Since knowledge is represented and coded in a manner more closely akin to the way humans think, theoretically, it is easier to maintain the information.

### **Selecting Expert System Applications**

Although an aura of mysticism sometimes surrounds expert systems and expert system applications, no magic is involved. More than anything, expert systems represent the application of relatively new programming techniques and methodologies to problems which were difficult to solve with conventional computer languages and techniques. As with any programming techniques, it is important to recognize where and when it is applicable. Thus, a key aspect to the development of a successful expert system is proper selection of the problem domain.

In general, this has meant using expert systems on problems with the following characteristics: well defined areas where the subject is well understood, capable experts exist and are available, automation of the task provides a high payback (i.e. highly repetitive or labor intensive), and conventional programming solutions are impossible or cost prohibitive. For the Space Station, proper domain selection is of critical importance, but some of the traditional criteria may not apply. In particular, experts do not currently exist for most Space Station subsystems. Since the systems are still being designed, the knowledge about the domain is still being developed. This does not mean that it is impossible to use expert systems, but that knowledge programming techniques must be incorporated into the design and development process. Also, it means that the definition of the specific interfaces for the expert system must be flexible at the early stages, and verification of the performance must depend on simulation of expected events as opposed to actual test cases.

However, the responsibilities of Space Station expert system must still be clearly defined, and expert systems should still be limited to problems that really require expert decision making capability. If the problem can be solved using conventional languages at a reasonable cost, it

probably should be. Due to the relative ease of modification to the knowledge base, the use of expert systems will also be beneficial for problems that require frequent modification or updating, which is likely early in the Space Station program.

Using criteria such as those just discussed, potential automation candidates can be evaluated and the most beneficial chosen for early development on the Space Station (For an example of specific selection criteria, see reference 1). Table 1 provides a sample list of expert system candidates identified by companies working on Space Station design. Although nearly all systems could benefit from automation, the high cost of automation development and the unfamiliarity with the technology will probably allow expert systems to be initially applied in only a few select areas.

### **Impact of Expert Systems on Space Station**

Merely allowing the option of expert system processing onboard the Space Station will have an impact on hardware and software systems. Expert systems will impact at least three major areas, the on-board Data Management System (DMS), the Software Support Environment (SSE) and the Operations Management System (OMS). For the purposes of this paper, the Space Station DMS is composed of all on-board data processing equipment, including computers, network media (data buses), network interface units (NIU's), mass storage, and other data processing hardware. The SSE is the standard development environment for all Space Station software, and the OMS is the high level software architecture within which all Space Station software will run. The OMS has components both onboard the Space Station and on the ground.

Software on board the Space Station can be grouped into eight or nine major subsystems. The OMS controls the interaction between the major subsystems. The subsystems are the Environmental Control and Life Support System (ECLSS), the Electrical Power System (EPS), the Data Management System (DMS), the Guidance, Navigation, and Control (GN&C) system, the Communications and Tracking (C&T) system, the Thermal Control System (TCS), and various

systems associated with the crew and payloads. This breakdown of systems is synthesized from the DR-17 reports of two Space Station contractors<sup>2,3</sup> and is the same as the system breakdown being used by DMS designers<sup>4</sup>. The OMS functions, as defined in reference 5, are executing and editing the short term plan, monitoring system payload status, simulating and testing systems, logging activities and configurations, managing resources, handling global cautions and warnings, handling global fault management, handling command management, maintaining an inventory of hardware and consumables, tracking system and payload maintenance status, and running training simulations.

Expert systems could be applied to every subsystem. Expert systems for ECLSS should monitor, diagnose, and reconfigure the following sub-systems: atmosphere and water, CO<sub>2</sub> removal, waste water management, temperature and humidity management, airlock and cabin pressure, and utilities connections. The EPS will require expert systems for load management and for monitoring, diagnosing, and reconfiguring the power generation and distribution sub-systems. The DMS should have expert systems for fault recovery, trend analysis, network configuration, resource management, and redundancy management. The GN&C system will need expert systems for hardware monitoring and checkout, navigation filter monitoring, momentum management, performance analysis, rendezvous planning and control, and traffic control, and proximity operations control. The C&T system will need expert systems for sensor control, configuration, resource management, redundancy management, and intelligent data buffering and multiplexing. The TCS will need expert systems to manage heat rejection and to control the curvature of keels and trusses due to thermal effects. Due to a lack of familiarity with crew systems and the proposed Space Station payloads, the AIS cannot assess the expert system requirements in those areas at this time.

In this paper, no attempt is made to partition the expert system applications into those present at the initial operational capability (IOC) and those delivered post-IOC. The need to add new capability was considered, and the systems and architectures

examined were assumed to have robust capabilities that will probably only be on-board during the post-IOC (or growth) phase.

Also, no attempt was made to determine which applications would be on-board and which would be on the ground. Instead, it was assumed that all applications would reside on-board. Of course, at IOC there will be a preponderance of ground processing, some of which will later migrate on-board. Yet, the division between on-board and ground software has not been determined by the Station's designers.

### **General Impact**

Some needed Space Station hardware and software capability can be defined without detailed examination. These requirements are drawn from the experience of expert systems programmers and from the requirement that the Space Station's DMS have growth capability throughout the life of the Station.

- 1) Expert systems must be embedded with the traditional control software that will be on-board the Station. This means that each processor should allow expert systems to be embedded and fully integrated with other code running on the processor. This is the most logical configuration for expert systems processing, because expert systems and traditional programming each have an important and mutually supportive role to play in problem solving. This also means that expert systems most likely will need to be coded in conventional languages.
- 2) The SSE should support a highly distributed workstation environment. Different applications will require different development environments. For expert systems development, the LISP machine environment is currently the most productive. The advanced software development tools resident on the LISP machine provide a rich prototyping environment. The SSE should either support all the capabilities of LISP machines, or LISP machines themselves.

- 3) The DMS hardware architecture should be distributed, and it should allow non-standard processors to access the DMS (either directly or through an NIU). There may be a need for specialized on-board processors during the life of the Space Station. Hardware optimized for symbolic processing, parallel processing, high data rates for observational experiments, and other non-standard architectures could play a role in post-IOC on-board data processing. The DMS should be able to accept non-standard processors by defining a communication protocol at the NIU (or other interface) level that allows data to be used by all computers that have the software needed to support the protocol.

Some more specific requirements can be identified in at least three areas: sensors and data bus bandwidth, processor speed requirements and memory requirements. Assessing specific impact is difficult at present due to the limited knowledge and the lack of reliable sizing metrics. The sizing estimates are based on estimating the number of rules in an expert system, which is not a well defined process. Table 2 shows the estimates for each subsystem and the source of those estimates. The results summarized here are discussed in more detail in reference 6.

#### **Sensors, Data Bus Bandwidth Impact**

The expert systems impact on sensors and data bus bandwidth is not easily determined. Expert systems perform an interpretation function that would otherwise be performed by humans. This places an additional burden on the computational capability (both processing power and memory) of the DMS.

Because expert systems are largely a substitute for human interpretation, one would suspect that the sensor requirements for Space Station sub-systems are independent of expert systems processing. It is assumed that sub-systems will have the necessary sensors regardless of whether that data is interpreted by humans or expert systems. Yet, expert systems can provide additional interpretation beyond the ability of humans, and it may be desirable to add additional sensors or increase data rates to take advantage of the expert system capability. Overall, expert

systems require little additional sensing, but it may prove advantageous to provide expert systems with sensor information that is beyond the practical interpretation capability of humans.

If an increase in sensor information is desired due to the presence of expert systems, the data bus bandwidth must increase to handle the new data. In addition to sensor information, expert systems will communicate with other expert systems and with procedural software. Communication between expert systems will generally add a low volume of traffic to the DMS data bus, but occasionally expert systems may request significant amounts of data. To go beyond these rather hazy communication issues, a distributed architecture and communication protocol must be developed for on-board expert systems. Once a communication protocol and software architecture has been developed, a more specific understanding of the expert system impact on the DMS data bus bandwidth can be determined.

#### **Impact on Processor speed**

Expert systems are both processor and memory intensive programs. The use or potential use of expert systems on board the Space Station will require that the processors be capable of providing all the processing speed required to run the conventional applications AND expert systems.

The AIS has developed a very rough numerical gauge of the processing power required for rule-based expert systems of a given size. The gauge is based on a measure of rule firings per second (RPS). Because a single rule firing can call procedural code that may perform considerable additional computation, rules per second can be a deceptive measure. The rules per second benchmark used here (developed by Gary Riley of the AIS<sup>7</sup>) does not call external procedural code, and thus provides a good measure of rule system efficiency. By combining the top rule per second speeds available in current expert system tools with some estimates of the needs for Space Station systems, the AIS was able to come up with a translation formula for estimating processor speed given the number of rules in an expert system. The formula is primarily intended for monitoring type systems. Although simplistic and very preliminary, the formula does attempt to take into account the complexity of real world systems.

This information is combined with the preliminary estimates of processor speed for conventional applications from reference 6 in Table 3.

### **Impact on Memory**

The AIS has also developed a method for estimating the amount of memory required for rule-based systems. There are two factors to consider in gauging memory usage. First, the expert system tool will require some memory. Second, the knowledge base (or rule base in a rule-based system) will require memory. The address space needed by the tool is a blanket overhead for running expert systems. The space needed by the knowledge base can be measured by the amount of memory needed per rule.

The AIS examined a number of expert system tools to derive memory estimates for C-based tools with robust capability. The memory usage is based on the tool and the rules. Facts will probably not require large amounts of memory, although pattern and join net instantiations can use significant memory. The amount of pattern and join net instantiations is dependent on the actual expert system.

The results of our study suggest that a robust C-based tool will require 2 to 5 megabytes of memory. The knowledge base will use about 2 kilobytes per rule. Each processor will need to support at least one expert system tool and the knowledge bases for the expert systems resident on that processor. The memory required to support expert systems applications for the OMS and each system is given in Table 3, along with preliminary estimates for the memory needed to support conventional applications.

### **Conclusions**

The Space Station is an important step for the American space program which will require some new concepts in long-term system usage. Expert systems have tremendous potential to provide a more reliable, more productive Space Station. This paper has pointed out some of the benefits to be gained by using expert systems, where they can be applied and some of the impacts expert systems will have on the Space Station design.

### **References**

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**Table 1****Examples of potential Space Station Expert System applications**

crew exercise protocol	training (on-board & ground)
ECLSS - atmosphere and water	medical diagnostics
CAP scheduling, resources, etc.	HW/SW design eval, safety
resource planning and allocate	identify persons for tasks
EPS load management	mission planning
ECLSS - CO <sub>2</sub> , O <sub>2</sub> , humidity	DMS fault recovery
OMV, OTV rel. state vector	DMS trend analysis
Payload checkout	DMS network configuration
GN&C H/W monitor	GN&C checkout
Comm & Tracking sensor control	rendezvous/prox op guidance
heat rejection and transport	traffic control
Payload servicing	trajectory plans and windows
Comm & Tracking mgmt	bandwidth compression
MRMS operations	fluid management
multiplex and buffer data	EVA monitoring, planning
EPS fault detect, isolate, and reconfigure	Payload health, maintenance, configuration

(From references 2 and 3)

**Table 2****SIZE ESTIMATES FOR EXPERT SYSTEM CODE IN SPACE STATION SYSTEMS**

<u>system or sub-system</u>	<u>number of rules</u>	<u>source</u>
ECLSS (environmental control)	1450 rules	AIS
EPS (electrical power)	800 rules	AIS
DMS (data management)	1200 rules	AIS
GN&C (guidance and nav)	1900 rules	AIS
Comm. and Tracking	1300 rules	AIS
Thermal Control	550 rules	AIS/MDAC
Miscellaneous	1400 rules	MDAC
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Grand Total	8600 rules	

(Note: These estimates do not account for code associated with medical advisor applications, testing, or payload management)

**Table 3****Estimated Space Station processor requirements for both Conventional and Automated Software, by subsystem**

Subsystem	Processor Speed (MIPS)			Processor Main Memory (MB)		
	Conv.	Aut.	Total	Conv.	Aut.	Total
Power/EPS	1.4	.33	1.73	.87	3.6 - 6.6	4.47 - 7.47
DMS	1.9	.5	2.4	1.7	4.4 - 6.6	6.1 - 9.1
Thermal/TCS	.68	.2	.88	.5	3.1 - 6.1	3.6 - 6.6
C & T	.84	.5	1.34	2.5	4.6 - 7.6	7.1 - 10.1
GN & C	.68	.8	1.48	.96	5.8 - 8.8	6.76 - 9.76
ECLSS	.12	.6	.72	.63	4.9 - 7.9	5.53 - 8.53
EVA	-	-	-	-	-	-
Manned Sys	.10	-	-	.92	-	-
FLUID	.13	-	-	.77	-	-
OMS	-	2.5 - 3.2	-	-	14.4 - 21	-