Paper Session I-A - Employing Artificial Intelligence to Meet Space Requirements

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Employing Artificial Intelligence to Meet Space Requirements

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Abstract

In January 1989, AFSTC began the Artificial Intelligence (AI) Initiative as a means of accomplishing two objectives: 1) to determine requirements in the Air Force space community that could best be met employing AI techniques and 2) to ensure current programs were adequate to meet these requirements. The approach was to determine requirements by surveying the users, identify current programs, and then identify redundancies and omissions for the purpose of recommending a future course of action.

Ten requirements were identified as being well-suited for AI techniques. Three of these requirements were determined to have high payoff and be attainable in the near term. The three requirements are range scheduling, intelligent consoles for satellite control, and intelligent computer aided training.

In identifying current projects, it was found that the majority of the space related AI work is performed by NASA. Projects at the Jet Propulsion Laboratory, Johnson Space Center, and Lewis Research Center were found to be directly applicable to Air Force requirements. Sharing of space-related technology is currently being addressed through the Space Technology Interdependency Group.

This paper discusses the results of the AI Initiative including the ten requirements and related projects. Also discussed are the future plans for AI in AFSTC.

Introduction

Although the field of Artificial Intelligence (AI) has been in existence for over 25 years, there is still no single, uniformly accepted definition for AI. Minsky is credited with the most accepted definition: "the science of making machines do things that would require intelligence if done by men." The scientific community believes AI techniques can increase human productivity and automate many complicated, dangerous, and tedious human activities [7].

While the Air Force has invested significantly in research of AI, very little has been targeted to meet space requirements. In January 1989, AFSTC began the AI Initiative as a means of determining requirements of the Air Force space community that could best be met employing AI techniques and ensuring current programs were adequate to meet these requirements. Potential AI applications were determined by surveying the users (e.g. Space Systems Division (SSD), AF Space Command). As a result, ten space applications were identified as being well-suited for AI techniques.

Applications for AI in Space

1. Range Scheduling. Range Scheduling addresses the problem associated with the limited number of ground stations, the growing number of satellites, and the need to schedule resources to meet the user's needs. The scheduling includes routine activities such as ephemeris updates and mission data processing, as well as critical operations during a satellite's early orbit check-out or in cases of satellite anomalies.

   Currently, scheduling is performed by attaching variously colored tapes to a paper scheduling chart to reflect requests for satellite contacts. A conflict is identified simply by noting that two strips of tape occupy the same space. The conflict is then resolved by the scheduler manually searching the chart for a empty...
location corresponding to a station that can support the request at a time that the satellite is visible to that station. If both contacts cannot be supported in the time requested, users are contacted to determine which satellite has priority. No portion of this process is automated. Organizations involved in developing automated range scheduling include the MITRE Corporation and Unisys. In addition, NASA Jet Propulsion Laboratory (JPL) has developed a system which addresses a similar resource scheduling problem.

2. An Intelligent Console for Satellite Control. Satellite control is a complicated, tedious, and labor intensive process. According to a 1989 GAO study, over 4,000 government and contract staff are required to operate the Air Force Satellite Control Network consisting of fixed ground-based tracking stations, central control facilities, and communication links. This network currently controls the operations of approximately 80 on-orbit satellites. Predictions are that 135 satellites will be on-orbit by the year 2000, and 150 will be on-orbit by 2015 (these estimates do not include satellites required to support SDI). However, the number of controllers supporting the network is likely to remain constant while the level of expertise decreases due to retirements.

Another consideration is Air Force plans for a more survivable network which would rely on dispersed mobile ground control stations. According to a 1987 satellite control architecture study, these mobile stations will require expert systems capable of automatically performing satellite control operations [3]. It is expected that the operators of the mobile control stations will have a significantly lower level of expertise than the current network support staff.

The goal of providing an intelligent console is to increase the power of tools available to the satellite controller. This will reduce the need to increase the number of controllers and enable mobile system operators to control different families of satellites without requiring extensive (and unrealistic) levels of training. Organizations involved in developing intelligent consoles include NASA Johnson Space Center (JSC), NASA JPL, The Aerospace Corporation, and several corporate independent research and development (IR&D) projects.

3. Training Aids for Controllers. The current practice of training satellite controllers requires over two years of training before they are allowed to send a single command to a satellite. It has been proposed that the Air Force go to an all "blue suit" operation to ensure continuity during wartime operations. Since the average tour of an Air Force officer is about four years, the effective time on station is reduced, guaranteeing an inexperienced force.

Intelligent Computer Aided Training (ICAT) is an application of AI that develops autonomous systems for training personnel in the performance of complex procedural tasks [1]. This method can be used to reduce the time required to train controllers, thereby increasing their effectiveness. Organizations involved in developing ICAT include NASA JSC and the Air Force Human Resources Laboratory (HRL).

4. Satellite Autonomy. As early as 1985, AI technology was identified as capable of supporting high levels of satellite autonomy. A JPL study, performed for AFSTC, identified specific applications that could benefit from one or more AI techniques [6]. Rome Air Development Center (RADC) began a program in 1986 to determine the applicability of current knowledge-based systems to autonomous satellite systems [2]. Although the program was designed to be a three phase, five year program, it was terminated in November 1987 due to a reduction in funding. Although US Space Command incorporated a requirement for satellite autonomy in their Integrated Satellite Control System (ISCS) Multi-command Required Operational Capability (MR0C) statement, no major satellite autonomy programs are currently funded by the Air Force. Organizations involved in developing satellite autonomy include NASA JPL as well as corporate IR&D projects.

5. Autonomy for Satellite Subsystems. As a method of meeting the goals of satellite autonomy, it is possible to develop autonomous subsystems for the satellite.
Autonomy for each subsystem would be valuable in its own right and could serve as components of an fully autonomous satellite. Subsystems that appear to have the most potential in the near term include 1) Guidance, Navigation, and Control, 2) Power Management, 3) Thermal Control, and 4) Payload Management. Organizations involved in developing satellite subsystem autonomy include SSD System Program Offices (SPOs), several NASA centers, and corporate IR&D projects.

6. Fault Diagnosis of Satellite Anomalies. Current methods require constant monitoring of satellite telemetry, interpretation, and detection of anomalies. When anomalies are detected, a corrective procedure is formulated, often requiring consultation with the factory responsible for development of the satellite.

Fault diagnostics are the most widespread industrial application of expert systems [5]. Expert systems applied to fault diagnosis have achieved some of the most rapid returns in terms of the ability to do useful work. Organizations involved in developing AI techniques for fault diagnosis of satellite anomalies include The Aerospace Corporation, several NASA centers, and corporate IR&D projects.

7. Environmental Problem Identification. Twenty percent of satellite anomalies are due to anomalies induced by the orbital environment (e.g. single event upsets induced by solar flares). Although other satellites may be in the area, there is no way that the responsible operator can determine if other satellites are experiencing similar difficulties. If environmental problem notification were implemented, 20% of anomalies could be discounted, thereby eliminating costly consultation with experts.

The Aerospace Corporation is developing an expert system that attempts to distinguish between environmentally induced anomalies and anomalies caused by equipment failure. An AFSTC proposed approach is to couple this expert system with a communications network to share anomaly information among owners of satellite systems. The NASA Goddard Space Flight Center, with Air Force funding and Aerospace Corporation support, is adding the anomaly identification expert system to EnviroNet, an environmental monitoring network and effects data base.

8. Satellite Survivability. Methods of satellite survivability are normally divided into passive and active measures. Active measures are those that the satellite would take to evade the possibility of destruction. These measures require a system capable of assessing the situation, determining actions to take, and executing those actions. Development of an expert system is a logical approach to meet the space system requirement for a timely response.

9. Pre-launch Processing. One approach to deterring an adversary from destroying a satellite is a concept called responsive launch. Under this concept, enough spare satellites are maintained ready for launch to convince the enemy that destroyed satellites can be rapidly replaced. Currently, the time required for pre-launch processing would prohibit responsive launch from being a realistic deterrent.

Expert systems can automate portions of the processing, thereby reducing the time required. It is possible that this could be extended to cover launch and post-launch operations as well. The only organization identified as developing expert systems for automating pre-launch processing was the SSD Advanced Launch System (ALS) SPO.

10. Weather Prediction at Launch Sites. Weather considerations are a critical aspect of ensuring a safe and successful launch. While the Air Force Geophysics Laboratory (GL) continues to investigate both weather phenomena and forecasting, it has not been tied directly to providing near-term forecasting at a launch site. One GL research area which is of interest to launch sites is fog prediction (because of the sites' coastal locations). In 1986, GL contracted with GEOMET Technologies to develop an expert system for fog prediction. The expert system, Zeus, was highly dependent on the experience level of the operator, and was only useful in areas for which it had been explicitly programmed.

AFSTC has proposed supporting an AFIT thesis study for the development of a generic fog prediction AI system with a layered structure, as originally proposed by
Rosemary Dyer of GL. The bottom layer would be a collection of the basic physical and meteorological principles gathered from scientific literature. The next layer would consist of the effects of regional climatology and topography. The third layer would address the effects of local climatology and topography. Finally, the top layer would be based on the individual station practices and rules of thumb derived from the local expert forecaster. After development, the system would be tested at Vandenberg AFB and Kennedy Space Center.

Three High Payoff Areas

Three of the applications discussed above have potential for high payoff in the near term. They were determined by assessing the impact to the mission of a successful AI application and the existence of programs that have addressed the problem, or a similar problem. The three areas are range scheduling, intelligent consoles for satellite control, and intelligent computer aided training for satellite controllers.

As a means of addressing these areas, and to foster and coordinate AI research and development in the space community, AFSCC formed a Space AI Working Group (SAIWG). The first meeting was held in November 1989 and attracted over fifty representatives from the Air Force, NASA, and industry. Programs briefed at the meeting in each area are discussed below [1]. To protect proprietary information, IR&D programs are not included.

1. Range Scheduling

   Range Scheduling Assistant. ESD has a program with MITRE to develop the Range Scheduling Assistant (RSA) for the Consolidated Space Operations Center (CSOC). RSA is a computer program that automates the current method of tapes and butcher-block paper. In addition, RSA employs an expert system to identify and resolve conflicts.

   Automated Scheduling Tool for Range Operations. SSD has a program with Unisys to develop the Automated Scheduling Tool for Range Operations (ASTRO). ASTRO automates the paper process using a high resolution, large screen display with a simple natural language interface. ASTRO identifies, but does not resolve, conflicts.

   Operations Mission Planner. NASA JPL has developed the Operations Mission Planner (OMP). OMP is an automated planning system to assist human planners with resource allocation problems. OMP has a unique method of resolving conflicts and optimizing resource allocations.

2. Intelligent Consoles

   Advanced Satellite Workstations. The Advanced Satellite Workstation (ASW) is being developed by The Aerospace Corporation. The goal of ASW is to address the need for reduced manning, diminished contractor support, and improved data-handling techniques. ASW accomplishes this by merging several types of media and presenting them as a cohesive display.

   Satellite Health Automated Reasoning Prototype. NASA JPL developed the Satellite Health Automated Reasoning Prototype (SHARP) in an effort to apply AI techniques to the task of multi-mission monitoring of spacecraft and diagnosis of anomalies. SHARP was used to support Voyager's near encounter with Neptune in August 1989, and continues to be used to provide the necessary level of support for Voyager's next mission, to locate the heliopause while manpower is sharply reduced.

3. Intelligent Computer Aided Training

   Johnson Space Center ICAT Programs. JSC has several programs for the
development of ICAT systems. Of particular interest is the general purpose development environment for ICAT systems. This system uses a blackboard architecture to model the trainee as well as the evaluator to tailor the session to the individual student.

**Human Resource Laboratory ICAT Programs.** HRL is the Air Force Center of Excellence for ICAT. HRL has already developed programs for AF Space Command including a tutor for orbital mechanics courses at Undergraduate Space Training (UST). HRL has worked with NASA JSC to develop ICAT systems. They have expressed a willingness to work with SSD and AFSPACECOM to develop an ICAT system for the satellite controllers.

**Enabling Technologies**

In order to meet the space related requirements with AI techniques, there are underlying technologies which must be addressed. These include radiation hardened space qualified processors, software development environments for space processors, and verification and validation of expert systems.

1. **Radiation Hardened Space Qualified Processors.** The processors used on today’s satellites are not capable of hosting expert systems. There are various programs at AFSTC, RADC, and DARPA to develop advanced satellite processors. These programs include the Generic VH Sic Spaceborne Computer (GVSC) and Advanced Spaceborne Computer Module (ASCM) programs at AFSTC and the Radiation Hardened 32-bit (RH-32) Processor work at RADC and DARPA.

2. **Software Development Environments.** Phase I of the ASCM program, which will provide the next generation of satellite processors, uses the 1750A architecture. This architecture requires that programs fit into 64 Kilobytes segments. Existing expert system shells have overhead associated with the inference engines that require approximately 500 Kilobytes of memory that cannot be segmented. To overcome this limitation, AFSTC is sponsoring an effort at Merit Technologies to provide a development environment for the generation of efficient expert systems that will operate on DoD-STD-1750A computer systems and which can also be used to implement AI techniques in avionic systems.

3. **Verification and Validation of Expert Systems.** Due to the high cost of space assets, SPOs are reluctant to introduce any new technology perceived to increase programmatic (e.g. cost or schedule) or operational risk. Because of the history of significant problems associated with software development, coupled with the status of expert systems as a new technology, SPOs are extremely hesitant to include AI techniques in space systems. Verification and Validation (V&V) of expert systems is an important factor in achieving acceptance of expert systems in ground based applications and critical to acceptance of on-board expert systems. Organizations involved in developing V&V for expert systems include AFSTC, RADC, and The Aerospace Corporation.

**Conclusions**

Due to the high cost of space assets coupled with the inability to service these resources on a routine basis, employment of AI techniques in space significantly trails the employment of AI techniques in other Air Force areas. This hesitancy to employ AI has resulted in limited AI research within the military space community.

NASA has been able to overcome this resistance to AI chiefly because of the severe demands of deep space missions. This realization of the necessity to use AI has led to intensive research in AI techniques for space applications. NASA is very
open about research performed and willing to share the results of this research with
the Air Force.

Additional AI research is in progress in many Air Force Laboratories, most
noteworthy, WRDC and RADC, the two Air Force Centers of Excellence in AI. Although
this research is not performed specifically to meet the needs of space requirements,
significant portions are applicable.

In the long term, the Air Force space community must increase research in AI for
space requirements and educate decision makers in the AF space community about the
potential of AI. However, the best short term solution is to transition existing AI
technology from NASA and AF Labs to meet space community needs.

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