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An Operations and Command System for the Extreme Ultraviolet Explorer

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INTRODUCTION

About 40% of the budget of a scientific spacecraft mission is usually consumed by Mission Operations & Data Analysis (MO&DA) with MO driving these costs. In the current practice, MO is separated from spacecraft design and comes in focus relatively late in the mission life cycle. As a result, spacecraft may be designed that are very difficult to operate. NASA centers have extensive MO expertise but often lessons learned in one mission are not exploited for other parallel or future missions. A significant reduction of MO costs is essential to ensure a continuing and growing access to space for the scientific community.

We are addressing some of these issues with a highly automated payload operations and command system for an existing mission, the Extreme Ultraviolet Explorer (EUVE). EUVE is currently operated jointly by the Goddard Space Flight Center (GSFC), responsible for spacecraft operations, and the Center for Extreme Ultraviolet Astrophysics (CEA) of the University of California, Berkeley, which controls the telescopes and scientific instruments aboard the satellite. The new automated system is being developed by a team including personnel from the NASA Ames Research Center (ARC), the Jet Propulsion Laboratory (JPL) and the Center for EUV Astrophysics (CEA).

An important goal of the project is to provide AI-based technology that can be easily operated by nonspecialists in AI. For example, CEA personnel are experienced with the specific EUVE scheduling problem but not with general scheduling methodologies. Since a dedicated AI expert cannot be supported, it is difficult for them to extend and customize their current scheduling tool within a coherent framework. This situation is typical of the smaller NASA satellites programs.

Another important goal is the reusability of the techniques for other missions. Models of the EUVE spacecraft need to be built both for planning/scheduling and for monitoring. In both cases, our modeling tools allow the assembly of a spacecraft model from separate sub-models of the various spacecraft subsystems. These sub-models are reusable; therefore, building mission operations systems for another small satellite mission will require choosing pre-existing modules, re-parametrizing them with respect to the actual satellite telemetry information, and reassembling them in a new model. We are stressing multi-mission support during the tool's development process. The planning and scheduling tools are also being evaluated by science planning and spacecraft sequencing teams for the Cassini Saturn orbiter's mission.

We briefly describe the EUVE mission and indicate why it is particularly suitable for the task. Then we briefly outline our current work in mission planning/scheduling and spacecraft and instrument health monitoring.

THE EUVE MISSION

NASA's EUVE was launched on June 7, 1992. The satellite's mission included three phases. The first phase was a six month long all-sky survey for sources of extreme ultra-violet (EUV) radiation. This phase was completed in January 1993 and resulted in the detection of more than 400 sources of EUV emission. The second phase occurred simultaneously with the all-sky survey. This involved a deep-survey and spectroscopy of much fainter EUV sources in a narrow band of the sky along the ecliptic. The third phase EUVE mission began on January 21, 1993 and is still underway. During this phase, Guest Observers from around the world are using spectrometers and photometers to investigate EUV sources found during the all-sky and deep surveys. The expected output of this phase are spectroscopic and imaging data for over 100 targets per year.

The nominal completion date for the mission is the end of 1995. However, this does not depend on lack of scientific interest nor on an expected deterioration of the excellent health of the spacecraft. MO activities at GSFC and CEA are very labor intensive and, therefore, costly. For this reason, it is not expected that NASA will be willing to continue supporting the EUVE MO after 1995. Some options are being considered in order to lengthen EUVE's contribution to the astrophysical community [1]. These include: (1) the reduction of operations from 3 to 1 shifts a day as soon as possible and the redirection of savings into developing more automated operations, and (2) transferring complete spacecraft operation to CEA using a robust workstation-based operation system.

The set of tools developed by our project will provide payload health management, real-time science data analysis, trending and classification, and science command planning and scheduling for the extreme ultraviolet telescopes. ARC will also provide advanced data systems support for the ground network and control stations. This enhancement of the EUVE science operations center (ESOC) will make the previous options viable.

From the point of view of the ARC and JPL team, EUVE is an ideal demonstration testbed for various information science and AI technologies. Perhaps the most favorable characteristic is that the spacecraft is currently in flight with a good historical database of operations. Spacecraft systems, constraints, and operational procedures are known. This makes spacecraft modeling easier than for missions still in the design phase. Also, CEA already has experience with the use of AI-based tools for science planning. This experience can be leveraged to facilitate the transition to the new generation of tools that ARC and JPL will provide. Another important aspect is the fact that EUVE is structurally simpler than other more ambitious spacecraft (e.g., HST, Cassini). Therefore it will be easier to apply automation of spacecraft sequencing, monitoring and diagnosis, and data systems management. The experiences gathered with EUVE will build confidence for an aggressive automation of more complex missions.

SPACECRAFT SEQUENCING

To continue operation after 1995 CEA will need to take greater responsibility for the spacecraft command sequencing and uplink process. ARC will support this transition with an integrated planning and scheduling system. Such a system will allow; (1) simplification of sequence validation, since at any stage the system will guarantee satisfaction of spacecraft constraints on the base of a detailed, internal model of the spacecraft; (2) generation of schedules with higher science output, since it will be possible to take advantage of detailed knowledge of spacecraft constraints even in preliminary stages of science planning.

Currently, planning and scheduling are done at EUVE through a mixture of manual procedures, utilities and programs developed around SPIKE [4]. SPIKE is an AI-based scheduling tool originally developed at the Space Telescope Science Institute (STScI) for long-term scheduling of the Hubble Space Telescope. SPIKE is being successfully used in operation for HST and has been applied to other space telescopes. Experience in the use of SPIKE for EUVE operations suggest some features missing in SPIKE but essential in a more useful automated tool. The main problem in using SPIKE has been the difficulty in integrating spacecraft ephemeris calculations into the basic scheduling engine. This is not surprising given SPIKE's original focus on long-term scheduling. For such a task coarse approximations are sufficient (e.g., a fixed percentage of orbit time available for observation over the entire scheduling horizon). However, EUVE's task is eminently *short-term;* and coarse approximations become too inaccurate to be useful (e.g., an accurate calculation of exposure time requires knowledge of exact South Atlantic Anomaly (SAA) traversal times for each orbit). In the cases when a modification of the SPIKE constraints are possible, the work involved requires either mapping new constraints onto the heuristics used by SPIKE or modifying SPIKE's own inference engine. Both the previous tasks require personnel with qualifications that are outside of the reach of a more cost-effective, small satellite MO organization. In the case of CEA, this has led to complement SPIKE *from outside*, with extensive preprocessing routines and a mostly manual observation scheduling process. The mismatch between the long-term scheduling philosophy and the needs of short-term scheduling are likely to become even more severe when CEA will take over the spacecraft command sequencing task.

The scheduling system that ARC is developing is based on HSTS [8], a planning an scheduling framework originally aimed at HST's short-term scheduling problem; in that domain HSTS has demonstrated the ability to build schedules that take into account most of the detailed spacecraft constraints and that can be easily transformed in executable spacecraft command sequences. A major effort has been put into providing easily usable constraint modeling facilities; these will allow a mission sequencing expert to easily express spacecraft constraints even without a deep understanding of the functioning of the underlying scheduling engine. Given the similarity of constraints across spacecraft domains and the modularity of the HSTS modeling framework, it will be easy to reuse model components across several missions. Currently, the multi-mission emphasis is being pursued by providing HSTS's domain modeling language to science planners for the Cassini mission in order for them to model constraints in their domains. As the number and types of constraints in a model increases, it is likely that a single schedule building philosophy (e.g., SPIKE's min-conflicts) will not be sufficient for the task. HSTS will provide an underlying modeling and temporal data base capabilities on which a suitable EUVE scheduler will be assembled from a number of possible scheduling and planning methodologies [8, 9, 3, 6, 2, 7]. Easy schedule visualization and manipulation is an important factor in order to complement and adjust the automatic scheduler's decisions to the needs and wants of EUVE's sequencing operators; we are developing such system in collaboration with Heuristicrats Inc. using DTS's scheduling interface toolkit.

PAYLOAD HEALTH MONITORING

A major area of interest to the ARC, JPL and CEA is the automated monitoring and diagnosis of system failures of both the ground and flight systems of the EUVE. The previous and current work on the Augmented Monitoring and Diagnosis Application (AMDA) system [10] for the Control Center Complex at NASA Johnson Space Center can be applied to the EUVE monitoring and diagnosis. The EUVE spacecraft and EUV instrument controllers face a number of problems in monitoring normal operations, diagnosing potential problems, and developing work-around procedures. These problems include determining the initial failure point, determining degraded operation modes, diagnosing the faults, and providing a range of diagnostic hypotheses. Currently, determining and diagnosing faults is a laborious, time consuming process which is highly dependent upon the expert knowledge of a few people. The research and development effort in the area of automated monitoring and diagnosis will be focused on assisting mission controllers to overcome these problems. The architecture of this system includes fault management techniques which utilize digraph failure models as well as model-based diagnosis and expert systems.

Automated fault diagnosis of the EUVE flight and ground systems requires utilization of modeling techniques that will allow inexpensive and quick diagnosis. The automation of much of the tedious systems analysis performed by the current flight controllers and an overview of the system status will help to reduce the operational requirements for the EUVE. This is especially important during low data gathering swing shifts and should eventually allow the elimination of the two swing shifts, with the automated diagnosis and warning system acting as the primary monitoring agent during those times. This 3-to-1 shift reduction effort was the focus of the ARC/CEA collaboration for the spring and summer of 1994.

The first element of that effort is developing the ESOC software version that actively monitors and detects system anomalies and pages off-duty support personnel based upon the severity of the anomaly. ARC and CEA have developed a new version of the ESOC software for the payload mission operators. This system, called EWORKS/EPAGE is developed in the commercially available software RTworks from Talarian, Inc. and the Sun NetManager. EWORKS performs the payload health monitoring and anomaly detection functions for the EUV telescopes onboard the platform. Initially five subsystems are being monitored for each of the seven telescope detectors. The general health, power, thermal control, high voltage, and command echoes. This first step is to be completed on August 31, 1994.

On September 1, 1994, the second step will begin, a simulated single shift operation. The EWORKS software will be frozen and put into operation for a two month trial period. During this time the ESOC personnel will continue 24 hour shifts. At the end of this period the decision for reduction from three to one shift of operations will be made based upon the feedback from GSFC and the ESOC mission operators. Pending approval the transition to single shift operations is scheduled for November 1, 1994.

ARC will develop system engineering models from the designs and operational parameters of the EUVE spacecraft and instrument components [5]. To develop the EUVE spacecraft systems model, the spacecraft system parameters such as mass, size, operational constraints, avionics, power, communications, thermal system, and instrument systems need to be modeled as separate subsystems. In order to successfully develop each of the subsystem models, we must perform a top-level analysis to adequately parametrize and understand them. The models will be integrated into a complete representational model of the EUVE spacecraft and verified against the operational data. The objective of the small satellite system model is the development of a model which identifies and quantifies the key system characteristics necessary for failure diagnosis and fault tracing. High-fidelity modeling and attention to actual system design are necessary for the model to be used to evaluate the performance of EUVE systems and to develop robust monitoring and diagnosis systems.

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