CRI Planning and Scheduling for Space

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Computer Resources International (CRI) has many years of experience in developing space planning and scheduling systems for the European Space Agency. Activities range from AIT/AIV planning over mission planning to research in on-board autonomy using advanced planning and scheduling technologies in conjunction with model-based diagnostics.

This article presents four projects carried out for ESA by CRI with various subcontractors:

- DI, Distributed Intelligence for Ground/Space Systems is an on-going research project,
- GMPT, Generic Mission Planning Toolset, a feasibility study concluded in 1993,
- OPTIMUM-AIV, Open Planning Tool for AIV, development of a knowledge-based AIV planning and scheduling tool ended in 1992,
- PlanERS-1, development of an AI and knowledge-based mission planning prototype for the ERS-1 earth observation spacecraft ended in 1991.

DISTRIBUTED INTELLIGENCE FOR GROUND/SPACE SYSTEMS

DI is short for Distributed Intelligence for Ground/Space Systems and the DI Study is one in a series of ESA projects concerned with the development of new concepts and architectures for future autonomous spacecraft systems. The kick-off of DI was in January 1994 and the planned duration is three years. The total budget is 600,000 ESA Accounting Units corresponding to approximately $720,000.

The background of DI is the desire to design future ground/space systems with a higher degree of autonomy than seen in today's missions. The aim of introducing autonomy in spacecraft systems is to:

- lift the role of the spacecraft operators from routine work and basic trouble shooting to supervision,
- ease access to and increase availability of spacecraft resources,
- carry out basic mission planning for users,
- enable missions which have not yet been feasible due to eg. propagation delays, insufficient ground station coverage etc,
- possibly reduce mission cost.

The study serves to identify the feasibility of using state-of-the-art technologies in the area of planning, scheduling, fault detection, model-based diagnosis and knowledge processing to obtain a higher level of autonomy in ground/space systems.

A demonstration of these technologies will be developed in the form of a prototype to run in a laboratory environment for the purpose of evaluating future ground/space system designs, and to experiment with the distribution of functionalities of the autonomous architecture between the ground and space segment. DI will use the ERS-1 earth observation mission as the reference mission for the study.

Reference Mission

Not all missions will benefit equally from AI and autonomy in space. AI is mainly applicable in complex domains where complicated decisions, based on several inputs have to be made. Autonomy on the other hand is beneficial in cases where human intervention is either inappropriate or directly impossible. Thus an interesting reference mission for this study should involve a complex spacecraft in an orbit that is either partly without ground contact or so distant that significant delays are inevitable. A natural choice is to select the ERS-1 mission as the reference since:

- ERS-1 is equipped with several scientific instruments with many operational constraints, implying very complex mission planning,
- ERS-1 is in a low polar orbit causing it to be out of ground contact during prolonged periods of time,
- operational experience has been gained, making it possible to quantify the advantages of on-board autonomy and AI,
- ERS-1 systems engineering expertise exists in the DI consortium,
- The ERS-1 simulator is available in the DI consortium.

Approach

The DI study is divided into two phases. In phase I, as a practical mean for obtaining a higher degree of abstraction, we have taken the rather provocative liberty to simply consider the ground and space segment as one combined system. This allows focusing on the essential user requirements on the overall system and on the interaction of the various modules of the autonomous ground/space system. Phase I creates a combined architecture that will be developed into the phase I prototype mock-up to ensure feasibility of integrating existing software developments.

In phase II the focus will be concentrated on the distribution aspects of the ground and space segments taking into account issues of distributed artificial intelligence. The development of the distributed phase II prototype will further improve the integrated software tools of the phase I prototype mock-up enabling the evaluation and demonstration of benefits.

The current status as of June 1994 is that a Draft User Requirements Document for the phase I prototype has been produced and the ERS-1 mission demonstration scenarios have been described. The prototype mock-up development has just begun with a clarification of the general MMI strategy.

GENERIC MISSION PLANNING TOOLSET

GMPT is a pilot study performed for ESA-ESOC, concerned with the development of a concept for a Generic Missions Planning Toolset in support of operations planning and scheduling. The main objectives are to provide a survey of general mission planning approaches, to define generic mission planning user requirements and standards, and to define a GMPT and develop a small prototype. The study was performed for ESA/ESOC with Computer Resources International A/S (Denmark) as prime contractor and with Science Systems Ltd (UK) as subcontractor. The kick-off was in January 1992 and the final presentation was held at ESOC in November 1992.

The study is divided into two phases with the following main objectives:

- provide a general survey of current mission planning approaches, analyze future ESA requirements for mission planning systems, define generic mission planning user requirements, as well as related interface standards,
- elaborate GMPT concepts, i.e. define baseline software requirements and overall architectural design, and develop a prototype demonstrating the feasibility of the elaborated concepts. As a bi-product, GMPT also resulted in a mission planning glossary list aiming at harmonizing the terminology used by the various mission planning teams.

Naturally there is a great variation in the extent to which elements in the mission planning process are generic, thus the GMPT modules have been categorized according to their degree of generality:

- *Fully generic* modules with no need for adaptation from mission to mission,
- *Configurable* modules, eg. a knowledge based system holding mission specific knowledge,
- *Mission specific* modules, eg. special external interface modules for translating non-standardized file formats to GMPT-compatible form.

The GMPT prototype was built around the OPTIMUM-AIV planning and scheduling tool previously developed for ESA, and aimed at demonstrating

- feasibility of implementing GMPT,
- schedule lifecycle under GMPT,
- efficient coding and decoding of state vectors,
- principle of activity-to-command conversion.

The GMPT is foreseen to operate in the ESOC spacecraft operations infrastructure. The current infrastructure is based on SCOS-I which will be replaced by SCOS-II after 1995. Therefore the architecture of the GMPT will depend on the structure of SCOS-II and the Mission Information Base defined within the framework of the SCOS-II project.

OPTIMUM-AIV

The size and complexity of the tasks involved in the Assembly, Integration and Verification (AIV) of a spacecraft, raises the need for efficient and flexible planning and scheduling tools. This lead ESA to award a contract to a consortium, with CRI as prime contractor together with Matra, AIAI and ProgEspace, to assess the applicability of AI and KBS techniques in a prototype AIV planning and scheduling tool. This study results in a set of user and software requirements and a demonstration system exploring some of the aspects of AIV planning.

The objectives of the OPTIMUM AIV project are four-fold:

- to develop an operational kernel of a planning, scheduling and plan repair tool consisting of a set of software functionalities for assistance in:
  - initial specification of AIV plans,
  - generation of valid plans and schedules for the various AIV activities,
  - interactive monitoring of the AIV plan execution,
  - identification of immediate effects and plan repair of problems,
- to embed external interfaces which allow integration with alternative scheduling systems and project databases,

- to provide facilities which will allow individual projects to customize the kernel to suit its specific needs,
- to implement knowledge-rich plan representations and enable the active use of this rich domain knowledge in the planning and scheduling process.

Artemis Interface

The system has embedded an interface to the widely used Artemis Project Management System. The interface is primarily intended for:

- importing space project data, i.e. activities and events, constraints, and resource data sets,
- exporting and displaying plans,
- report writing and graphics,
- aggregation, i.e. summarizing numeric data held in network data sets, e.g. resource requirements for all activities.

It can also be used for network construction, examination of the network logic, time analysis and updating, resource-limited or time-limited scheduling, and multiple network processing. However, in these latter uses of Artemis, it is not feasible to return the results directly to OPTIMUM-AIV.

Programming Interfaces

The system is designed as to allow external documentation programs to be written. It provides an interface that permits any user to develop their own documentation, in particular any new representation of the plan and schedule. That means that all activities, resources and constraints and any schedule will be accessible by any external program (written in C, Pascal or Ada).

Information can then be derived about alternative activities, soft constraints that may be relaxed, and potential activities that may be performed in advance.

PlanERS-1

The planERS-1 system was developed for ESTEC by a consortium primed by CRI together with Matra and AIAI, with the primary aim of assessing the applicability of knowledge-based and artificial intelligence techniques to planning and scheduling problems. The system was developed on SUN 3 workstations using CommonLisp and the Knowledge Engineering Environment (KEE). It has been used at ESTEC to evaluate the recorder and downlink strategy applied on the spacecraft.

Though conventional planning and scheduling systems have been used on a daily basis, they present various drawbacks. In general, these drawbacks appear because the scheduling domain is not static but evolves gradually; the cause may be the degradation of the spacecraft and its resources, changes to the satellite utilization, or increased demand for remote sensing data. One approach taken to handle these problems has been to manually pre-process the plan and over-constrain the input to the planning software. This, however, increases the risk of producing sub-optimal plans, and raises the question whether artificial intelligence technology can provide tools where the planning knowledge rather than the input data, is modified in order to reflect the changing environment of the satellite.

The planERS-1 system overcomes some of these problems by providing a flexible environment in which the modelling of the earth observation mission can be dynamically updated.

The planERS-1 System is a prototype system developed to assist payload planners of the ERS-1 satellite with constructing a Preferred Exploitation Plan (PEP) based on customer requests, background missions, and detailed modelling of the spacecraft.