A Scheduling and Diagnostic System for Scientific Satellite "GEOTAIL" Using Expert System

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KEY WORDS AND PHRASES

"Scheduling satellite operation, diagnosing satellite troubles, actual scientific satellite operation"

ABSTRACT

The Intelligent Satellite Control Software (ISACS) for the geomagnetic tail observation satellite named GEOTAIL (launched in July 1992) has been successfully developed. ISACS has made it possible by applying Artificial Intelligence(AI) technology including an expert system to autonomously generate a tracking schedule, which originally used to be conducted manually. Using ISACS, a satellite operator can generate a maximum four day period of stored command stream autonomously and can easily confirm its safety. The ISACS system has another function -- to diagnose satellite troubles and to suggest necessary remedies. The workload of satellite operators has drastically been reduced since ISACS has been introduced into the operations of GEOTAIL.

INTRODUCTION

ISAS (Institute of Space and Astronautical Science) is receiving telemetry data from satellites and spacecraft on a daily basis. In recent years, satellite size has increased significantly and the mission objectives have expanded rapidly resulting in much more complex satellite functions. Therefore, ground system operators are required to have increasingly complicated and high-level knowledge of the satellite system. Moreover, it is becoming more difficult to keep as many high-level operators in the steady state phase of spacecraft operations as in the initial operation phase.

We have developed an artificial intelligence application software system for satellite monitoring and controlling on the ground to reduce the operators' workload by simplifying satellite operation and increasing reliability in satellite maintenance. Called ISACS, which stands for Intelligent Satellite Control Software, this system has been applied to the GEOTAIL satellite launched in July 1992.

Many reports on the application of expert systems to satellite operation have been published. However, most of them are just ideas or prototype systems needing verification. ISACS is one of the few instances where expert systems have successfully been applied to actual scientific satellite operation.

ROLES OF ISACS IN GEOTAIL CONTROLLING

GEOTAIL is a joint project between Japan and the USA and aims at the study of the geomagnetic tail region of the magnetosphere. This satellite is the largest and most complicated one that ISAS has ever launched and with many onboard scientific instruments. GEOTAIL is tracked using a 64 mø parabolic antenna at Usuda Deep Space Center (UDSC) in Japan, and is remotely controlled from Sagamihara Spacecraft Operation Center (SSOC) at ISAS. Three NASA stations are also used to receive the recorded data.

In these circumstances, GEOTAIL operators are required to have a wider variety of expert knowledge to monitor and control the satellite than those of other satellites that ISAS has launched. Furthermore, GEOTAIL is tracked for eight hours every night in real time because its purpose is to observe the night side of the magnetosphere. However, resources for night-shift operations at ISAS are limited.

For these reasons, it has been requested that the satellite be safely controlled by a small number of operators by applying AI technologies.

ISACS has following functions:

(1) ISACS-PLANNER (ISACS-PLN)

ISACS receives the tracking schedule from abroad, observation requests from both home and abroad, and orbit and attitude data through an on-line data feed system, then it generates the operation schedule autonomously. ISACS checks the safety of this schedule, and converts it to command codes.

(2) ISACS-DOCTOR (ISACS-DOC)

ISACS reads the telemetry data sent from GEOTAIL and watches the status of the satellite in real time. If the operator finds the satellite in trouble, ISACS supports the operator in diagnosing the problem and taking the necessary actions.

Expert systems have been applied to the generation of the satellite operation plan and also to the satellite diagnostic system.

AIMS OF ISACS-PLN

We can define 'the scheduling of the satellite operation' as follows:

> *"To schedule satellite operation is*
> *to put 'the requirements' in order*
> *under 'the restrictions'."*

'The requirements' and 'the restrictions' are classified as follows:

Restrictions:
- Orbit and attitude of the satellite,
- Time and duration of eclipses in which the satellite is shadowed by the Earth or the Moon,
- Communication link margin between ground stations and the satellite,
- Power consumption and thermal condition,
- Tracking schedule for each ground station,
- Requirement for range and range rate(R&RR) measurement,
- Requirement for maneuver operations,
- Priority of operations,
- Operations inhibited for the safety of the satellite, and
- List of command codes corresponding to the operations.

Requirements:
- Power on/off of the instruments,
- Observation mode,
- Rewriting of Random Access Memory (RAM),
- Bit rate of telemetry data,
- Ground station antenna selection, and
- Tracking schedule for each ground station.

It is easy to update the application software when the operational condition or mode is changed if the restrictions are defined in the knowledge base as logic or parameters and the requirements from each scientist are input from independent data files.

Basically, the GEOTAIL satellite is controlled and operated by an Operation Program (OP) which consists of a stream of stored commands. The OP commands are autonomously executed during invisible time from UDSC. Once an OP is transmitted to the satellite from SSOC via the 64 mø antenna at UDSC, GEOTAIL is operated autonomously for three or four days. An OP sequence consists of 128 control elements called Organized Command (OG) to govern, for example, the record (REC)/replay (REP) cycles of the data recorders(DRs), the pointing of the high gain mechanical despun antenna to the ground tracking stations, and the control of the scientific instruments according to their observation plans.

It would be a heavy load for the operators at SSOC if they had to manually generate the OP because the restrictions and the requirements as shown above should be considered for scheduling the satellite operation. To overcome the difficulties of carrying out such complicated mission operations, and to safely and reliably generate the operation program, we have developed ISACS-PLN by applying AI technology.

OUTLINE OF ISACS-PLN

ISACS-PLN has been developed on a Sun Work Station using a scheduling expert tool. The function of this scheduling expert tool is to support a programmer in constructing a knowledge base using the Black Board (BB) model based on object-oriented programming. Figure 1 shows the system configuration.

This system has three major functions: initialization, inference engine, and command checking.

Following is their outline.

Initialization

To generate an OP for GEOTAIL, the ISACS-PLN needs the following data:
- Orbit and attitude data,
- Tracking schedule of DSN stations for receiving DR's playback data, which is provided by Jet Propulsion Laboratory (JPL),
- Tracking schedule of UDSC and SSOC, and
- Operation requests for onboard subsystems.

Though some of these data must be manually input at SSOC, most data come into the Work Station through the network and are input to ISACS-PLN. The operation requests for onboard subsystems are written in a simple computer language called ORL (Operation Request Language). Using ORL, the scientists both at home and abroad can give the operation requests freely without worrying about restrictions such as the difference in time, the place where they are, or the period of request time.

Inference engine

The inference engine part is developed using an expert tool. The knowledge base is described using the frame (~50), the data-class (~1500) and the BB's. The data-class is used for defining the inhibited operation mode and command code table. The BB's are used for both adjusting the events and converting the status data. Special events, difficult to describe using prepared functions of the expert tool, are described by CLOS.

The inference engine has three parts -- input processing, schedule processing, and output processing as follows:

<u>Input processing</u>. After setting time parameters such as start and end times for scheduling on a time control table, the instances concerning the following items are generated in the request lists.

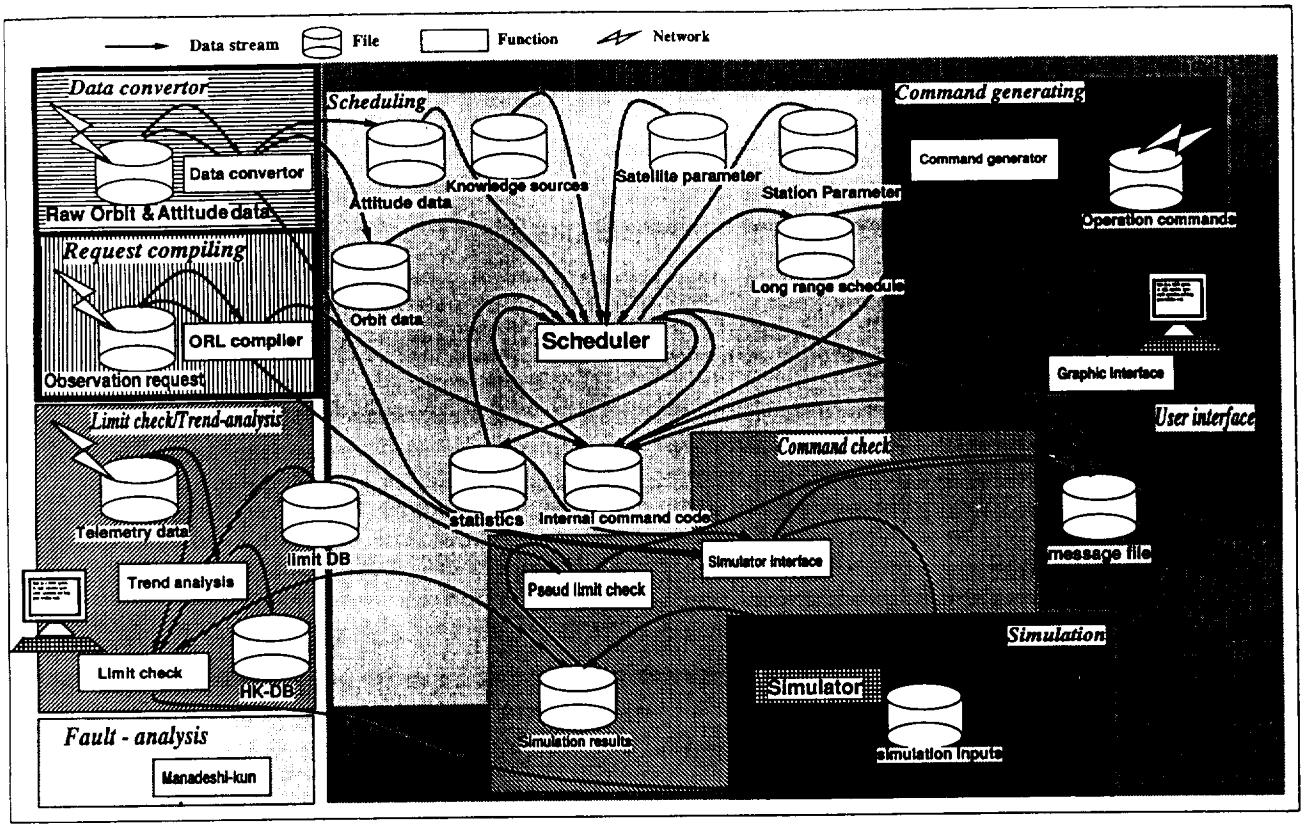

Figure 1 ISACS System Structure.

1) Input of the request file written in ORL.
The correspondent request items are cut out from the request file sent from each scientist according to the period of scheduling time.
2) Generation of the record cycle of the data recorders.
All the data obtained by scientific instruments onboard GEOTAIL is to be recorded by only one of two data recorders (DRs). In this function, the event-data for alternating the DR usage is generated by referring to the parameter data such as capacity of the DRs, overlap time for switching the DRs, and initial status of the DRs.
3) Generation of the tracking schedule of DSN stations.
The event data for receiving the DR's playback data or measuring R&RR data at the DSN stations is generated referring to the schedule data that have been planned at JPL based on the orbit data previously provided by ISAS and the initial status of GEOTAIL.
4) Generation of the standby sequence of UDSC station.
The command sequence required to be sent to the satellite at the beginning of every tracking pass is generated autonomously.
5) Generation of the control schedule of communication system.
The most suitable onboard antenna which provides enough link margin is selected from orbit information.
6) Generation of the switching cycle of the onboard heater system.
Power on or off schedule of the onboard heater system is generated.

Schedule processing. The schedule processing part has the following functions to adjust the requests.

1) The request list that has been generated in the input process is adjusted by considering the time control table data and priority of the command executions, and then the time series status list is generated.
2) In order to check the command sequence, the status list is searched for contradictions and prohibited command orders.
3) The request data that were canceled, due to conflict of time with other request data, are shifted within their permissible time span.
4) If ISACS-PLN cannot find a solution through adjusting request data, ISACS-PLN outputs an error message and entrusts the decision of which or what request should be selected to the satellite operator, since subjective criteria, such as importance of the observation or academic interest, can only be evaluated by scientists.

Output processing. A preliminary operation plan is thus generated in the inference part and then the list of command sequence is output.
Following is an example of how ISACS-PLN includes the preference of each scientists:
Figure 2-1 shows the time chart of the request data and figure 2-2 shows the result generated by ISACS-PLN autonomously. A, B, or C in both figures mean a subsystem onboard the satellite and each has an independent operation schedule. The numbers with parentheses indicate the priority of the observation previously defined in the knowledge

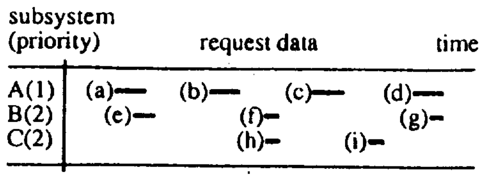

Figure 2-1 Input data to ISACS-PLN

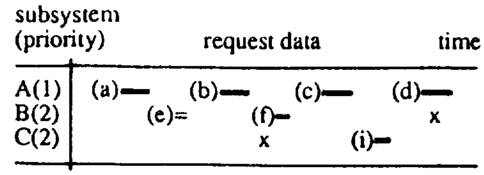

Figure 2-2 Output data from ISACS-PLN

base. The small letters in parentheses indicate the operation mode which has a series of commands, and the length of the line is proportionate to the time scale.

<Explanation of request data in figure 2-1>
Request from A: (a)(b)(c)(d) are operation requests of the Common Instruments (CIs) and their priority of execution is primary (=1).
Request from B: (e)(f)(g) are operation requests of the Physical Instruments (PIs) and their priority of execution is secondary (=2). The execution time of (e) has a scope, and the execution time of (g) is limited.
Request from C: (h)(i) are operation requests of the Physical Instruments (PIs) and their priority of execution is secondary (same as B).

ISACS-PLN generates the following results.

<Explanation of results in figure 2-2>
Output to A: All requests from A are accepted.
Output to B: The execution time of (e) is shifted back within its scope because a part of request (a) has a higher priority than (e) and conflicts with (e). Request (g) is canceled because (g) conflicts with (d) and the execution time of (g) is limited.
Output to C: Request (h) is canceled because the priority of (h) is same as (f) and (h) was put in to ISACS-PLN later than (f).

As mentioned above, ISACS-PLN does not fix the execution order among conflicting operation requests with the same priority because the rule of adjustment is affected by elements such as the importance of the observation or academic interest of scientists.

Command checking

The operation plan can be applied to the command checking function to simulate the temperatures, power consumption, and communication status of the satellite using mathematical modeling programs as follows:

1) Power analysis program.

The power consumption and remaining battery capacity are estimated from the power generated by solar cells and the load current predicted by the operation plan.

2) Thermal analysis program.

The temperature of each subsystem is predicted by the thermal analysis program.

3) Communication analysis program.

The antenna gain and span loss are evaluated from the satellite status estimated in the operation plan and orbit/attitude data. Then the receiving level, link margin, and C/N ratio are estimated.

OPERATION RESULTS

For the ISAS satellites launched before GEOTAIL, it took almost one day to manually generate an operation plan by adjusting the requirements of satellite operation using telephone or facsimile.

Now ISACS-PLN has shortened the processing time for operation plan generation to less than two hours. Moreover, ISACS-DOC can analyze the satellite status quickly using about 500 diagnosing rules defined in the knowledge base. About 80% of necessary information for diagnosis is fed on-line in real time. And, the scientists can send their observation requests in text file format through a network from home or abroad without concern for time limits. ISACS-DOC is very useful in protecting against overlooking satellite abnormality by checking the entire satellite's condition at least once every tracking pass.

CONCLUSION

From the viewpoint of AI technology, it is hard to say if the technique used in constructing the inference part of ISACS-PLN takes full advantage of AI technology, but this is not from a lack of skill in developing an expert system. We would like to emphasize that we have successfully merged, for the operation of a scientific satellite, 'the expert system' and 'the preference of scientists', so one is not emphasized over the other. This is a point much appreciated by both scientists and satellite operators.

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