N95- 23681

TIKON
An Intelligent Ground Operator Support System

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ABSTRACT

This paper presents first results of the project "Technologien für die intelligente Kontrolle von Raumfahrzeugen" (TIKON). The TIKON objective was the demonstration of feasibility and profit of the application of artificial intelligence in the space business. For that purpose a prototype system has been developed and implemented for the operation support of the Roentgen Satellite (ROSAT), a scientific spacecraft designed to perform the first all-sky survey with a high-resolution X-ray telescope and to investigate the emission of specific celestial sources. The prototype integrates a scheduler and a diagnosis tool both based on artificial intelligence techniques. The user interface is menu driven and provides synoptic displays for the visualization of the system status. The prototype is used and tested in parallel to an already existing operational system.

KEYWORDS AND PHRASES

Diagnosis, ground operations, scheduling, synoptic displays.

INTRODUCTION

The TIKON project is sponsored by the German Space Agency (DARA) and performed by DASA/ERNO with support of the German Space Operation Center (GSOC). It will be finished in December 1994. As shown in Figure 1 the TIKON system consists of three main parts: The synoptic display manager, the scheduler and the diagnosis tool.

The goal of the project is the development of a ground operator assistant system for the ROSAT satellite ground activities. Those activities consist of :

- the scheduling of a half year observation plan for X-ray stars which is constrained by user requirements, orbital aspects and contract requirements
- the scheduling of a weekly observation plan considering additional short term wishes of the users and actual orbital data
- the monitoring of ROSAT housekeeping telemetry-data for the attitude measurement and control system (AMCS) and the data handling system (DHS). This includes the detection and isolation of anomalies and failures.

The above mentioned activities are actually performed using classical operational methods which offer not very much clearness and graphical support for the operator.

TIKON provides a user friendly and convenient tool on a SUN workstation which visualizes the incoming telemetry-data on a synoptic display. The synoptic display shows the ROSAT system in different component levels and depicts finally the selected subsystem's data in a graphical form on meters and charts. In addition to that

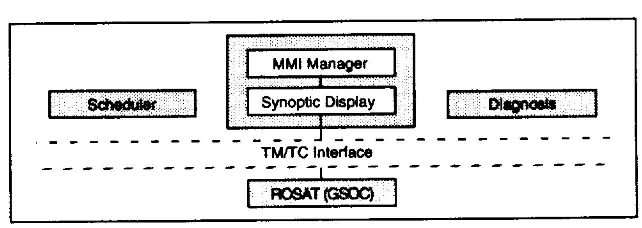

Figure 1. Main Components

limit violations are indicated by color changes. For the failure detection and analysis a so-called diagnoser is installed which evaluates the probability of component failures out of a combination of telemetry-data.

USER INTERFACE

The applied synoptic display is an intelligent user interface that processes ROSAT telemetry data in a graphical and user friendly way and that reacts on events by displaying the subsystem's data in question. Those events may be a limit violation or user requests. Figure 2 depicts in a simplified manner the main display of the tool representing the ROSAT subsystems at one glance.

DIAGNOSIS

An important objective of the TIKON project is the evaluation of advanced Fault Detection, Isolation and Recovery (FDIR) methods in order to identify the potentials of improved operator support in case of spacecraft malfunctions.

Application

In the frame of the TIKON project, the ROSAT AMCS has been selected as a sample application for knowledge based FDIR. Twenty knowledge bases related to ROSAT AMCS components have been defined which are used to evaluate the ROSAT Telemetry (TM) data in order to find malfunctions of these components. The FDIR system is executed as a separate process that analyses pre-processed TM data, displays diagnostic results in specific windows and also sends the diagnostic results to a synoptic display utility in order to visualize them. Whereas the synoptic display offers an easy to comprehend schematic view of the AMCS components, the FDIR windows provide more detailed information that is closer related to the diagnostic processing.

Method

The TIKON FDIR component is based on the Connection Matrix Based Expert System Tool (CONNEX) technology, which in the frame of

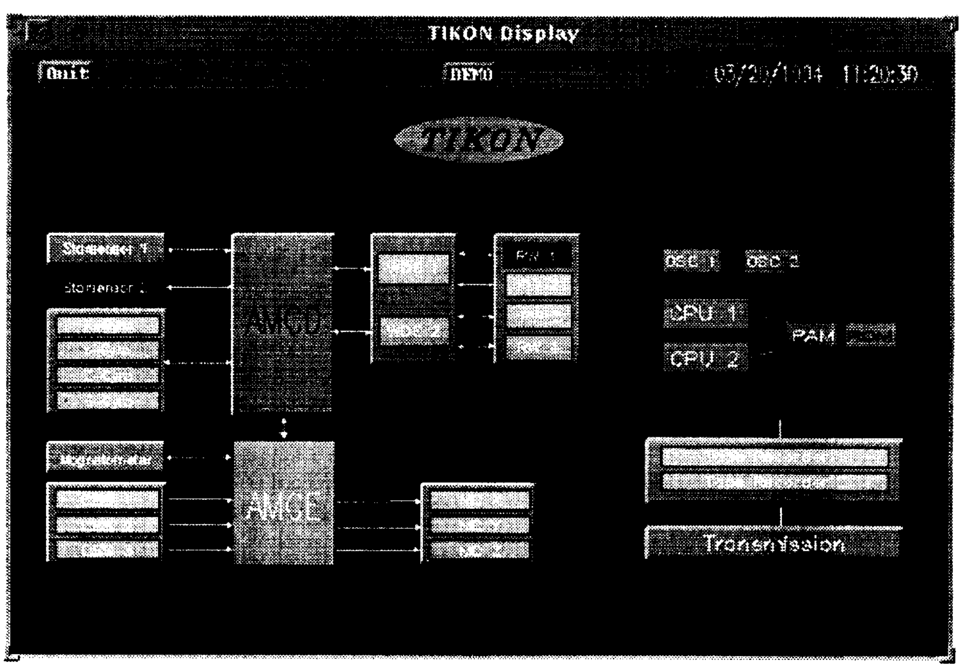

Figure 2. TIKON Synoptic Display (Main Level)

the Computer Based Payload Operation Support System (COMPASS) project has already been applied to a payload during the German D2 Spacelab mission. For the TIKON project, template knowledge bases have been added as a new feature in order to facilitate knowledge acquisition and maintenance in the presence of multiple instances of structurally similar technical systems. For example, ROSAT contains four Gyros of similar structure with similar related telemetry data. Instead of defining four distinct knowledge bases only one template knowledge base needs to be defined which is then used to instantiate four concrete knowledge bases.

Connection Matrices can be seen as extended decision tables, allowing for fault diagnosis based on approximate matches between observed exception patterns and expected exception patterns for predefined faults. Key advantages of this approach are:

- increased robustness against local deviations between expected and observed system behavior
- better ability to cope with evolving anomalies and improved early warning capability
- increased robustness against sensor failures
- improved ability to handle multiple faults

Basically, diagnosing a system for a given exception vector is performed as follows: First, the diagnoses are grouped into so called discrimination sets. Each discrimination set consists of diagnoses which are related to the same set of observed exceptions. Only those discrimination classes which are related to a set of exceptions that is not a true subset of the set of observed exceptions related to another discrimination class are considered for further processing. At least one member of each of these discrimination classes must be a valid diagnosis, since it accounts for at least one otherwise unexplained exception. The members of a particular discrimination class on the other hand are competitors, since they account for the same subset of exceptions. The selection among the members of a discrimination class is performed by computing the proximity ratio between the cardinality of the intersection between observed exceptions and the exceptions expected for the particular fault and the cardinality of the set of exceptions expected for this particular fault. Figure 3 illustrates an example of the diagnostic processing.

	A1	A2	A3	A4
E1		*		*
=> E2	*	*		
=> E3	*	*	*	
E4	*			*
=> E5			*	*
E6	*			*

Figure 3. Example of a Connection Matrix

In Figure 3 the inputs E1 to E6 denote exceptions, A1 to A4 anomalies (i.e. faults). An asterisk indicates that the anomaly in the top most row and the exception in the left most column are related, i.e. that this anomaly will cause this exception. Provided that the exceptions E2, E3 and E5 are observed, the reasoning goes as follows:

There are three discrimination classes:

C1 = {A1, A2} which accounts for E2 and E3

C2 = {A3} which accounts for E3 and E5

C3 = {A4} which accounts for E5

The elements of C3 are discarded, since the set of exceptions they account for is a true subset of those the elements of C2 account for.

A3 is selected, since it is the only anomaly that accounts for E3 and E5 simultaneously.

A2 is preferred over A1, since it has the higher proximity ratio (2/3 vs. 1/2).

A3 and A2 remain as final diagnoses, with A1 being a possible alternative to A2.

SCHEDULING

The TIKON scheduling tool is based on the Mission Activities and Resources Scheduler (MARS), a general purpose scheduling tool developed by DASA/ERNO for scheduling of space missions. A new MARS feature required in the scope of the TIKON study is an optimization scheduling strategy, which depends on user defined optimization criteria for a Schedule. MARS intends to find not only a Schedule fulfilling all hard constraints but also tries to optimize the Schedule by pre-selecting Activities according the optimization criteria before applying of the Rule system.

Objectives

The scheduling of ROSAT concentrates only on the pointing phase. During this phase typically 1800 requests for observations of different sources must be handled by the system to schedule a period of 6 months. These need to be scheduled as efficiently as possible to avoid wasting of valuable observation time.

The observations are basically constrained by:

- must be scheduled within a slot between particle belts (hard celestrial constraint)
- their visibility (hard celestrial constraint)
- observation instrument (hard operational constraint)
- time share between observations of different countries (soft operational constraint)
- Observations must be separated by a slew operation (hard operational constraint)

Thereby, two principal goals shall be achieved:

- Generation of a timeline, fulfilling for all scheduled observation requests the constraints
- This timeline shall maximize the observation time in comparison to the principal available slot duration during the pointing phase

Approach

For TIKON the following functionalities had to be added to the MARS system:

- Optimizing scheduling process
- Possible interruption of Activities

These functionalities have been added without changing the principal way of the MARS scheduling method. The advantage is that future not yet known constraints might well be handled by the generic MARS data description possibilities and scheduling functionality.

The following approach for the representation of the ROSAT scheduling problem was used:

- All observable sources are represented by MARS Resources,which have as discrete Availability Profiles the time spans where the source is visible (i.e. could be observed) or not. These Resources have the type reusable since they are handled like targets, which however can only be observed one at a time.
- An observation request for a source is represented by a MARS Activity, which basically has as Resource Request the specific Resource representing the source to be pointed at.
- The scheduling process shall schedule Activities under the following conditions:
    - All hard constraints must be fulfilled
    - Activities must not be scheduled parallel, they can be interrupted
    - The soft constraints (e.g. country share) are met as far as possible
    - The generated timeline shall approximate the optimization criteria as far as possible

For an example of a ROSAT scheduling situation see Figure 4 (next page).

Scheduling and Optimization Approach

The general MARS Scheduling can be seen as a heuristic search process, but with a certain restriction of the search space. This can inhibit to find the best solution, but allows to handle praxis relevant and therefore very complex problems.

Aim of an optimization is to find a Goal Schedule s_g which is optimal with respect to some goal function v:

$$v(s_g) = \text{Optimal !}$$

The goal function v for a TIKON Schedule is defined as the percentage of the unused observation time measured against the available observation time. Then the best Schedule would use all available observation time.

The general idea of an optimizing strategy in MARS is now the following:

Use function v as an estimation of the heuristic function which guides the search process so that the optimal search path corresponds to the optimal solution in the sense of the function v. Even if not the complete search space can be used, it is hoped that MARS will find a sub-optimal solution.

The scheduling algorithm was extended by a pre-selection module which provides the set of Activities fulfilling all hard constraints and which would optimize the so far generated Schedule with respect to v. To provide enough Activities for further processing also a certain percentage of sub-optimal candidates is taken into account. Thereafter the Rule system is applied to achieve the soft constraints.

CONCLUSION

Although the test phase has just been started and will continue until end of this year some first results are:

- improvement for operators through the hierarchical user interface which allows a quick orientation
- this interface enables also a reduction of required training periods for newcomers
- the integration of data acquisition and diagnosis as well as the presentation of diagnostic results at various levels of detail reduces the operator workload and leads to an accelerated failure diagnosis cycle
- The graphical plot facilities of the Schedule represent a new quality of user information, e.g. about possible alternatives
- The new scheduling approach achieves in first tests a utilization of 88 percent of the possible observation time while fulfilling the soft constraint with a deviation of less than 5 percent.

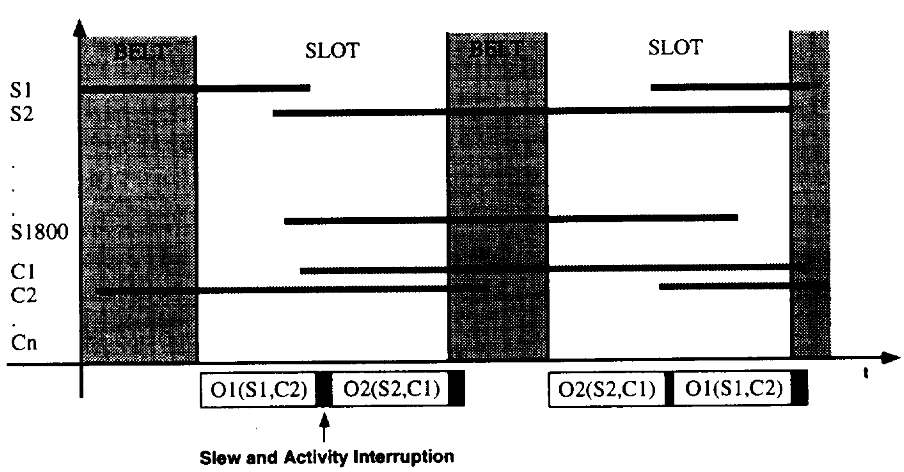

Figure 4. ROSAT Scheduling