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USING GRAPHICS AND EXPERT SYSTEM TECHNOLOGIES TO SUPPORT SATELLITE MONITORING AT THE NASA GODDARD SPACE FLIGHT CENTER

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ABSTRACT

At NASA's Goddard Space Flight Center, fault-isolation expert systems have been developed to support data monitoring and fault detection tasks in satellite control centers. Based on the lessons learned during these efforts in expert system automation, a new domain-specific expert system development tool named the Generic Spacecraft Analyst Assistant (GenSAA), was developed to facilitate the rapid development and reuse of real-time expert systems to serve as fault-isolation assistants for spacecraft analysts. This paper describes GenSAA's capabilities and how it is supporting monitoring functions of current and future NASA missions for a variety of satellite monitoring applications ranging from subsystem health and safety to spacecraft attitude. Finally, this paper addresses efforts to generalize GenSAA's data interface for more widespread usage throughout the space and commercial industry.

INTRODUCTION

A group of spacecraft analysts are responsible for the proper command, control, health and safety of each spacecraft managed by NASA's Goddard Space Flight Center (GSFC). During numerous contacts with the satellite each day, these analysts closely monitor real time data searching for combinations of telemetry parameter values, limit violations, and other indications that may signify problems or failures. This is a demanding, tedious task that requires well-trained individuals who are quick-thinking and composed under pressure. However, as our satellites become more complex, this task is becoming increasingly more difficult for humans to conduct at acceptable levels of performance [Ref. 2].

At GSFC, fault-isolation expert systems have been developed to support data monitoring and fault detection tasks in satellite control centers. Based on the lessons learned during these efforts in expert system automation, a new domain-specific expert system development tool named the Generic Spacecraft Analyst Assistant (GenSAA), was developed to facilitate the rapid development and reuse of real-time expert systems to serve as fault-isolation assistants for spacecraft analysts. Although initially developed to support GSFC's satellite operations, this powerful tool can support the development of highly graphical expert systems for data monitoring purposes throughout the space and commercial industry.

This paper describes GenSAA's capabilities and how it is supporting monitoring functions of current and future NASA missions for a variety of satellite monitoring applications ranging from subsystem health and safety to spacecraft attitude. Finally, this paper will address efforts to generalize GenSAA's data interface for more widespread usage throughout the space and commercial industry.

GenSAA OVERVIEW

GenSAA is an advanced software tool that allows the rapid development of intelligent graphical monitoring systems. Through the use of a highly graphical user interface and point-and-click operation, GenSAA facilitates the rapid, "programming-free" construction of graphical expert systems to serve as real-time fault-isolation assistants for spacecraft analysts.

GenSAA expert systems are easily built and maintained using an integrated set of utilities called the GenSAA Workbench which are used to define the expert system's telemetry data interface, rule base, and X/Motif-based user interface. GenSAA insulates the expert system developer from the complicated programming details of the systems with which the expert system will interface. This tool promotes the use of previously developed rule bases and graphic objects, thus facilitating software and knowledge reuse and a further reduction in development time and effort.

The development of GenSAA was motivated by the lessons learned from a research effort to evaluate the value and effectiveness of using graphical rule-based expert systems for fault detection purposes. The project, which was named the Communications Link Expert Assistance Resource (CLEAR), was quite successful. Although CLEAR was initially conceived to serve as a proof-of-concept prototype, it was ultimately used to support real-time operations for NASA's Cosmic Background Explorer (COBE) satellite where it was instrumental in demonstrating the advantages that expert systems offer mission operations. More importantly, CLEAR provided insights into how expert systems could be developed more quickly and with less effort. GenSAA addresses this issue by insulating the expert system developer from the programming details by employing a "drag and drop" method of developing these systems.

In addition to meeting the previous objective, GenSAA was created as an alternative to high-end, complex and expensive commercially available expert system development environments. In an attempt to meet a wide variety of application needs, these general-purpose programming tools are often too complex to be effectively used by domain experts (spacecraft analysts in this case) to create graphical expert systems. They typically require weeks of training and specialized programmers to implement the data interface, graphical user interface, or rule base for each expert system. GenSAA empowers the spacecraft analysts to easily select the data to be monitored, layout and define the behavior of the expert system's user interface and build rules for fault detection purposes without the intervention or delay of programmers.

GenSAA consists of two major components: a Workbench and a Runtime Framework. [see figure 1]. The Workbench is used to specify expert systems in an offline mode (i.e., not connected to a live data source). The Workbench creates several resource data files that are read into the Runtime Framework which uses these resource files and connects to the data source.

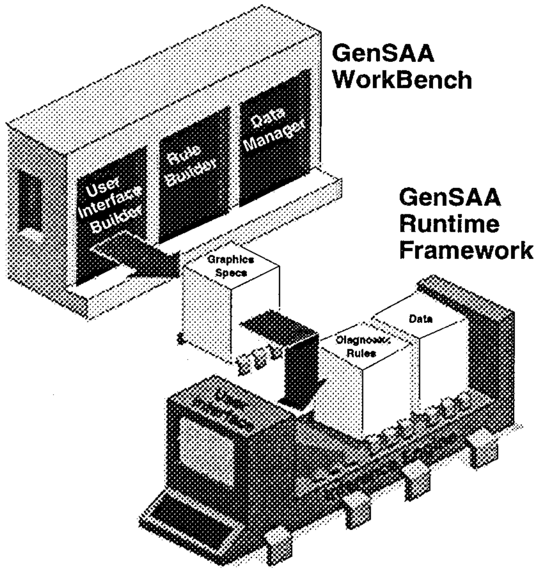


Figure-1: GenSAA Architecture

The GenSAA Workbench consists of a Data Manager, a Rule Builder, and a User Interface Builder. The Data Manager is used to select the telemetry data that is desired for use by the expert system; the Rule Builder is used to create expert systems rules based on the telemetry data; and the User Interface Builder allows the user to create graphical user interfaces to display the telemetry data and the data inferred from the expert system rules. The GenSAA Workbench is tightly integrated and easy to use, employing direct manipulation techniques such as "drag and drop." The Workbench also provides mechanisms to automatically generate expert system rule statement syntax.

The GenSAA Runtime Framework is the executive for a GenSAA Expert System. It controls the user interface, distributes the real-time data received from the data server, and manages rule execution. The core element of the Runtime Framework is the 'C' Language Integrated Production System (CLIPS). CLIPS is an inference engine and rule-based programming language that was developed at the NASA Johnson Space Center. It is widely used throughout NASA, other government agencies, academe, and the commercial sector.

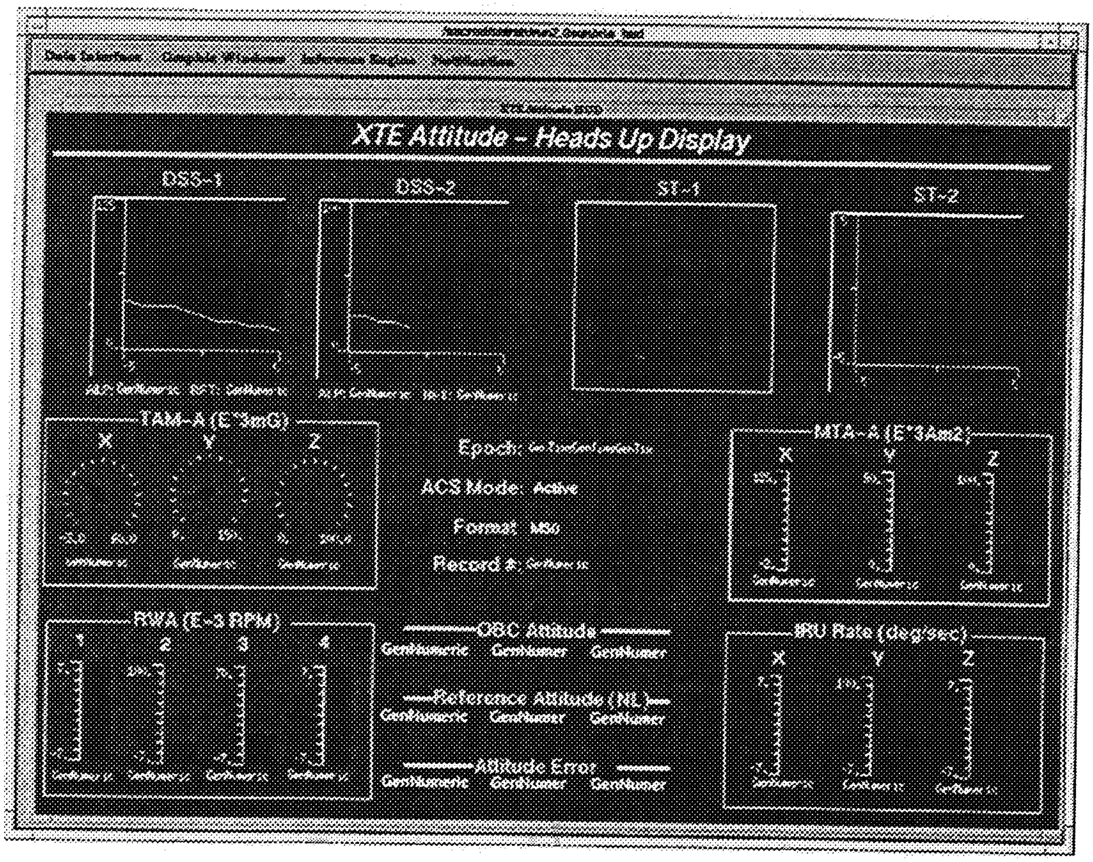
Expert systems that are created using GenSAA require no source code development, and therefore facilitate very rapid development life cycles. Changes and enhancements to existing expert systems can also be made rapidly at very low cost.

GenSAA runs on Sun and Hewlett-Packard UNIX workstations using X-windows with Motif. Earlier this year GenSAA was delivered to operations for acceptance testing. At the time of publication, it is expected that GenSAA will be in operations in a number of divisions at GSFC and at a few external sites.

The next sections describe several specific applications of GenSAA at GSFC. The first group of applications is associated with spacecraft attitude monitoring. The second group is associated with the monitoring of spacecraft and their payloads. The applications are currently under development and should become operational soon.

GenSAA APPLICATIONS SUPPORTING FLIGHT DYNAMICS

GSFC's Flight Dynamics Division (FDD) is responsible for maintaining the orbit and attitude of many Goddard spacecraft. The FDD has used Heads Up Displays (HUDs) for previous missions to graphically portray attitude



ACS Mode: Active

Figure-2: XTE HUD Created Using GenSAA

and orbit parameters in a manner that is similar to the gauges and dials that appear in an airplane cockpit. These HUDs enable flight analysts to quickly view the basic orbit, attitude, and sensor status of a given spacecraft.

The FDD is using GenSAA to create the HUDs for the X-ray Timing Explorer (XTE) spacecraft, the Submillimeter Wave Astronomy Satellite (SWAS) spacecraft, and the Solar and Heliospheric Observatory (SOHO) spacecraft. These missions are among the first FDD missions to be supported on UNIX workstations using X-windows. By using GenSAA, the FDD expects to reduce the effort needed to create the HUD while increasing the ability to respond to change requests.

The XTE and SWAS HUDs are using GenSAA's inference engine to infer engineering unit values based on raw telemetry values. The inferred engineering unit values are displayed on the HUD via graphical and textual user interface objects. Values that are displayed include: magnetometer, gyroscope, and torquer bar biases and rates, guide star and sun sensor positions, and predicted versus actual attitude. Figure-2 is an example of a prototype HUD generated with GenSAA for the XTE mission.

The FDD is also using GenSAA to support the SOHO mission. The HUD for SOHO is similar to the XTE and SWAS HUDs, however, SOHO is enhancing the GenSAA Runtime Framework by embedding a number of 'C' functions to compute the spacecraft real-time attitude based on the current telemetry data received from the data server. Although the SOHO HUD development team had the option to link these functions with the inference engine for invocation via expert system rules, this group chose to embed the functions to optimize performance of these computationally intensive attitude algorithms. This situation demonstrates one advantage of having direct access to the source code of GenSAA.

GenSAA APPLICATIONS SUPPORTING MISSION OPERATIONS

In GSFC's Mission Operations Division (MOD), GenSAA is being used to support real time satellite monitoring in the control centers. GenSAA will be used to build simple advisory expert systems that monitor spacecraft telemetry and ground system parameters. Monitoring these parameters during spacecraft contacts has traditionally been the responsibility of satellite operators.

Two of the primary objectives of this organization's applications are to expedite the fault detection and resolution process and to reduce the amount of data (telemetry points) that human operators must monitor in order to assess the current health and status of the spacecraft and the scientific instruments onboard. With GenSAA, spacecraft engineers will develop simple expert systems that will assist console analysts by reducing the number of data points they must monitor from hundreds of sensor values to dozens of derived system level status points.

GenSAA does not constrain the user in how to represent the system being monitored. Some groups are planning to model the functional operations of the system (i.e., functions across subsystems) while others are planning to develop physical models of the system being monitored. For example, the Solar Anomalous and Magnetospheric Particle Explorer (SAMPEX) project plans to develop a series of GenSAA expert systems to monitor the scientific instruments (LEICA [See Figure 3], MAST/PET and HILT) and some of the spacecraft's subsystems including the Small Explorer Data System (SEDS), the attitude control system (ACS), and thermal system.

In contrast, members of the Gamma Ray Observatory (GRO) Flight Operations Team plan to develop discrete expert systems for both functional and physical perspectives. This team plans to develop expert systems to monitor the power subsystem, communications function and a high level health and safety monitoring system. In addition to the above mentioned missions, GenSAA will support satellite operators for Transportable Payload Operations Control Center (TPOCC) based missions including, but not limited to, Wind/Polar, SWAS, XTE, SOHO, Tropical Rainfall Measuring Mission (TRMM) and the Advanced Composition Explorer (ACE) missions.

GenSAA is expected to provide numerous benefits to the mission operations arena at GSFC. In addition to assisting the satellite operators with the data monitoring task, GenSAA will reduce the development time and effort of the these systems; serve as a training tool for student controllers; and protect against the loss of satellite operations expertise, especially during periods of personnel turnover. This last benefit even spans beyond a single mission; control center expert systems that capture fault-isolation knowledge preserve expertise from mission to mission which may prove to be beneficial as we embark on multi-mission flight operations teams (i.e., a single set of operators responsible for operating multiple satellites) as a means to reduce satellite operations costs.

GENERALIZING GenSAA FOR BROADER USE

A variety of groups outside of GSFC's Flight Dynamics and Mission Operations Divisions have expressed an interest in using GenSAA to monitor their real time data. However, application to other domains has been limited because GenSAA is currently designed to interface to GSFC-specific ground system formats. To broaden GenSAA's potential application, work was begun earlier this year to generalize its data interface to enable it to receive data in other formats.

The approach adopted is to create bridge processes that interface GenSAA to external data sources. A bridge receives data from an external source and converts it to a format that GenSAA understands. A bridge template is being developed that will be used to simplify the construction of bridges for specific interfaces. To facilitate reuse and to accelerate the application of GenSAA to new domains, the GenSAA Project will maintain a library of bridges to databases and other data sources.

To build a new bridge, the installer creates a file containing a description of the variable names and data types to be received from the external interface. This file is used to automatically generate a large portion of the bridge software. The installer must also write a small amount of program code that will request and receive the data. Finally, these software components are

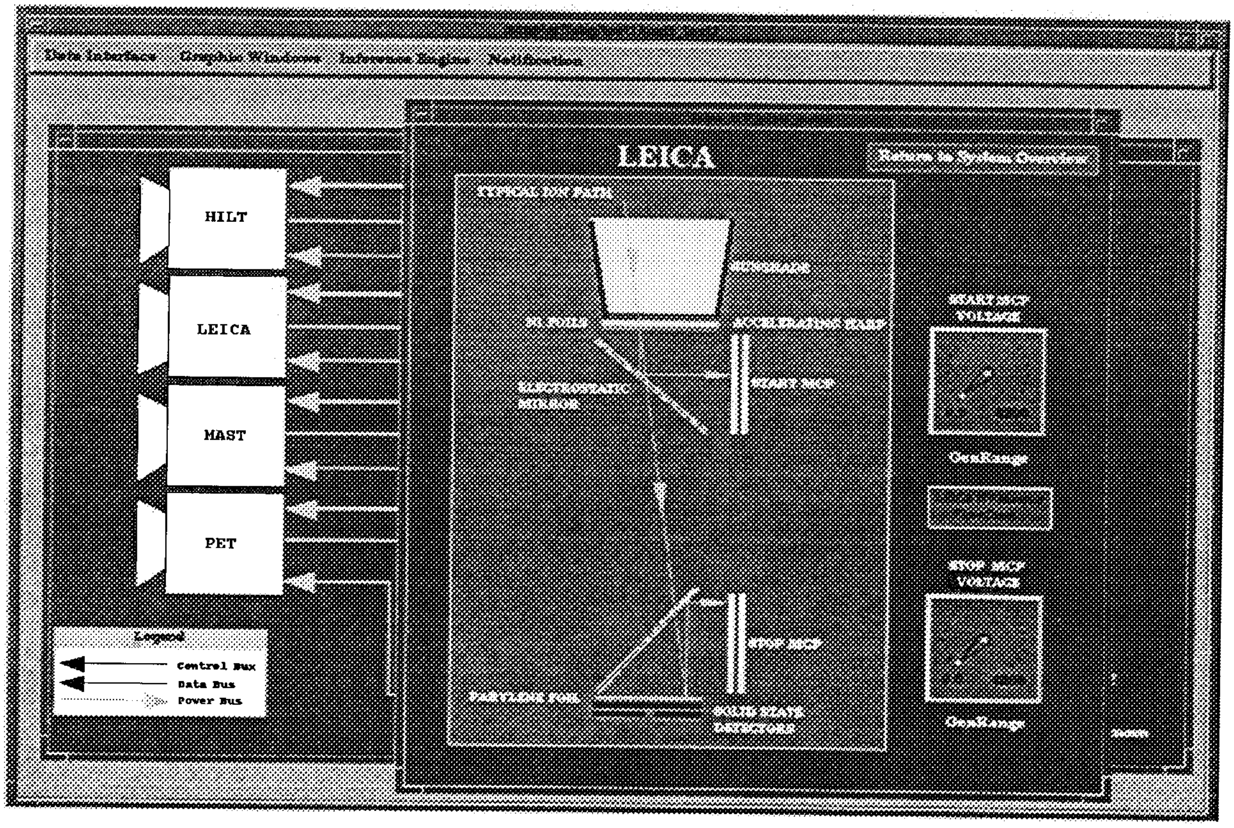


Figure-3: Leica Status Monitor Created Using GenSAA linked together to form a bridge which provides data conversion capabilities enabling the use of GenSAA in new domains.

AUTOMATING SATELLITE OPERATIONS WITH GenSAA

During the past year, a new research project was started to develop a proof-of-concept prototype that demonstrates how expert system technology can be used to automate routine, nominal-situation control center operations that involve both monitoring and commanding actions. [Ref. 6]

The project is enhancing GenSAA to enable the automation of nominal pass operations for the SAMPEX spacecraft. The enhanced software, called the Generic Inferential Executor (Genie), will perform monitoring and commanding operations in the SAMPEX Payload Operations Control Center (POCC) as specified in a pass script that is defined by members of the Flight Operations Team (FOT). The pass script defines precondition tests, actions, results checks, decision branches, and background monitoring activities. In nominal situations, Genie will execute the pass script without the intervention of FOT members; if an unexpected situation arises, an FOT member will be alerted. Automated operations include verifying the pre-pass readiness test data flow, examining spacecraft event log messages, starting configuration monitors, evaluating system events, initiating the uplink of the daily command load, and initiating dumps from the spacecraft.

The automation prototype will be demonstrated during a live SAMPEX pass. It is anticipated that the results gathered on this project will influence the development of enhanced ground system software that will automate operations in future GSFC missions, including the Earth Observing System (EOS) project.

CONCLUSION

GenSAA is being used to develop several expert systems that will support current and upcoming spacecraft missions. GenSAA is making it easier for spacecraft analysts to build expert systems, and to thereby preserve and apply their spacecraft knowledge in automated monitoring systems.

Reduction of spacecraft mission cost is a high priority at GSFC. GenSAA is providing a means of reducing the cost of developing mission support software while increasing operations automation using expert system technology. GenSAA is well suited to support monitoring, fault detection, and fault isolation for spacecraft missions. GenSAA is now being generalized to support other application domains, and is being enhanced to support both monitoring and commanding operations.

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