A KNOWLEDGE-BASED SYSTEM FOR MONITORING THE ELECTRICAL POWER SYSTEM OF THE HUBBLE SPACE TELESCOPE

BY

PAT EDDY

LOCKHEED ARTIFICIAL INTELLIGENCE CENTER
2710 SAND HILL ROAD, MENLO PARK, CA. 94025

ABSTRACT

Lockheed is currently in the process of developing expert systems that perform on-line monitoring, statusing and trend analysis of major Hubble Space Telescope (HST) systems. The three major systems under development are the Pointing Control System (PCS) [KLSRD87], the Data Management System (DMS) and the Electrical Power System (EPS). These expert systems are part of the TALOS [CW87] system for assisting in HST ground operations which is being developed at Goddard Space Flight Center. This paper will treat the EPS expert system (a part of the TALOS distributed architecture).

This paper will describe the design and the prototype for this system as demonstrated on 9/23/87 at the LMSC Artificial Intelligence Center, Menlo Park, California. This prototype demonstrated the capability to use real time data from a 32k telemetry stream and perform operational health and safety status monitoring, detect trends such as battery degradation and detect anomalies such as solar array failures. This prototype along with the PCS and DMS prototype expert systems form the initial TALOS capability.

INTRODUCTION

Lockheed Missiles and Space Company (LMSC) is the prime contractor for the Support Systems Module (SSM) and Integration Systems Engineer for the Edwin P Hubble Space Telescope (HST). Additionally, LMSC is the HST Mission Operations Contractor, responsible for the ground operations that ensure the health and safety of the HST.

The HST is a complex, state-of-the-art satellite with unique ground operations requirements. Accordingly the ability to reliably monitor telemetry in real-time is highly desirable. To this end the Telemetry Analysis Logic for Operating Spacecraft (TALOS) system is being developed.

The Talos system consists of real-time and off-line deep analysis knowledge-based modules. This paper will concentrate on the real-time monitoring and analysis EPS monitoring system. The basis for this system is L*STAR, a Lockheed proprietary tool. This shell [SRLK87] consists of a multiprocessing architecture for performing real-time monitoring and analysis using knowledge-based problem solving techniques.

In order to handle asynchronous inputs and perform in real-time, the system consists of three separate processes which run concurrently and communicate via a message passing scheme. The Data Management Process gathers, compresses, and scales the incoming telemetry data before sending it to the other tasks. The Inferencing Process consists of a proprietary high performance inference engine, written in the C programming language, which can run at a rate of close to 1000 rules per second. It uses compressed telemetry data to perform a real-time analysis on the state and health of the Space Telescope. The I/O Process receives telemetry monitors from the Data Management Process and status/health messages from the Inference Process, updates its graphical displays in real-time, and acts as the interface to the console operator. The I/O Process resides on DEC VAXStation II/GPX high resolution color graphics workstation. It consists of a hierarchy of displays which the user may traverse using a mouse. The three tasks run concurrently and may reside on the same or different processors. Furthermore, the multitasking architecture has been designed in such a way that multiple inference processes, multiple data management processes, and multiple I/O processes can run concurrently and communicate with each other. It processes several hundred telemetry monitors per second.

The population of L*STAR with HST EPS knowledge has produced a very fast and reliable operator assistant to be described in this paper.

EPS REAL-TIME TELEMETRY MONITOR

The TALOS EPS real-time telemetry monitor will provide operators with the following real-time telemetry capability:

- HST Mode/Configuration Monitoring.
- Real-time EPS Statusing.
- Command Verification.
- Multi Orbit Health History Tracking.
- Ability to Handle Unexpected Telemetry Loss.
- Correlation of Temperature, Power Error Histories.
- Real-time warning of approaching intelligent thresholds.
- Real-time comparison of an EPS model generated power profile with telemetry based EPS status.
- Projection of telemetry based EPS status in accordance with load and time parameters defined by a model generated power profile.
- Suggested load changes to prevent exceeding limits.

One of the key elements required for this system to be able to reason about the health and safety of the HST is knowledge about the present and projected future operational mode of the HST. Accordingly, this system establishes the following contexts for the reasoning process:

- Battery Reconditioning
- Off Normal Roll
- Stationary HST
- Maneuvering HST
- Orbit Day
- Eclipse
- Hardware/Software Sunpoint
- Solar Array Repositioning
- Seasons Of The Year
- Orbital Decay

This system provides the operator with a top level functional diagram of the end to end power flow of the EPS starting with the Solar Arrays and ending with the Power Distribution Units. Lower level displays show more detailed diagrams of EPS components until all telemetry values are accounted for. The EPS statusing capability consists of the following:

- EPS Configuration
- SA power output
- Status of K relays
- Structure Current
- Battery voltage/temperature
- Battery Recharge Ratio
- Diode Bus Current/Voltage
- Sun to Orbit Ratio
- Power Distribution Unit Current
- Battery Shunt CKT Status
- Solar Panel Assembly Connect/Disconnect
- Distribution Bus On/Off
- Heater Status
- Voltage VS Temperature Change Current Controller Activation Curves

The following capabilities will provide an EPS real-time telemetry monitoring assistant that uses temporal reasoning and communicates with other expert systems:

- Command verification will allow the automatic indication of command group execution on a display of the mission timeline. In addition, the EPS expert system will receive indication of a command reject from the DMS real-time monitor and such information as maneuver status from the PCS monitor.

- Multi-orbit health, history tracking will display and compare a 15 orbit history set of events such as the following:

  - Trickle Charge Time
  - Maximum battery Voltage at Eclipse
  - Minimum Battery Voltage at Eclipse

o Management of unexpected telemetry loss is necessary to support multi-orbit event tracking above. It will be accomplished by designating a beginning/end of orbit event that occurs at a predictable time such as K-relay closure. If the required data has not been collected by the end of orbit then that orbit will be shown as missing data and the data collection process will be reinitialized for the beginning of the next orbit.

o Correlation of temperature, power and error histories will allow the operator to compare any multi-orbit health histories for the purpose of identifying failure trends.

o Intelligent threshold warnings consits of monitoring real-time EPS telemetry to provide operator warnings of approaching anomalies as a result of reasoning about the current operational mode on future loads.

o EPS status and power profile comparison compare an EPS model generated power profile with the actual EPS to show a projected status based on the load as defined by the EPS model. The operator may project the power status to a number of orbits or hours in the future.

o Projection of load and time changes will allow the system to obtain the results of proposed load and time changes by extrapolating the telemetry based EPS status into the future. In addition, the expert system will have access to the projected electrical activity as defined by the power profile and will be able to warn the operator of HST components or science instruments that are scheduled to come on and approach load limits.

o Suggested load changes will give the operator access to the projected loads created by HST components in their operational configurations. When the power profile deviates from the current EPS status the system will be able to access a load shedding component list and make recommendations to the operator.

ACKNOWLEDGEMENT

This work was done under the sponsorship of Tom Laffey of the Lockheed Artificial Intelligence Center.

CONCLUSIONS

The work accomplished to date provides the operator with an intelligent assistant that reasons about current system status such as the following:

- Battery Voltage
- Charge Current
- Bus Voltages and Current
- Component Temperatures
- Solar Array Output

It then advises the operator whether the above parameters are normal in accordance within the following contexts:

- HST maneuvering
- HST Stationary
- Solar Arrays repositioning
- Orbit Day
- Eclipse

Thus, this system advises the operator that a given current is normal, not just within limits, while taking into account maneuvering status and time of day. Future work will add safemode, seasons, and orbital decay to this reasoning process.

The above information is presented in meaningfull displays showing the end to end energy production and usage along with lower level detailed displays. Warnings and adviseries are provided. This work is on-going and future work includes completing the requirements listed in this paper.

REFERENCES

[CW87] B. Cruse and E. Wende. Expert system support for HST operations. In Proceedings of the 1987 Goddard Conference on Space Applications of Artificial Intelligence and Robotics, NASA Goddard Space Flight Center, May 1987.

[KLSRD87) S. Kao, T. Laffey, J. Schmidt, J. Read, L. Dunham. Monitoring the PCS of the Hubble Space Telescope. Third Conference On Artificial Intelligence for Space Applications, George C. Marshall Space Flight Center, November 1987.

[SRLK87) J. Schmidt, J. Read, T. Laffey, S. Kao. A Multiprocessing architecture for real-time monitoring. Third Conference On Artificial Intelligence for Space Applications, George C. Marshall Space Flight Center, November 1987.