EXPERT DIAGNOSTICS SYSTEM AS A PART OF ANALYSIS SOFTWARE FOR POWER MISSION OPERATIONS

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ABSTRACT

The operation of interplanetary spacecraft at JPL has become an increasingly complex activity. This complexity is due to advanced spacecraft designs and ambitious mission objectives which lead to operations requirements that are more demanding than those of any previous mission.

For this reason, several productivity enhancement measures are underway at JPL within mission operations, particularly in the spacecraft analysis area. These measures aimed at spacecraft analysis include: the development of a multimission, multisubsystem operations environment, the introduction of automated tools into this environment, and the development of an expert diagnostics system.

This paper discusses an effort to integrate the above mentioned productivity enhancement measures. A prototype was developed that integrates an expert diagnostics system into a multimission, multisubsystem operations environment using the Galileo Power / Pyro Subsystem as a testbed. This prototype will be discussed in addition to background information associated with it.

1. INTRODUCTION

The operation of interplanetary spacecraft at JPL has become an increasingly complex activity. This complexity is due to advanced spacecraft designs and ambitious mission objectives which lead to operations requirements that are more demanding than those of any previous mission. JPL is now at a point where the current mission operations infrastructure is not sufficient to support future mission operations requirements unless this support is provided through increased staffing. Because of the cost constraints now being placed on spacecraft operations by NASA, staffing increases are not an option and an improvement over the current mission operations infrastructure is needed.

In order to address this problem, several software development efforts are underway at JPL. One such effort is the Engineering Analysis Subsystem Environment (EASE) prototype. EASE is a collection of software programs providing a framework within which spacecraft engineering analysis can be done. This multimission , multisubsystem environment provides tools and a friendly graphical user interface to support spacecraft engineering analysis activities such as telemetry monitoring and performance predictions.

Another effort that has been ongoing in order to address the mission operations problem is the Spacecraft Health Automated Reasoning Prototype (SHARP). SHARP is an expert system that contains subsystem specific knowledge which is used to provide diagnostics about that subsystem. SHARP was developed to assist the engineering analysts in diagnosing anomalous behavior on the spacecraft and recommending actions to take in these situations.

Because the operations environment provided by EASE and the diagnostics capabilities provided by SHARP compliment each other, the two prototypes were integrated to provide a more complete operations environment for spacecraft engineering analysis. This integrated system uses the Galileo Power / Pyro subsystem as its prototype subsystem.

Following is a discussion of the EASE / SHARP prototype in terms of its integration and rules. Background information concerning the JPL mission operations process, EASE, and SHARP is also provided.

2. MISSION OPERATIONS

Spacecraft operations at JPL involves several steps. It includes developing sequences to send commands to the spacecraft, receiving telemetry from the spacecraft, and analyzing this telemetry to characterize the spacecraft state. Figure 1 shows a simplified mission operations process.

The uplink process is shown across the top of the diagram. It begins with science and engineering requests being mapped with the Deep Space Network (DSN) coverage and other requirements to create a mission plan. The mission plan is a time ordered set of activities. This set of activities is then expanded into a time ordered set of commands through preliminary and final sequence generation. The validation of sequences and resolution of conflicts is an interactive process between the sequence and spacecraft analysis elements of mission operations.

The downlink process begins when the spacecraft sends telemetry via the DSN to the JPL Space Flight Operations Center (SFOC). This data is decommutated, stored in a database, and

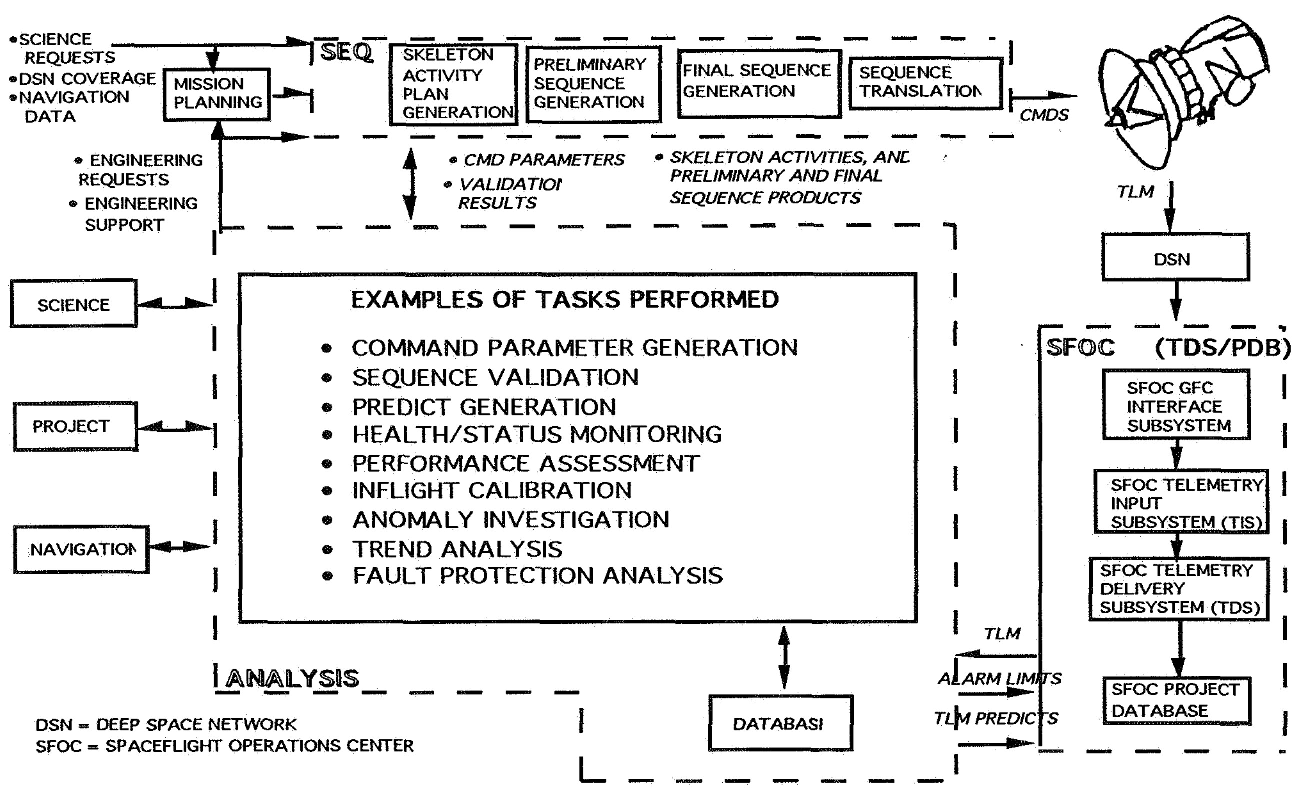

FIGURE 1. *A typical Spacecraft Operations Process*

delivered to the engineering analysts.

The engineering analysis downlink portion includes performance monitoring, trend analysis, anomaly investigation, performance assessment, and fault protection analysis. Uplink support functions carried out by engineering analysis include command parameter generation, sequence validation, and predict generation. [Ref. 1 - 3].

The EASE / SHARP prototype addresses the engineering analysis portion of the operations process. It provides a software environment within which engineering analysis tasks can be carried out more efficiently through automation, software tools, and expert systems diagnosis.

3. THE ENGINEERING ANALYSIS SUBSYSTEM ENVIRONMENT (EASE)

The EASE system is a modular multimission, multisubsystem software environment. For a particular mission, various mission specific subsystem analysis modules (SAMs) are added to the environment to provide subsystem specific telemetry processing. Figure 2a shows the environment when applied to a single mission and populated with SAMs. In a typical case, the SAMs are as follows:

- Attitude and Articulation Control Subsystem (AACS)
- Command and Data Handling Subsystem (CDS)
- Electrical Power Subsystem (EPS)
- Propulsion Subsystem (PROP)
- Systems Subsystem (SYS)
- Telecommunications Subsystem (TELECOM)
- Temperature Subsystem (TEMP)

When two or more single mission applications are interconnected through a multimission graphical user interface (MMGUI), it forms a multimission analysis system as shown in Figure 2b. As can be seen from the diagram , the modular EASE architecture facilitates the integration of new SAMs for a specific mission in addition to applications for different missions.

The functionality of the EASE environment is provided through common interface formats, common display windows, development tools,

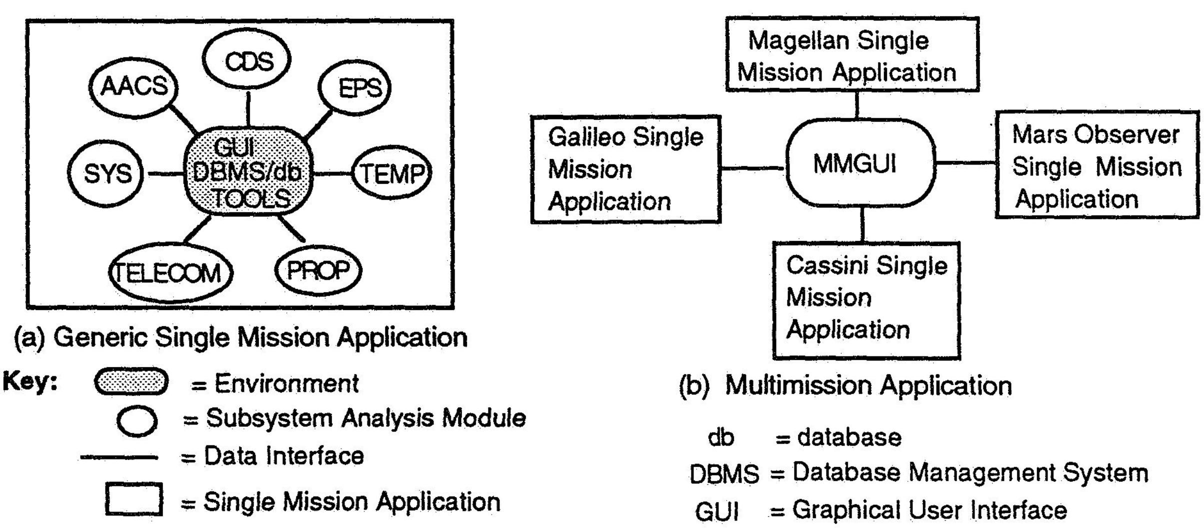

Figure 2. *The EASE Architecture*

analysis tools, and a Database Management System (DBMS). By using the environment as a framework, SAMs can be integrated efficiently. Also the DBMS and tools provide opportunity for automated data analysis and manipulation.

The EASE prototype currently includes several subsystem modules such as: GLL PPS and CDS, Voyager (VGR) EPS, and Mars Observer (MO) PPS. The most developed of these subsystems is the GLL PPS.

4. THE SPACECRAFT HEALTH AUTOMATED REASONING PROTOTYPE (SHARP)

SHARP is a diagnostics system that has been described in depth in a previous report [Ref. 5] . It is written in LISP and has been developed for the VGR and Magellan (MGN) TELECOM subsystems. The VGR and MGN versions of SHARP are stand alone implementations that contain a diagnostics kernel, VGR and MGN specific TELECOM knowledge, and diagnostics displays.

SHARP for the GLL PPS subsystem implementation contains just the SHARP diagnostic kernel and GLL PPS specific subsystem knowledge.

5. THE EASE / SHARP SYSTEM

The primary motivation for integrating SHARP into the EASE framework is to enhance the EASE operations environment developed for monitoring and analyzing the spacecraft data by adding capabilities for diagnosing the state of the spacecraft. Below is a discussion of the integration process of SHARP into EASE and the rules currently included in the SHARP diagnostics module.

5.1 Integration

The first step in the integration process was to separate the SHARP kernel from the rest of the SHARP system. An interface between the C and LISP programming languages is used to pass data from EASE to SHARP. SHARP uses this data to determine alarms and anomalies on the spacecraft and reports these back to EASE. A LISP to C programming language interface is used to send alarm and diagnostics messages form SHARP to EASE.

These alarm and diagnostics messages contain a substantial amount of subsystem specific information. For channels in alarm, the messages contain the mission name, channel type, channel number, time, alarm limits, alarm state (high hard, low soft etc.), a title message, summary message, and a message key which points to a detailed message about the problem. The diagnostics messages contain similar information with most of the subsystem specific knowledge being included textually in the title, summary, and detailed messages.

5.2 Rules

The set of rules the prototype uses for testing is for diagnosis of a GLL PPS bus undervoltage. Although this is a rare anomaly, the reasoning process in determining the cause of a bus undervoltage is well understood providing a useful basis for developing and testing this prototype. The GLL PPS power bus is tightly regulated between 30.1 and 31.5 volts. If the voltage on the bus goes under the allowable limit of 30.1 volts, the bus undervoltage rules within SHARP will trigger. SHARP uses all related telemetry in order to determine the cause of the anomaly. Possible causes for a bus undervoltage anomaly include a failure in a shunt regulator stage, a dc bus short, an ac bus short, or an ac inverter failure.

Another set of rules in development for SHARP is for determining load status (power consumption value of loads). The GLL spacecraft has 121 total

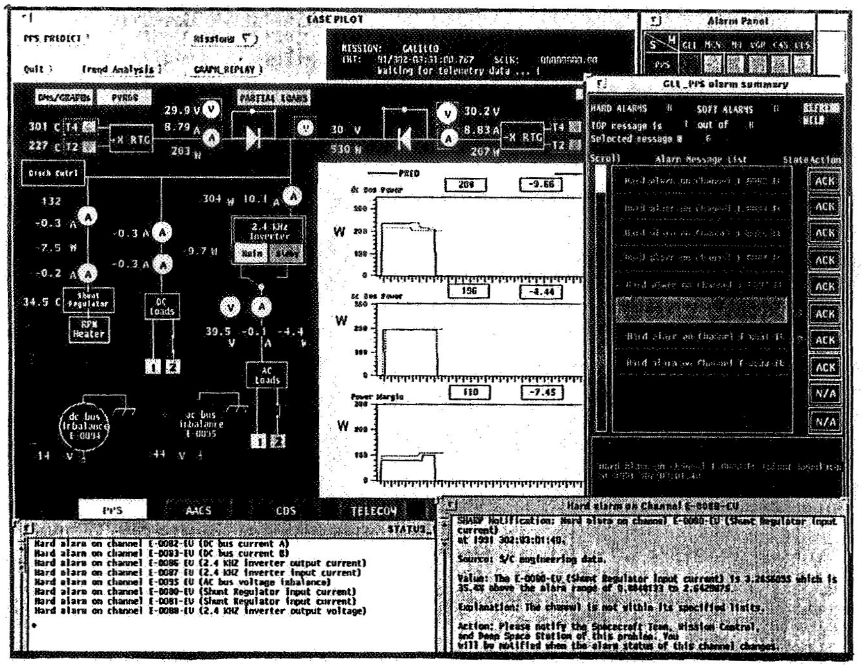

FIGURE 3. *The EASE / SHARP Display Screen*

dc and ac loads. Power status telemetry that gives visibility into these load states consists of the bus and ac inverter output voltages, and the ac inverter output, shunt regulator, and dc bus currents. Additional information such as thermal and command data must be used by SHARP in order to infer the state of each of the 121 spacecraft loads. Because of telemetry and processing constraints on the spacecraft, determining the state of spacecraft loads on GLL must be done by the Ground System.

5.3 Displays

The displays for the EASE / SHARP prototype are developed within the EASE environment. The "LISP" to "C" interface is used to pass data from SHARP to the EASE display module.

In designing the displays, concerns about the overload of information whenever an anomaly or several alarms occur was addressed. The display design chosen for the EASE / SHARP prototype uses the concept of "layering" information to deal with this problem. "Layering", as used here, means presenting summary information to the user at all times. More detailed information concerning an alarm or diagnosis can be accessed by the user simply by clicking the mouse on the summary information. In this way, the analyst is aware of all alarms and diagnoses and can access any information about them, but is not overwhelmed with large amounts of detailed data.

Figure 3 shows the GLL PPS block diagram shortly after the occurrence of a simulated bus undervoltage anomaly. The top three layers of display windows are shown on the right side. Layer 1 is the alarm panel, layer 2 the alarm summary, and layer 3 the detailed alarm message. The operator may acknowledge or ignore alarms that are listed on the alarm summary table.

6. CONCLUSION

Through the development of prototypes such as the EASE / SHARP prototype, much can be learned about using software to improve the mission operations process at JPL. This particular prototype has given valuable insight into the advantages of using a modular, multimission, multisubsystem architecture as a framework for integrating analysis modules such as SHARP. Data was also obtained concerning how to display large amounts of information, and the importance of operations considerations in spacecraft design.

The modular, multimission, multisubsystem architecture provided by the EASE environment was found to be a stable, efficient way of incorporating different capabilities into one system. Interface code from other modules within EASE could be modified and used to integrate SHARP and the new displays. The idea of using a common environment to provide displays, interfaces between modules, and common tools made the integration of SHARP into EASE straightforward.

Because of the additional analysis information that was added to the EASE system through the integration of SHARP, the display of information became a concern. A "layering" approach was selected and was useful in showing the operator summary information, and allowing for detailed information to be accessed.

A final point that was learned in this process is the possible implications of "operationally blind" spacecraft design. Much time was spent in knowledge engineering and software development for the load status rules. This would not be necessary if appropriate telemetry was provided from the spacecraft. The Cassini project has realized this and has included load current telemetry for all Cassini loads. This problem is not specific to the power subsystem, however, and early operations involvement in spacecraft design is a necessity at both the subsystem and system level in order to aviod problems such as this.

The EASE / SHARP prototype has provided useful information in exploring the use of advanced software for mission operations. The purpose of these software packages is to provide functionality and assistance to the analyst so that fewer analysts will be needed for mission operations and cost reductions in this area will be possible.

7. ACKNOWLEDGEMENTS

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