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THE FEASIBILITY STUDY AND EVALUATION OF APPLYING EXPERT SYSTEM TECHNIQUES TO THE MISSION OPERATIONS FOR THE AXAF-I SPACECRAFT

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1. INTRODUCTION

Advanced X-ray Astrophysics Facility - Imaging (AXAF-I) is a spacecraft for X-ray emitting sources observation and has been tentatively scheduled for a space shuttle launch in late 1998 at the Kennedy Space Center. Its main objectives are "to determine the nature of astronomical objects ranging from normal stars to quasars, to understand the nature of the physical processes which take place in and between astronomical objects, and to add to our understanding of the history and evolution of the universe." [AXAF1] The AXAF-I will have an expected five year life time for the science mission phase. During the science mission phase, the monitoring and management operation of the flight and ground systems is personnel intensive, requiring system experts on duty around the clock. The purpose of the expert system presented in this report is intended to reduce the level of expertise, training, and personnel requirement for the mission operation.

The telemetry data from the spacecraft can be divided into two categories: the science observation data and the engineering status data. The science data contains the outputs from the X-ray sensing devices and will be forwarded to the AXAF-I Science Center for interpretation; while the engineering status data will be monitored by the Operation Control Center (OCC) for the operation diagnosis of the spacecraft. The expert system is designed to assist the operation controllers at the OCC to perform the daily mission operations.

Since there are hundreds of engineering telemetry data points and the interpretation of the telemetry depends on many factors, e.g., sun or eclipse, the monitoring of the AXAF-I is not a trivial task. In this phase of expert system development, the focus has been limited to the engineering data interpretation, i.e., warnings will be provided to the operation controllers to signal any anomaly. The system is hosted in a Silicon Graphics Indigo-2 workstation running the IRIX operating system. The expert system tool used is the G2 system from Gensym [Gensy].

2. AXAF-I DESCRIPTION

The major components of the AXAF-I include a spacecraft, an X-ray telescope, and a science instrument module (SIM) [AXAF1]. The spacecraft contains six subsystems that provide the necessary services to the telescope and the SIM. The telescope consists of a 10 meter optical bench, a high resolution mirror assembly, and the related optical support hardware. The SIM contains four X-ray sensing devices with different spectrum range capabilities.

For the monitoring and management purposes, sensors are installed throughout the spacecraft to provide the component status information. There are two types of sensors, analog (i.e., numeric) and bilevel (i.e., on/off). Since the number of sensors is in the order of hundreds and complex relationships exist among the sensor readings, the discussion of this paper will focus on the Electrical Power System (EPS) of the spacecraft to provide a clear presentation. At the time of this expert system development, the EPS contains 17 analog telemetry outputs and 28 bilevel telemetry outputs. Most of the analog telemetry outputs concern with voltages and currents; while most of the bilevel outputs concern with the status of components, like on/off and enabled/disabled. The number and the type of sensors in the EPS are still evolving. For this reason, the expert system must be able to accommodate future changes.

One major factor affects the functioning of the EPS is the sun/eclipse status. In the sun, the solar arrays provide all the power for the operation needs and maintain the full charge of the batteries. During eclipse, the batteries will provide the power. The number of eclipses is limited throughout the operation lifetime of the AXAF-I (<160) and readings will be popped out. By this selective observation, the user will be able to focus on an appropriate level of monitoring.

A system level physical object workspace is given in Figure 1. In this figure, under normal status, each major subsystem has a green icon. When a subsystem or object is signaled for a warning, its icon color will be changed to red. In addition, a sun icon is shown in this workspace. When the AXAF-I is under the sun, the sun icon color is orange; while in eclipse, the color is gray. For simulation purpose, two buttons are provided to the user for the sun or eclipse selection. Figure 2 shows the top-level components of the EPS subsystem and Figure 3 shows the telemetry readings subworkspace of BATTERY-1.

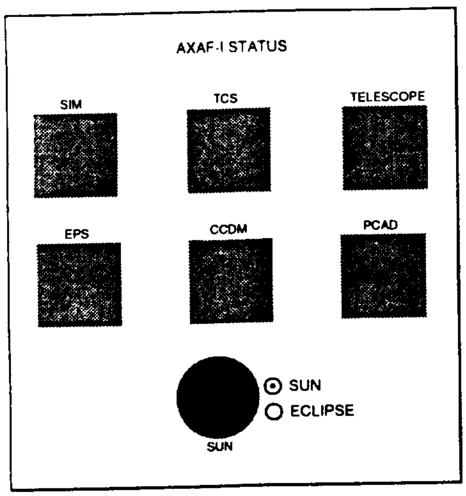

Figure 1 System level physical object workspace

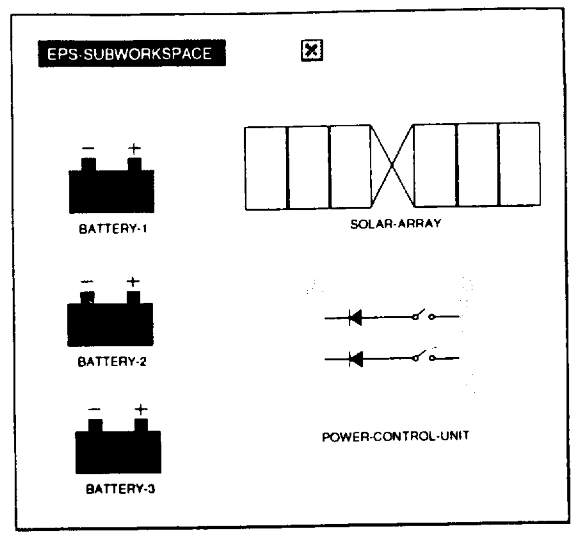

Figure 2 EPS workspace

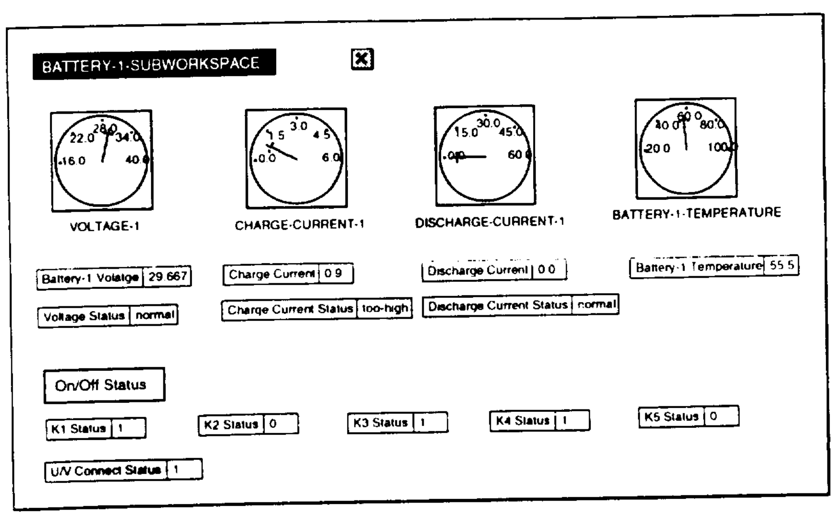

Figure 3 Telemetry readings workspace for BATTERY-1

3.3 Rules

The rules determine when a telemetry reading is out of range and when to signal a warning. A range checking rule typically requires information on the operation mode, e.g., sun/eclipse, the valid ranges of telemetries, and the actual telemetries to reach a conclusion. The (partial) table of a range checking rule for the BATTERY class is given in Figure 4 as an example. It can be seen that G2 provides a natural-language like rule syntax [Gensy].

```
For any battery whenever the charge-current of the battery
receives a value and when the  value of the charge-current >
the Batt-charge-current-sun-k5-off-max of battery-limits and
the state of sun = 1 and the k5-status of the battery = 0
then conclude that the charge-current-status of the battery
is too-high
```

Figure 4 The battery CHECKING-FOR-CHARGE-CURRENT-TOO-HIGH-WHEN-SUN-K5-OFF rule

3.4 Telemetry Variables

Every telemetry reading processed by the prototype must be defined in the G2 environment. The reason is that different telemetries may need different treatments. For example, some telemetries should cause forward chaining immediately after its reception; while other telemetries should be accessed only when a backward chaining has requested them. The telemetries of AXAF-I are defined as *variables* in G2. They are organized in a hierarchy as well. The top level class of the variable is AXAF-VAR which is a subclass of the system-defined QUANTITATIVE VARIABLE. Subclasses are then defined for voltage, current, temperature, etc. In this prototype, all telemetries are individually simulated using formulas.

3.5 Valid Ranges for Telemetry Variables

Each telemetry reading has a valid range in a specific operating mode. Instead of specifying these ranges along with the telemetry variable definitions, they are defined and specified in a table. This arrangement provides easiness to locating a desired range and performing modification - especially when multiple modifications are needed.

3.6 User-Controlled Simulation Biases

These are the values that will be added in the telemetry simulation formulas. For example, on a slide, the user can slide the pointer to a desired value; while on the radio buttons, the user can simply click on the desired button.

4. CONCLUSION

The described prototype has demonstrated the feasibility of applying expert system techniques to the mission operations monitoring. Several findings are listed in the follows.

Hierarchical design: The hierarchical structure design for the object and telemetry definitions and the workspaces provide a conceptually clear framework for the prototype. It not only provides a reasonable way to specify the entity attributes and relationships, but also makes the system development and testing very efficient. This design also allows the user to choose the appropriate monitoring levels for different components which reduces the mental reasoning burden of the user.

System flexibility: In addition to the demonstration of feasibility, the prototype has also shown the flexibility to the system modification. Specification changes can be easily updated by editing the rules or the attributes of the related tables. This feature is extremely important in this system because the detailed specifications of AXAF-I are still evolving. This flexibility is mainly attributed to the hierarchical design and the G2 environment.

Graphical user interface: The powerful graphics capabilities of the Silicon Graphics workstation and the G2 environment have made the mission operations monitoring more pleasant. By using the combination of rule-based reasoning, status display colors, and different icon designs, the user can easily identify the status of any system components. The labor intensive telemetry observation task is now accomplished by the expert system. This leaves the user time to perform other more meaningful tasks.

G2 environment: During the course of the design, development, and testing of this prototype, G2 has been confirmed to be a powerful expert system development tool. Most of the positive features mentioned above are directly related to the G2 capabilities. Its natural language like rule syntax is easy to construct; while the attribute tables associated with objects and workspaces provide efficient way to describe the domain and configurate the relationships among entities. Another important feature of G2 is the built-in *modes*. Under different modes, the environment would provide different access capabilities. For example, under the operator mode, the user can only perform monitoring tasks; none editing or system parameter observation capability is allowed. While under the administrator mode, the user would have the authority to perform any necessary changes. Although G2 is proved to be a powerful tool, the learning curve to achieve proficient understanding of the tool can be long and costly. The standard training course of G2 should be a requirement for most project development team members using the G2 environment.

5. REFERENCES

[AXAF1] Advanced X-ray Astrophysics (AXAF) - Mission Operation Plan, AMO-1010, Mission Operations laboratory, George C. Marshall Space Flight Center, NASA, April 1994.

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