TES - A Modular Systems Approach to Expert System Development for Real-Time Space Applications

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Abstract

A major goal of the Space Station Era is to reduce reliance on support from ground based experts. The development of software programs using expert systems technology is one means of reaching this goal without requiring crew members to become intimately familiar with the many complex spacecraft subsystems. Development of an expert systems program requires a validation of the software with actual flight hardware. By combining accurate hardware and software modelling techniques with a modular systems approach to expert systems development, the validation of these software programs can be successfully completed with minimum risk and effort. The TIMES Expert System (TES) is an application that monitors and evaluates real-time data to perform fault detection and fault isolation tasks as they would otherwise be carried out by a knowledgeable designer. This paper discusses (1) the development process and primary features of TES, (2) a modular systems approach and (3) lessons learned.

Introduction

The Thermoelectric Integrated Membrane Evaporation Subsystem (TIMES) is a spacecraft life support system designed and produced by *Hamilton Standard* . The TIMES Expert System (TES) is a prototype developed as a first step toward capturing in-house diagnostic expertise on this subsystem. The primary goals of the prototype development effort were to (1) investigate expert systems as space-based tools for reducing reliance on ground based support and (2) explore a modular systems approach to developing real-time expert systems. To address these goals, TES was developed as a fault detection and fault isolation expert system to monitor real-time TIMES data. The TIMES Expert System was created under NASA/Johnson Space Flight Center contract number NAS 9-17209.

What is TIMES?

TIMES is a spacecraft waste water processor that employs vacuum distillation, thermoelectric heat pumping, and membrane separation to reclaim high quality product water [2]. A system controller contains the electrical and software logic necessary for process
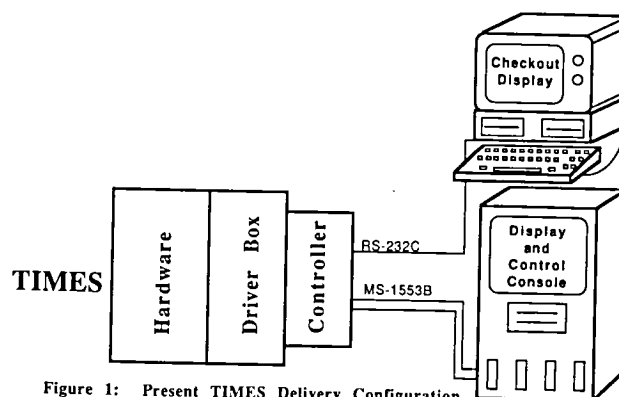

Figure 1:   Present TIMES Delivery Configuration

control, instrumentation and critical fault detection. In addition to data provided to a MS-1553B bus, sensor readings and performance calculations are made available by the controller via RS-232C for use by data checkout and recording systems. An electrical driver box standardizes all signals between the hardware and the controller. The TIMES, along with numerous other life support subsystems, is operated and visually monitored from a central Display and Control Console (DCC) via a MS-1553B bus (see Figure 1).

Primary TES Features

The TIMES Expert System was developed using Knowledge Engineering Environment (KEE) and Common Lisp on a *Symbolics* computer. Approximately 45 potential subsystem and sensor problems have been addressed as both independent and concurrent failures. The TIMES controller relies on threshold violations to provide limited error detection and will shut the subsystem down if a critical problem is suspected. TES enhances controller capabilities by operating as an early warning system, providing additional fault tolerance and acting as an extended problem explanation tool for the astronaut.

Combining the graphics features of KEE and Common Lisp has given TES versatile display capabilities. Some examples are dynamic flows, valve positions, and sensor readings presented on an operational schematic of the TIMES. In addition to these features, the operator also has the ability to customize the monitoring environment by replacing some or all numerical displays with dials and to view real-time historical trend plots of expected and actual values for all sensor and performance data.

A Modular System Design

When real-time prototype hardware output results in inputs to an expert system, the following key issues must be addressed:

1. Limited availability of system hardware for expert system testing and verification due to:
    * A limited number of each prototype system is usually developed and available.
    * Prototype systems are often dedicated to rigorous test schedules and numerous design changes.
    * System testing often has priority over expert system testing.
    * It is costly and difficult to move hardware from one site to another for demonstration or testing purposes.
2. Actual insertion of faults into prototype hardware is unrealistic in many cases because:
    * Altering a system component to introduce a fault can be costly and sometimes hazardous.
    * Many system sensors and components are not physically accessible for alteration.

These issues may be addressed by taking a modular approach to system design. The modular approach involves the development of an accurate

software simulation of the hardware (See Figure 2). The closer the model is to duplicating the hardware's data output in terms of content, format and protocol, the more valuable it will be when addressing the above issues.
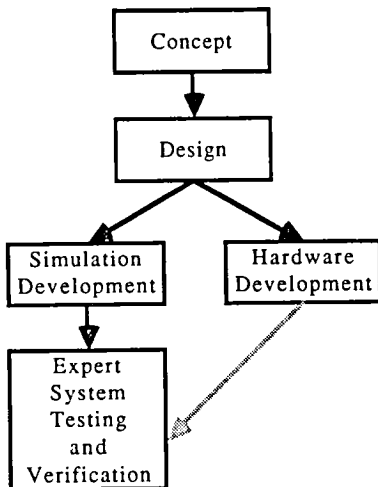

Figure 2: Modular Real Time Testing

Modularity has been applied to the TES program by using a thermodynamic model of TIMES as the expert system test data source. The TIMES model was developed using Quick BASIC on an IBM PC. The RS-232C output from this model realistically duplicates the RS-232C test data output from the TIMES controller in content, format and protocol. This data supplies TES with the sensor, control and performance information it needs to monitor the TIMES (model).

The TIMES model can be operated as a stand alone system or in conjunction with the TIMES Expert System. The model's graphics interface allow the user to visually monitor simulated normal TIMES operation, or to insert faults and observe the effects on subsystem operation independent of the TIMES Expert System. This allows for independent model verification using TIMES data and makes the model itself a valuable tool in understanding detailed TIMES performance and fault characteristics. The model, with its interface (Figure 3), effectively replaces the TIMES hardware and the DCC (Figure 1) for testing and demonstration of TES.
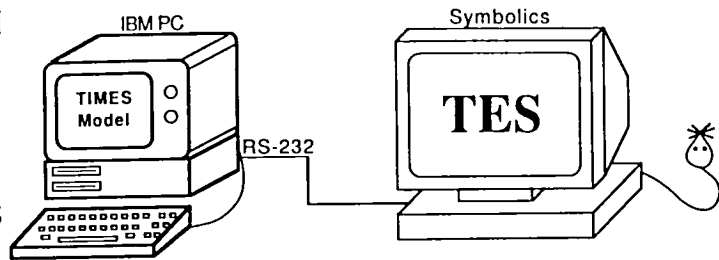

Figure 3: The TIMES Expert System

The modular approach taken in the TES design has helped to reduce development costs by providing a more flexible and accessible testing and verification platform. For example, TIMES operates on an approximate 24 hour cycle and fault symptoms often vary as a function of the cycle duration. To test the TES fault detection capabilities and insure that cyclic data is being handled successfully, testing must be conducted at numerous cycle points. Tests must be repeated a number of times because expert system evaluation is an iterative process [4] . These test constraints would demand valuable subsystem time and may require costly repair or replacement of components damaged during testing or additional hardware to simulate failures. By using a software model as the test bed, an open circuit in a thermoelectric module or a separator motor magnetic drive decoupling can be generated repeatedly. Simulation rates can be adjusted to decrease test time. In these ways, the TIMES model facilitates testing without damaging subsystem hardware or interrupting hardware testing.

A Modular Diagnostic Approach

Remaining consistent with a modular systems approach, TES's diagnostic content is also structured modularly. Application of verbal reporting techniques [3] during the formalization phase [4] of TES's development revealed a distinctly two level diagnostic approach used by the experts. High level performance parameters provide the first clues to a subsystem performance problem. Detailed diagnostics are only employed when such a problem is detected. Because it is the function of the TIMES to efficiently reclaim high quality product water, there are three primary indicators of degraded performance: (1) low water production rate, (2) poor product water quality, and (3) high power consumption. The first two areas have been addressed by the TES prototype. This approach has been captured in a modular fashion modelled after that of the experts allowing for rapid expert system performance, and facilitating future expansion to include other systems [1], [5].

A front end processor in TES monitors TIMES performance parameters using trend analysis to watch for significant indication of a problem. During normal operation, the only other functions performed by TES are the storing of trend data, real-time display update and periodic sensor checkout to flag drifts or inconsistent readings. Only when subsystem performance appears to have deteriorated does TES perform detailed diagnosis to isolate the problem and warn the astronaut before shutdown thresholds are exceeded. (Figure 4)
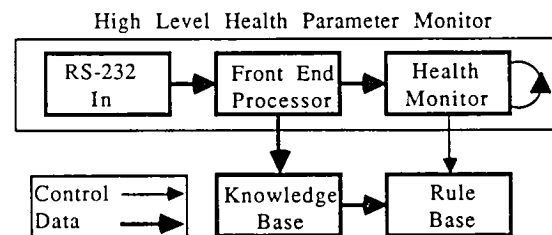
Figure 4: TES Functional Modularity

The rules in the TIMES expert system have been divided into four major categories: (1) General Health rules, (2) Water Production Rate rules, (3) Water Quality rules and (4) Sensor Health rules. Division of the rule base into problem areas has further enabled rapid fault diagnosis. For instance, if a low water production rate were detected, TES would reason over rule types (1) and (2) drawing on the current knowledge base and trend information to diagnose the problem. A separate Sensor Health rule base has increased TES credibility by flagging unreliable sensors so that they are not relied on in future reasoning, and by differentiating between sensor drifts or failures and actual subsystem health problems (i.e. high temperature).

Conclusions

Using the TIMES model as an input to the TIMES Expert System provides a flexible and portable means of addressing the availability, cost, and time issues associated with developing an expert system to monitor real-time hardware data. It also increases TES's diagnostic credibility by separating fault insertion and fault detection. The operator can observe TIMES sensor readings and performance indicators on the model to reach his own conclusions, while the expert system provides the expert diagnosis.

TES's, functional modularity, patterned after the expert's own diagnostic approach, increases its monitoring efficiency without limiting

future growth. The front end processor makes TES an efficient, high level health monitor until detailed anomaly analysis is needed. The front end processor also supplies TES (and hence the operator) with a trend history of all sensors and performance parameters. Detailed trend analysis on this data supplies the TES reasoning system with the information that the expert uses by either visually examining trend plots or performing detailed analysis of historical data.

Independent sensor monitoring increases TES's diagnostic capability by flagging unreliable sensors thus excluding them from use in future reasoning and by distinguishing between sensor drift or failure and actual performance problems.

Future TES expansion areas could include: (1) further development of the front end processor to address more complex data characteristics, (2) a detailed feasibility study that would address the modular system design to multiple systems, (3) connection to TIMES hardware, and (4) further investigation of multiple faults.

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