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NASA SYSTEMS AUTONOMY DEMONSTRATION PROJECT: ADVANCED AUTOMATION DEMONSTRATION OF SPACE STATION FREEDOM THERMAL CONTROL SYSTEM

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Abstract

Congress has displayed substantial interest in accelerating the dissemination of advanced automation technology to and in U.S. industry. Space station was selected as the high-technology program to serve as a highly visible demonstration of advanced automation, and spur dissemination of the technology to the private sector.

The NASA Systems Autonomy Demonstration Project (SADP) was initiated in response to the above stated Congressional interest for Space station automation technology demonstration. The SADP is a joint cooperative effort between Ames Research Center (ARC) and Johnson Space Center (JSC) to demonstrate advanced automation technology feasibility using the Space Station Freedom Thermal Control System (TCS) test bed.

A model-based expert system and its operator interface have been developed by knowledge engineers, AI researchers, and human factors researchers at ARC working with the domain experts and system integration engineers at JSC. Its target application is a prototype heat acquisition and transport subsystem of a space station TCS.

The demonstration is scheduled to be conducted at JSC in August, 1989. The demonstration will consist of a detailed test of the ability of the Thermal Expert System to conduct real time normal operations (start-up, set point changes, shut-down) and to conduct fault detection, isolation, and recovery (FDIR) on the test article. The FDIR will be conducted by injecting ten component level failures that will manifest themselves as seven different system level faults.

This paper describes the SADP goals, objectives, and approach; it describes the Thermal Control Expert System that has been developed for demonstration, and provides insight into the lessons learned during the development process.

Introduction

The NASA Systems Autonomy Demonstration Program (SADP) was initiated in response to Congressional interest for space station automation technology demonstration.[1] The technical objectives of SADP are to:

- Develop and validate knowledge-based system concepts and tools for real time control of a complex physical system
- Demonstrate enhancements to a space system's performance through advanced automation.

The programmatic objectives of SADP are to:

- Establish in-house expertise and facilities.
- Transfer advanced automation technology to operational centers.

Managed out of the Ames Research Center (ARC), SADP began its first joint cooperative project in 1986 with the Johnson Space Center (JSC), in an effort to transfer the expert system technology under development at ARC to a space station operations center. Ames is providing expertise in knowledge engineering, operator interfaces, and system architectures. Johnson Space Center is providing expertise in systems integration and in thermal engineering domain expertise.

The Space Station Thermal Control System (TCS) test bed at JSC was selected as the project application focus because it had several test articles under development, each requiring real time control and fault detection that an expert system could potentially provide. This paper gives an overview of SADP's Thermal Expert System (TEXSYS) project and describes some lessons learned.

Technology Challenge

The key technology challenge for TEXSYS is to provide real time control of a large electro-mechanical system. The TCS Heat Acquisition and Transport Subsystem is a complex physical system utilizing advanced thermal technology.

The specific prototype test article for the TEXSYS demonstration uses two-phase anhydrous ammonia as the coolant fluid, and consists of 5 evaporators, 4 condensers, 2 accumulators, a pump, 17 isolation valves, and numerous pressure-temperature sensors.

Comparison To Conventional Systems

Conventional control systems used by thermal engineers provide monitoring of system parameters, automatic control of nominal operations (startup, temperature setpoint changes, and shutdown), and notification of the operator when a parameter exceeds predetermined limits. The operator then has the task of analyzing the system situation to determine the best course of action. On the other hand, TEXSYS provides automatic control of nominal operations, monitors the system performance, and in addition, has the knowledge to analyze the data, take action to recover, and explain to the operator the fault diagnosis and reasons for actions taken. By elevating the task of the thermal engineer to a higher level of system monitoring and tasking, it is anticipated that operator performance and productivity will be enhanced.

Expert System Technology Thrusts

In response to the TCS challenge, the project's expert system technology development has been concentrated in the following areas: (1) integration of knowledge-based systems into a complex real time environment; [2] (2) causal modeling of complex components and elements through representation of first principles, quantitative models, and qualitative models in the knowledge-base; (3) use of combined model-based and rule-based reasoning; and (4) use of trend analysis heuristic rules. [3]

This research has lead to the development and use of a multi-purpose Model Toolkit (MTK) [4] and Executive Toolkit (XTK) for model-based expert systems. These tools were used to create TEXSYS, perhaps the largest real time expert system (327 rules, 3493 frames, and 156,000 lines of code) to date that performs actual control of a system as well as conducting monitoring and fault diagnosis.

Specific Functionality To Be Demonstrated

TEXSYS controls the TCS in real time through the following automatic controls: analog control of the system temperature control valve, on/off control of the pump, and open/close control of 17 valves. The expert system can also call for operator assistance in performing manual functions such as heat load manipulation.

The following Nominal Operations, and FDIR elements are expected to be demonstrated in both an advisory and automatic mode:

Nominal Operations

1. Startup
2. Temperature Set Point Changes (between 35-70 degrees fahrenheit)
3. Shutdown

FDIR for ten component failures

1. Slow Leak.
2. Pump Motor Failure.
3. Single Evaporator Blockage.
4. High Coolant Sink Temperature.
5. Temperature Control Valve Failure.
6. Gas Buildup.
7. Temperature Control Valve Actuator Failure.
8. Excessive Heatload.
9. Accumulator Sensor Failure.
10. Pressure Sensor Failure.

TEXSYS provides real time control of startup, setpoint changes, shutdown, and FDIR capability for faults 2, 3, 5, and 6. TEXSYS provides passive reasoning and advice in FDIR for failures 1, 4, 7, 8, 9, and 10.

The demonstration will be accomplished by directing TEXSYS to conduct normal operations, followed by random injection of any one of the ten component faults. TEXSYS is expected to detect both the system and component level repercussions of the injected fault, and to propose a recovery technique.

Operator Interfaces

The test article status and control will be provided to the thermal engineer operator through two display screens. The "Expert System Screen" provides the operator with communication media to the expert system for control and explanations. The "Color Schematic Screen" gives the operator a "window" into the test article for information on test article status and performance. The operator can mouse on the screen to call up any system level or component level schematics he might desire for viewing, in addition to data time histories.

Performance Metrics

The system performance will be evaluated as it is seen through the operator interface using the following criteria:

1. Speed and Duration: Reasoning and networking cycle times, and duration performance will be measured quantitatively.
2. Reasoning Accuracy: Accuracy of fault diagnosis and control actions will be measured relative to formally documented Operations/FDIR procedures.

3. System Robustness:System robustness to unplanned test article anomalies and hardware failures will be measured by observation and test data.
4. Flexibility: Operator interface flexibility will be evaluated subjectively by thermal engineers.
5. Displays: Operator interface display content and format will be evaluated subjectively by thermal engineers.

Project Approach

The project began with parallel development efforts in 1986 to meet a 1988 demonstration schedule. ARC began developing MTK, XTK, and operator interface tools while JSC documented its TCS expertise, built TCS brassboard hardware, and developed an integration strategy. As these early efforts neared completion, the resulting information and tools were then used in the development of control software for a TCS brassboard article at ARC.

After brassboard testing, the expert system portion of the software was modified for the prototype test article at JSC, and transferred to JSC for integration and checkout. In March 1989 testing of the integrated system was initiated using previously recorded test article data as a quasi-simulation of actual system operation. This testing continued until late June 1989, when the software was interfaced with the actual test hardware for its last seven weeks of checkout. The final demonstration is scheduled for the week of August 28, 1989.

Lesson Learned

Many valuable lessons have been learned in the course of the TEXSYS project's design, development, integration and test phases. The lessons are discussed below.

1. Specifically identify the user early in the project and focus efforts to solve his application problem. TEXSYS experienced minor problems in this area by selecting the application test article fairly far into the project, after building expert system toolkit capabilities that were not all required for the test article.

2. Real time considerations can be mitigated by choosing an application whose parameters change slowly with time and by using powerful dedicated computers. In TEXSYS, this approach eliminated most timing considerations, but careful analysis and utilization of the DNA symbolics network software was still required.

3. A new technology's operational immaturity, coupled with a lack of appropriate expert system tools adds time to the development effort. Time was invested early in the TEXSYS project to document the new application expertise and to develop the toolkits, before any real application software efforts could begin.

4. In an expert system assisted conventional control system, define clean, highly specified interfaces between the AI software system and the conventional software system. For TEXSYS, this interface took the form of a list of modular subroutines that the expert system uses to communicate with the conventional software. This approach resulted in a minimum of integration problems.

5. Iterative coding and testing the expert system software can both improve the users' understanding/acceptance of the software and improve the software's capabilities. TEXSYS was first tested against a brassboard test article, which stressed the performance aspects of the system. The software was then tested against actual test data from the application hardware, which improved the accuracy and repeatability of the system. Final testing directly on the application hardware will complete the iterative process. An alternate approach, described below, is recommended for further research.

Recommendation For Further Research

Although brassboard hardware and previously recorded test data can be used for iterative testing of expert system software, a properly designed simulation of the hardware system should be considered for this purpose and also for the development of the expert system. This simulation could actually replace the use of hardware/test data, especially during the early and mid-stages of a project, or could be used in conjunction with hardware/test data. The precise form that this simulation should take is an open research issue that should be addressed because the result may be enabling technology for the development of complex knowledge-based controllers. A development cycle that consists of 1) developing and testing the expert system using a simulation, 2) testing the expert system with the hardware and identifying properties of the simulation that are inconsistent with the hardware, and 3) correcting the simulation, and repeating 1) would be an efficient development cycle for extending conventional controller technology via the use of knowledged based systems. In this paradigm, the simulation serves, in some sense, as the repository for the current understanding of the hardware and is updated as that understanding improves. Ultimately this process may result in the simulation becoming a part of the controller software.

Conclusion

Although the SADP thermal expert system has not yet been demonstrated, it is expected to provide enhanced system capabilities and operator performance. TEXSYS is one of the largest real time expert systems that has been implemented, and is significant in that it will perform control and fault diagnosis of a complex system. The project has been a valuable experience for the developers, integrators and domain experts, and lessons have been learned that can be put to use on future software projects. An important lesson learned was to specifically identify the end user early and have the user continuously involved in the development process. SADP reduced its real time considerations by choosing an application whose parameters change slowly with time and by using powerful dedicated computers. The new thermal system technology's operational immaturity and lack of appropriate expert system tools added time to the project's development effort. The conventional to AI software integration time was held in check by defining clear, specific interfaces. And finally, an iterative process of software development and test appears to be an effective way to produce expert system software. Further research into the use of simulation software in this process is encouraged.

References

[1] Bull, J. S., Brown, R. M. , Friedland, P., Wong, C. M., Bates, W., Healey, K. J., Marshall, P.; "NASA Systems Autonomy Demonstration Project: Development of Space Station Automation Technology"; 2nd AIAA/NASA/USAF Symposium on Automation, Robotics, and Advanced Computing for the National Space Program; Arlington, Virginia; March 9-11, 1987.

[2] Healey, K. and Hack, E., "TDAS: A Thermal Expert System Data Acquisition System," SOAR-87: 1st Annual Workshop on Space Operation, Automation and Robotics; NASA/USAF/Univ. Houston, Houston, Tx, August 5-7, 1987

[3] Glass, B. J. and Wong, C. M.; "A Knowledge-Based Approach to Identification and Adaption in Dynamical Control Systems"; 27th IEEE Conference on Decision and Control, Austin, Texas, December 7-9, 1988.

[4] Erickson, W. K. and Schwartz, M. R.; "MTK: An AI Tool for Model-Based Reasoning"; 3rd Annual Conference on Artificial Intelligence for Space Applications, NASA MSFC, Huntsville, Alabama, November 2-3, 1987.