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TDAS
THE THERMAL EXPERT SYSTEM (TEXSYS) DATA ACQUISITION SYSTEM

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Abstract

As part of the NASA Systems Autonomy Demonstration Project, a thermal expert system (TEXSYS) is being developed by the Ames Research Center, the Johnson Space Center (JSC) and their contractors. TEXSYS combines a "fast" real time control system, a sophisticated human interface for the user and several distinct artificial intelligence techniques in one system. TEXSYS is to provide real time control, operations advice and fault detection, isolation and recovery capabilities for the Space Station Thermal Test Bed (TTB) at JSC. TEXSYS will be integrated with the TTB and act as an intelligent assistant to thermal engineers conducting TTB tests and experiments.

This paper will present the results of our work on connecting the real time controller (running on a conventional computer) to the knowledge based system (running on a symbolic computer) creating an integrated system. Special attention will be paid to the problem of filtering and interpreting the raw, real time data and placing the important values into the knowledge base of the expert system.

Introduction

The increasing complexity of space missions to be conducted in the next twenty-five years by the United States requires that the control and monitoring systems used to support these missions take advantage of the latest in automation technologies to reduce costs and more importantly, increase reliability and safety. The Space Station with its longer than 20 year operation lifetime and the proposed Mars sample return mission will both need to exploit the recent advances in artificial intelligence to perform their mission, most notably expert systems. This need was recognized by the National Commission on Space (aka the Paine Commission) whose final report suggests that:

> ...NASA explore the limits of expert systems, and tele-presence or tele-science for remote operations, including ties to spacecraft and ground laboratories.

Recognizing these needs, the National Aeronautics and Space Administration's Office of Aeronautics and Space Technology has initiated the Systems Autonomy Technology Program. The program consists of two programs, with the Core Research and Technology Program funding basic and

initial applied research in AI and automation. In the second program, the Systems Autonomy Demonstration Project (SADP), a series of four demonstrations will be conducted to show the capability of increasingly complex expert systems applied to Space Station subsystem needs.

The Thermal Expert System

The first of these demonstrations, the Thermal Expert System (TEXSYS) is being developed to show the use of artificial intelligence technology in operation and management of the prototypes for the Space Station Thermal Control System (TCS). This demonstration is a joint project of the Ames Research Center (ARC) and Johnson Space Center (JSC). TEXSYS will be used to monitor, control and diagnose faults in the Thermal Test Bed (TTB) at JSC.

The TTB program is designed to test ground-based engineering models of the Space Station active thermal management control system, to verify the readiness of two-phase thermal technology and to provide system level evaluation of advanced thermal control technology for Space Station use.

TEXSYS will incorporate the following features:

- Monitor and control of a single thermal subsystem
- Goal and causal explanation displays
- Qualitative and quantitative simulations
- Fault detection, diagnosis and limited reconfiguration
- Reasoning using standard procedures

While the features to be included in TEXSYS are well established, the combination of these AI techniques in a single system to be used in a real time environment will provide NASA with a benchmark system to test new ideas and further refine them for mission applications.

Hardware

TEXSYS will be demonstrated using a prototype of the Space Station central thermal bus. A simplified diagram of the central thermal bus is shown in figure 1. This central thermal bus has a conventional computer system for data collection and control. The control system is a commercial software package, FLEXCON, which runs on MicroVAX II computers. TEXSYS will use a Symbolics 3650 computer for the expert system and a unix-based graphics workstation to provide a sophisticated and flexible human interface to the operator.

The Conventional Control System

FLEXCON is a schedule driven system, with a master queue of processes to be used to initiate sensor readings from the Analogic Remote Terminal Units, to convert the sensor readings into engineering units, to schedule data display updates and to start control processes. FLEXCON is capable of simple limit checking to generate alarms to the users and can run simple control loops (such as open loop and closed loop PID controllers). FLEXCON is currently used for factory automation and process control in the food industry and for monitoring and controlling a series of dams in the southern U.S..

The TTB Data Acquisition and Control System (DACS) is a hierarchical system built

using FLEXCON, with a master system controller and a controller for each of the thermal subsystems. In this project only the central thermal bus will be used, but the DACS software is capable of controlling and monitoring up to five connected bus and radiator systems in later stages of the TTB project.

TEXSYS is to use the DACS system to collect the sensor readings and dispatch control commands to the thermal bus. For example, it is necessary, when using FLEXCON alone, for the operator to control some of the solenoid values that gegulate the fluid and vapor flow in the bus. These will be under automatic control of TEXSYS. The types of data to be collected and their update rates are shown in figure 2.

Real Time Data Acquisition Software

In order to minimize the load on the symbolic processor containing the expert system, a software system has been designed that will provide TEXSYS with data inputs in a flexible and timely manner. This software, the TEXSYS Data Acquisition System (TDAS) will run on the MicroVAX which hosts the master DACS software and will be written in FORTRAN 77. FORTRAN is being used for this software for compatibility with the FLEXCON system.

The TDAS software will be written to make use of a feature of FLEXCON, called the user process facility. In this facility, a process or group of processes can be created by the user and will be scheduled by FLEXCON to run in cooperaton with the normal FLEXCON processes.

There are two goals for this software. The first is to reduce the amount of data sent from FLEXCON to TEXSYS by examining the sensor readings as they are rcceived and only forwarding to TEXSYS those values that meet the current criteria of significance. The second goal is to perform as much of the numeric processing of data points in TDAS as possible, using a faster numeric processor (the MicroVAX). The DACS and TEXSYS are to be connected over a 10 mbps Ethernet connection using the DECNet protocols. (See figure 3.) This connection is to be established and managed by TDAS.

FLEXCON maintains an in-memory database of sensor locations, update rates, high and low limits, data validity limits, and current sensor readings. Also stored in this database are data items calculated from sensor inputs and the parameters associated with the control loops (setpoints, coefficients, etc.). After each set of updates is made by FLEXCON, the TDAS software will be signaled and it will scan the database looking for significant data. If nothing of significance is found, the expert system will be informed. This will also serve to verify the status of the Ethernet communications link.

The initial significance tests and calculations shall be fairly simple. As the input from some of the sensors is noisy, the data will first be low pass filtered to eliminate the high frequency noise. This process is one that the current operators perform mentally, as they watch the trend of the data points and the average value rather than the instantaneous value of a sensor reading. The data shall then be checked against previous values and the slope of the data sequence will be calculated. After these calculations are performed, the alarm limits in the data base will be compared to

the filtered readings. If the value is outside the normal range, it will be checked against the validity limits for that kind of sensor. If there is a limit violation, the reading, the slope and the type of limit violated will be posted to an agenda of items to be reported to TEXSYS. After all of the sensor readings that were updated are checked, the agenda will be examined and the information on it will be sent to TEXSYS. The data on the agenda can be prioritized so that the expert system can focus on those systems of highest importance. (See figure 4 for a diagram of this process.)

It shall also be possible for the expert system to ask for sensor values, both raw and filtered, to be reported at each update, regardless of the limit checks. This continuous reporting shall be selectable by sensor, by subsystem (e.g., cold plate evaporator #1, condenser #3, etc.) or by sensor type (all pressures in fluid/vapor loop A) allowing the expert system to automatically receive all information needed to support the reasoning of the current focus of attention of the expert system. For example, if an evaporator was reaching full heat absorption capacity, which could lead to dryout of the evaporator, the surface temperature will start to rise and the duty cycle of the inlet valves will approach 100%. The TDAS limit checks would notice the increasing temperature and the trend analysis would notice the increasing valve duty cycle and report these data to TEXSYS. TEXSYS would then request that all sensor readings associated with the evaporator be continuously reported to it until the problem was diagnosed, reconfiguration of the evaporator accomplished and the evaporator returned to normal.

TEXSYS shall also be able to modify the alarm limits used by TDAS. This is needed due to the operational characteristics of the thermal bus system during transition periods such as start-up, loop temperature setpoint change, and shutdown. During these operations, certain of the sensor readings will vary widely and may show readings that would be abnormal in the steady state. Alarm limits of the system therefore can be widened or changed in value without compromising safety, thus reducing the number of false alarms. This will allow improper performance to be spotted, reported and diagnosed with false alarms minimized.

The data reporting shall be performed synchronously, once each second (the fastest sensor update rate), and the amount of data that will be reported to the expert system each frame will vary. The largest size frames will occur as the temperature readings occur each 10 seconds. The data will be reformatted to allow rapid insertion into the knowledge base of the expert system. In addition, archival information will be stored and later retrieved by TDAS from a data base of sensor readings. This archival information will be analyzed, by TEXSYS at low priority, to spot long term trends.

The second form of interaction that TEXSYS will have with the DACS will be in TEXSYS' ability to control the thermal bus. TEXSYS shall have the capability for modification of the control loop constants used by the DACS. All of the control parameters (such as setpoints, gains, etc.) will be reported to TEXSYS at system startup. In addition, the direct control of crossover valves and other items not in control loops can be done by TEXSYS via TDAS.

Future Expansion Plans

These basic capabilities shall be implemented in the first version of the TEXSYS/DACS interface. Several additional techniques are being evaluated with domain experts for inclusion in later revisions of the TDAS software. First, the use of spectral analysis by Fourier transforms to look for cyclic information in the data is being studied. There are potentially damaging situations that can arise from undamped periodic pressure surges in the bus, and if the data rates are high enough to detect such surges this capability may be added. Data from past thermal bus tests are being assembled from data archives for this analysis. Secondly, noise analysis (also by spectral techniques) is being considered as a method for spotting incipient sensor system failure. Some sensor failures are preceded by increasing noise in the sensor readings. Again, the data from previous tests are being assembled to look for noise signatures characteristic of imminent failures.

Finally, the ability to build in contextual and situational sensitivity to allow TDAS to report additional relevant information immediately upon the detection of a significant sensor reading is under consideration. For example, if a pressure drop is reported in a pipe, the upstream and downstream pressures would be needed to determine if the drop is due to a leak or a faulty sensor. In addition, by knowing the current operational state of the bus (startup, shutdown, etc.) the data gathering capabilities can be further modified to allow the automatic capture of related sensor information when abnormal data is detected.

Conclusion

The use of incremental, layered interface software described here will allow us to decrease the risk in the program and to easily experiment with alternative approaches to individual problems. The flexibility in this approach will allow the system to be modified for subsequent demonstrations in the SADP program. These demonstrations will include integration of TEXSYS to cooperate with a power system expert system, a hierarchical expert system complex and finally a distributed expert system architecture. In addition, integration with other Space Station testbed hardware, such as the prototype Data Management System will be easier.

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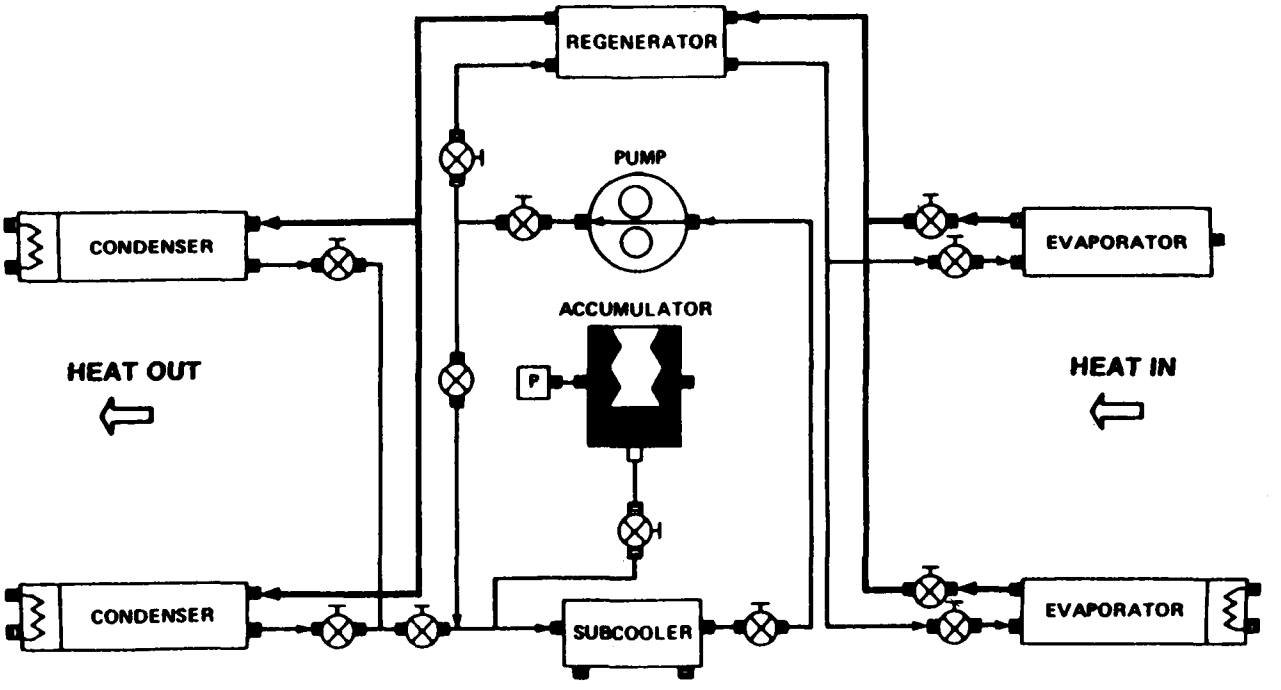


THERMAL CONTROL SYSTEM SCHEMATIC
TWO-PHASE AMMONIA SYSTEM

Figure 1

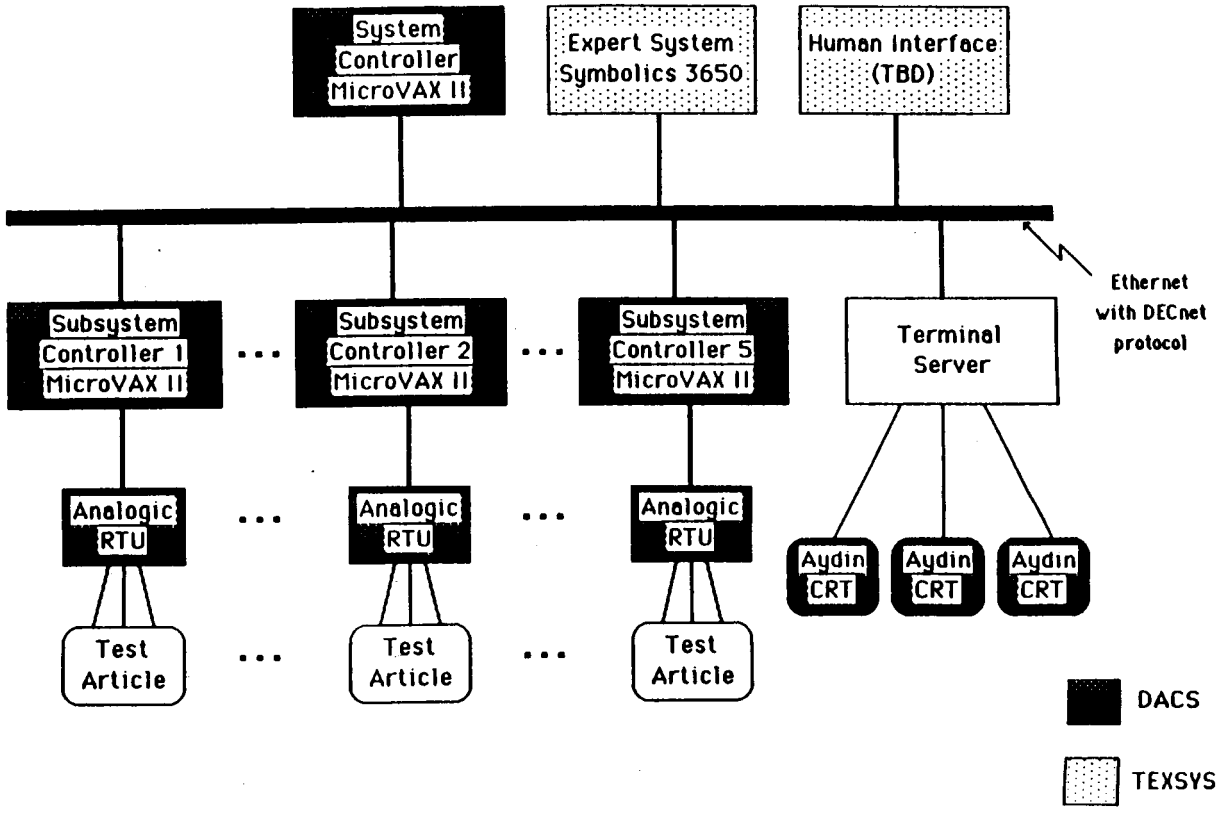
ANALOG SENSORS

	Update Rate (sec/sample)	Number	Length (bits)
Temperature	10	72	32
Flowmeters	1	8	32
Pressure	5	20	32
Liquid level	10	2	32
Pump RPM	1	1	32

DIGITAL INPUTS

Pump RPM	1	1	32

FIGURE 2.- REAL-TIME CONTROL INPUTS



Hardware Configuration

Figure 3

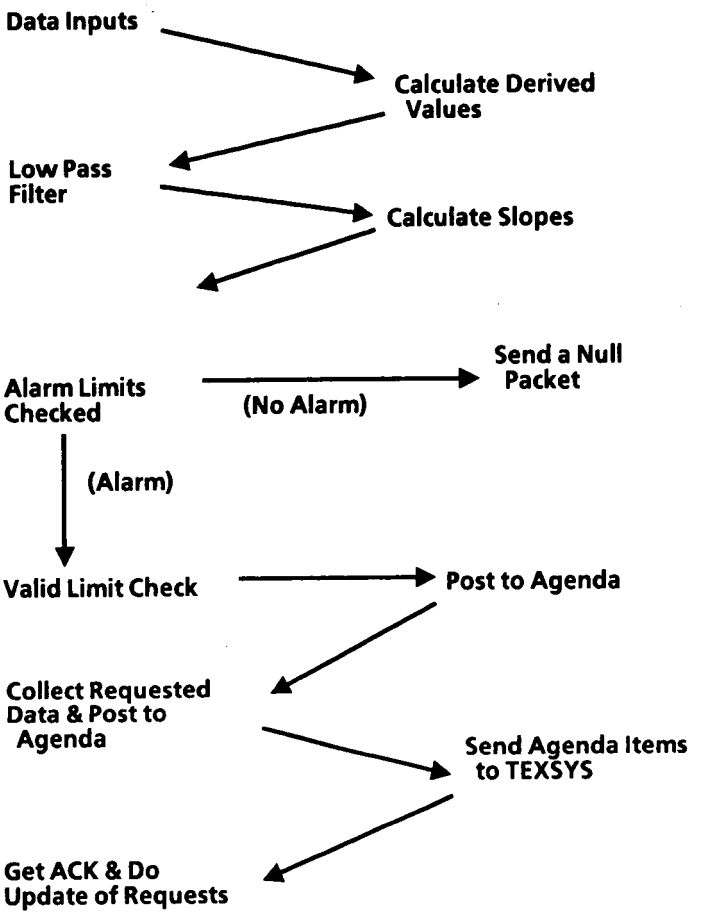

Data Inputs
Calculate Derived Values
Low Pass Filter
Calculate Slopes
Alarm Limits Checked
(No Alarm)
Send a Null Packet
(Alarm)
Valid Limit Check
Post to Agenda
Collect Requested Data & Post to Agenda
Send Agenda Items to TEXSYS
Get ACK & Do Update of Requests

FIGURE 4.