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EXPERT SYSTEM APPLICATIONS IN SPACECRAFT SUBSYSTEM CONTROLLERS

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ABSTRACT

As the NASA progresses into the development phase of the Space Station, it recognizes the importance and potential payback of highly autonomous spacecraft subsystems. This paper presents priorities for embedded expert system enhancements to the automatic control systems of the Space Station thermal, EVA, and life support systems. The primary emphasis is on top-level application areas and development concerns for expert systems.

INTRODUCTION

The primary intent of this paper is to identify potential application areas and development concepts for expert systems within the operational control scheme of some Space Station subsystems.*** The application areas considered are those which are felt to have the greatest payback potential to the Space Station in terms of system safety, autonomy, and operational costs. Although the capabilities mentioned here will be useful for any subsystem, not all subsystems have been considered nor are being represented in this discussion, nor is this paper intended to be a thorough treatment of all subsystem controller requirements.

The discipline area on which this paper focuses is Space Station life support. Specific subsystems which have been considered include the Thermal Control System (TCS), the Extravehicular Mobility Unit (EMU), the Manned Maneuvering Unit (MMU), and their associated checkout and servicing systems, and some aspects of the Environmental Control and Life Support System (ECLSS). All of these subsystems involve complex continuous processes which must be controlled. Of these processes, some are mechanical (circulating fluids, heat transfer, etc.) and some involve chemical reactions, both open-loop and closed-loop. Each of these systems is a complex integration of components and subassemblies (many of which need to be actively controlled) with a high degree of redundancy and, usually, multiple levels of control. Each incorporates a wide variety of system instrumentation and depend upon numerous interfaces with other vehicle subsystems (power, data, communication, etc.) and Space Station elements (modules, airlocks, truss, experiment bays, etc.).

The controllers for these subsystems support a vehicle-level control system currently being developed known as the Operations Management System (OMS). The OMS has an on-board component and a ground based component. The overall OMS structure is depicted in Figure 1. The on-board portion of the OMS would be integrated into the Data Management System (DMS) for access and communication with the other vehicle subsystems. The portion of the figure labeled "distributed systems" refers to the individual vehicle subsystem controllers which include those mentioned above.

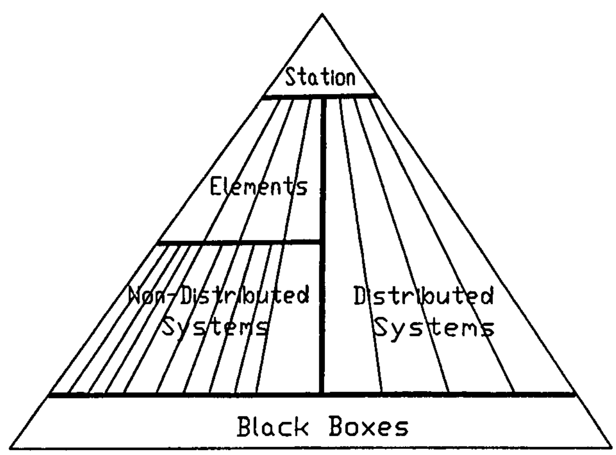

Figure 1 - Operations Management Systems Concept

***Many other functions have been identified as promising application areas for expert system approaches which also reside at the subsystem levels but may not relate to the operation and control of the subsystem itself. These higher level functions will not be discussed in-depth but some are mentioned below for completeness: resource management, maintenance assistance, logistics/inventory management, human interfaces, interactive training, and simulation support.

SUBSYSTEM CONTROL APPROACH

A very simplistic view of conventional process control, but one which is useful for the present discussion, is one which breaks a system down into a relationship of mathematical transfer functions, signal flows, and response characteristics tailored not only to the system being controlled but also to particular solution techniques. This approach has historically proven successful in the solution of control problems. Although the models used in the conventional approach have associated inaccuracies, when the technique fails it is usually due to influences which lie outside of the models and control laws. Specifically, the approach usually fails due to 1) influences of environment or other boundary condition changes which are difficult or impossible to incorporate into the control models (such as vehicle attitude perturbations, proximity to other equipment, etc.), 2) failure of system components, 3) changing goals or design assumptions, 4) improperly executed procedures, 5)incomplete or unreliable system data, and the like. If these influences could be properly identified and controlled, then the reliability and autonomy of the control law could greatly be enhanced.

It is best to view a more robust control approach to include the conventional capabilities enhanced with resources to accomplish the other aspects of the control problem. The overall control scenario can then be conceptually described as a process management system consisting of the following five functions (ref. 1):

-Data preprocessing
-System state/situation assessment
-Control action determination
-Command execution and verification
-Process management controls

The relationships of these functions are depicted in Figure 2. In the sections which follow, each of these functions are described and the areas where expert systems may be applied to accomplish the broader goals which have been established are identified.

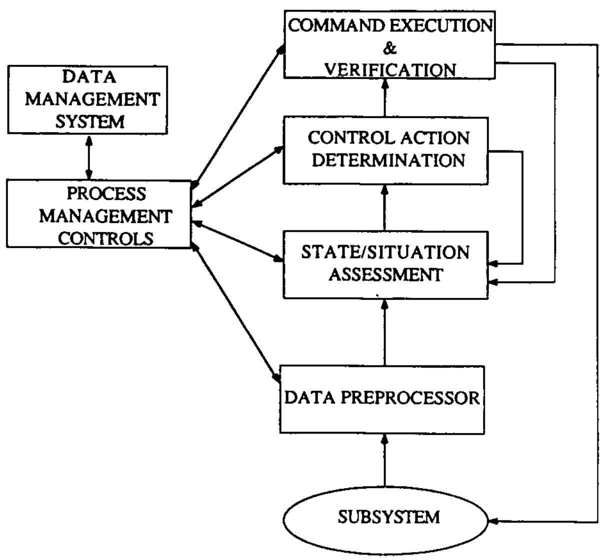

Figure 2 - Subsystem Controller Functions

DATA PREPROCESSING can be thought of as the set of tasks required to acquire raw data from the operating subsystem, and put them into a form which can be directly useful to the other functional areas. The preprocessor may also 'glean information' from the data by performing simple calculations using individual parameters, or recognizing or developing much more complex relationships between parameters which can generate qualitative descriptions of the system to be used in other functional areas.

While most of this task involves conventional data acquisition and numerical processing (such as engineering unit conversion, limit checking, etc.), there are some capabilities which an expert system may provide to take advantage of this functional area. These may include:

- A flexible facility for developing complex pattern matching relationships using the signatures of large amounts of data to generate qualitative information about the system, and to identify subsystem events. This function would be sensitive to subtle trends and patterns in not only individual parameters but groups of parameters as well. Statistics on the certainty of the quantitative or qualitative values returned would be maintained and passed on with the values. This facility could be the foundation of a structured and controlled data driven learning capability.
- A situation or experience driven capability to judiciously acquire data from the subsystem in order to satisfy the goals of the current operation without overloading the control system with data. This function would include a data sampling scheduler which adjusts sampling rates, or otherwise controls the supply of data according to the current and anticipated needs of the control system.

SYSTEM STATE/SITUATION ASSESSMENT tasks are associated with describing the current state of the system and identifying the state(s) to which the system may be headed at any time. Some of the activities included in this function would be configuration management, failure detection, subsystem performance status, subsystem response prediction, etc. This function would also establish specific control goals to optimize the current state and would accept higher level goals/objectives from the process management function with which to modify the specific control goals.

Expert system applications in this area may include:

- Goal management. In the context of OMS, vehicle operations imperatives and resource management objectives will be submitted to all subsystem controllers routinely. Each subsystem must, therefore, have facilities to process these objectives into subsystem control goals and to further modify these goals as operating environments or the objectives themselves change. Objectives will change, for example, with Crew Activity Plan modifications within the OMS which subsystems will need to respond to and plan for prior to implementation. The process controllers must be able to assign priorities and temporal order to the incorporation of these goals into the control strategy.
- Failure detection. Most critical failures which occur within systems of this nature can reliably be detected using conventional numerical techniques (i.e. redline limit violations, etc.) There may, however, be situations where qualitative reasoning can effectively enhance the purely numerical approach. Cascading failure detection, multiple independent failures, and failures involving incomplete or erroneous instrumentation readings are examples of these situations.
- Configuration verification. In this task, the subsystem configuration (e.g. valve positions, active components, operating mode, operational margins, etc.) is checked and verified prior to initiating any command plans. If the parametric information which the system normally uses to determine configuration becomes disabled or is otherwise incomplete, the conventional approaches will not work, and the control system could be in danger of issuing improper or incorrect commands. A knowledge based approach becomes necessary to indirectly ascertain the configuration by referring to other available instrumentation and inferring the result either through application of rules or by reference to directed (narrow scope) math models to establish plausible solutions.
- Trend analysis. The class of subsystems described here is naturally dynamic during normal operations. A qualitative analysis of the parametric trends (either individually or as groups of parameters) is often necessary to explicitly describe the state of the subsystem and to predict what states, or situations may arise with the current control approach. Trend analysis is sometimes required as well to help identify failures within the system.
- Model-based determinations will at times be required to establish details of the goal state for the system and to enable limited prediction capability for evaluating effects of proposed changes to the system as suggested by other controller functions. These process models would necessarily be of fairly narrow scope to allow efficient application of the models in real time and to assure reliable and consistent results which are easy to interpret. The models could be empirical, analytical, or hybrid representations of the process.

CONTROL ACTION DETERMINATION tasks combine to produce a control strategy and a plan to accomplish the established goals for the subsystem. The plan would consist of direct commands to be sent to the subsystem (with expected results of each), diagnostic strategies, or conditional strategies as required, in order to realize the goals. This function must also provide an effective replanning function whereby current plans are gracefully terminated and new plans are initiated as a response to changes in goals or to critical events within the system. This function would maintain flight rule standards and would verify the integrity of the system configuration and redundancy state as major factors of the provided plan.

An application area of expert systems within this planning function with great payback potential is adaptive control. Adaptive control in this context can be viewed as the techniques by which the implementation plans of the controller establishes and tailors the control strategies for the entire subsystem, and/or the response characteristics of the individual control loops (by modifying control loop gains, lag times, etc.), in order to realize the current and anticipated goal states for the process. Implementation of this function should be viewed as the principle area of enhancement to the conventional process control theory as applied to the subsystem. This activity necessitates the granting of control authority to an 'autonomous supervisor' function in order to change strategies and responses within a well developed performance envelope. It is an responsibility of this expert function to recognize its limits of control authority and never operate outside this envelope without the approval of human operators. Conceptually, the performance boundaries of the adaptive control planning function should be changeable, but only by appropriate human operators, not the controller.

Another potential expert system application area for this function is failure recovery. The proper response to failures, once detected, is not always clearly procedural. Responses can vary depending on the current state of the system, the desired goal state(s), the severity of the failure (if discernible), crew safety, changing flight rules, the criticality of the failure, available redundancy, other existing failures, and the management of other perceived contingencies, to name a few. Expert systems present resources to efficiently manipulate both qualitative and quantitative information to resolve the many conflicting inputs, or to quickly ascertain where conflicts cannot immediately be resolved.

COMMAND EXECUTION AND VERIFICATION tasks implement the plan of action provided, verify whether each command is executed in the proper order and discern whether the anticipated system effects were realized. This function also provides a check to determine whether assumptions made during the scheduling of a command plan (such as system configuration, or boundary conditions) are continuously valid. As such, this is a task highly oriented towards computer communications and data management and major expert system applications are not obvious here (other than tasks which favorably trade off against conventional techniques in terms of performance, reliability, etc.).

PROCESS MANAGEMENT CONTROLS tasks allocate resources to each of the above functions, assign top-level task priorities, schedule activities, oversee interrupts of tasks, and monitor the overall status of the subsystem controller. This function would also communicate with the DMS, receiving vehicle operations objectives, requests for information, routing these inputs to the proper controller functions in the proper form, and providing responses to the DMS.

The primary expert system task to be performed within this function is the maintenance of subsystem knowledge as it applies to the rest of the vehicle and to the other controller functions. Specifically, this involves the activity of translating vehicle commands, objectives, or resource guidelines into clear goals or instructions applicable to the controller functions without passing unnecessary information. Once subsystem goals are established, the process manager must pass the information to the affected controller functions, establish task interrupt priorities, reallocate processor resources, etc. as required in order to oversee transition to the new objectives. The process manager must process status requests from the vehicle and must determine when subsystem events should be communicated to the vehicle due to anticipated global effects which could impact overall operational capabilities (such as reduced resource capacity).

EXPERT SYSTEM APPLICATION ISSUES

Having a suggested functional framework for what the subsystem controller must do and major areas where expert system techniques may provide the most benefit, a few major development issues which relate to both warrant some attention.

REAL TIME PERFORMANCE is a primary concern for any control system. If the control system cannot 'stay ahead' of the process being controlled, the process cannot be reliably controlled. The performance requirements for the control systems vary depending on the responsiveness of the processes. For the subsystem applications considered here, response times can vary from on the order of hours with some thermal processes to fractional seconds for the navigational requirements of an enhanced MMU. But viewed as tasks contained within controller functions, not all expert system functions will need to be equally responsive. Some tasks will always be performed on a lower priority basis and should never be highly time critical tasks, such as model-based reasoning: The selection of any programming technique, tool, or mix of technology for application to any control system task needs to be made with consideration of its demonstrated performance as well as its ability to arrive at solutions, difficulty and cost of development, maintainability, etc.

THE BASING OF SUBSYSTEM CONTROLLER FUNCTIONS on-orbit or on the ground is a decision which requires careful consideration by subsystem and OMS designers alike. Given communications resources such as two TDRSS satellites and the Space Station Information System (SSIS), it is not obvious that any of the noncritical subsystem control functions should be placed onboard. Onboard computing services will always be more scarce and expensive than similar services on the ground, particularly if the computing requirements involve multiple processor types. While specifying the criticality of functions within the control scheme is premature at this point for Space Station, this must be a strong criterion in arriving at a consistent common approach for subsystem control design.

CONCLUSIONS

Expert system applications within subsystem controllers provide the system engineer with tools to solve problems which cannot reliably be solved with conventional techniques. From this perspective, expert systems can enhance the conventional control approach and should be designed to easily interact with numerical processes. Operating within a real time system, expert system tasks should be well constrained within the envelope of known solutions, and should provide new methods for moving around the envelope with a high degree of autonomy from onboard or ground based operators. Expert system tasks should respond to human requests and commands at a high level of priority and should never be allowed to address problems which lie outside the known and demonstrated set of solutions.

While this discussion provides a structure to identify potential expert system application areas within the overall controller context, it is not a comprehensive approach. Each subsystem discipline should be made part of a process to develop subsystem controller functional requirements from the 'bottom-up' in the context of the 'top-down' development of the vehicle OMS. This should allow both hardware and software technologists to focus on what will be required for the Space Station subsystem controllers. It should also provide

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program managers clear programmatic requirements to make it possible to attain them. An effort like this will also highlight to line organizations the skills needed to support development of controller software, and should reduce subsequent software conversion and interface problems later in the program.

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