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THE APPLICATION OF INTELLIGENT PROCESS CONTROL TO SPACE BASED SYSTEMS

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Abstract

The application of Artificial Intelligence to electronic and process control can help attain the autonomy and safety requirements of manned space systems. An overview of documented applications within various industries is presented. The paper then presents a discussion of the development process and associated issues for implementing an intelligence process control system.

1.0 Introduction

Intelligent process control can be defined as the application of various artificial intelligence techniques to the control of chemical and electrical processes. Intelligent process control can provide input data validation, fault detection, diagnostics, and fault recovery implementation. Space systems to which this technology may apply include Space Station environment control systems, on-board process experiments, cooling systems for various space based systems, and future space based fuel production systems. This paper presents an overview of intelligent process control technology, and how it can be applied to various space systems.

The development of intelligent process control systems can help meet the autonomy and safety requirements of manned, space systems. For example, space station autonomy requirements specify that (6):

1. Systems be "capable of detecting and reacting to selected anomalous conditions."
2. Vital system functions must be maintained during abnormal operations.
3. "Platform systems. . . be capable of autonomously placing the platform in a safe condition."
4. Platform systems collect and transmit system information to the ground.

The first three requirements can be addressed by integrated, in-line intelligent control systems.

2.0 Applications Overview

The application of intelligent control technologies to space systems can have significant payoffs in several major areas, including:

1. Improved system reliability due to intelligent monitoring;
2. Rapid fault correction due to diagnostic and repair expert systems; and
3. Increased system efficiency due to intelligent resource management, and automated fault recovery strategies.

This section describes related commercial process control projects and how similar technologies can be applied to space applications.

The first area to which intelligent process control can be applied is intelligent monitoring of space based process systems. Embedded knowledge bases can act in a supervisory role to existing feedback controllers. The knowledge base can monitor input data to detect problems with sensory equipment or with the process itself. An expert system to validate sensor input has been developed by DuPont (8). The expert system monitors analyzer operations and notifies the operator when a fault arises. Other applications of intelligent process monitoring have been described in nuclear (7), chemical (3,9), food processing (5), and circuit board manufacturing (4) industries. Each of these applications includes the validation of sensor input. Once a thorough understanding of the system model is developed, rules concerning "feasible" input data can be developed. Factors which may indicate sensor problems include:

1. Inconsistent readings between related inputs,
2. Unreasonable input data, based on system bounds (i.e., negative fluid levels, etc.),
3. Sudden step changes in signal value, and
4. Unexpected "noise" levels in sensor values.

Some of these factors may also indicate problems with the actual process. The knowledge base must be designed to distinguish between sensor and process problems. Other factors (assuming valid sensor readings) which may indicate process problems include:

1. Unstable trends,
2. Values outside given thresholds, and
3. Performance measures determined from related process variables.

One method for detecting sensor and process problems is Statistical Process Control (SPC). SPC techniques can be integrated into the intelligent process control system's knowledge base. The use of SPC methods can be used to detect process trends before warning thresholds are exceeded, to detect shifts in the overall process, and to identify unrealistically constant input values. The application of SPC techniques to intelligent process control is described by Bailey (1) and by Blickley (2).

Once a problem is detected, the second major function of an intelligent process control system begins: diagnostics. Each of the above mentioned applications included fault diagnostics. Particularly in space applications, rapid diagnosis of system problems is critical. Diagnostic modules of intelligent process control systems are based upon system design knowledge, maintenance and repair information, and an accurate process model. Much of this knowledge is collected during ground testing of the system before it is launched. The diagnostics knowledge base should be thoroughly tested and validated with the ground system to ensure accurate diagnoses of problems once the system is deployed.

Accurate diagnostics are crucial to the implementation of system recovery or repair procedures. These procedures can be incorporated into an intelligent control system at two levels: advisory or integrated. An advisory level system suggests recovery strategies based upon the determined diagnosis. The user can then implement the suggested procedures or implement alternative procedures. An integrated in-line system would automatically begin recovery procedures where possible. Only in extremely well defined systems with time critical recovery requirements should an integrated in-line system be used. Even then, command personnel should be notified of all actions taken by the automated system.

One of the most important steps in developing an integrated intelligent process control system is the testing and validation of the knowledge base. Standard algorithm or model validation techniques are not generally applicable to knowledge-based systems. Although there have been several documented implementations of advisory level intelligent control systems, there has been very little evidence of knowledge base testing procedures or of integrated intelligent control systems.

3.0 Application Principals

The common experiences among intelligent process control applications help define some basic principals in designing such a system. The basic steps to developing an intelligent process control system are:

1. Develop an accurate process system model
2. Determine techniques for detecting problems
3. Develop a method for discriminating between sensor and process problems
4. Collect diagnostics knowledge
5. Generate recovery strategies and associate with diagnostics
6. Construct the knowledge base
7. Implement required data acquisition routines
8. Test and validate the knowledge base
9. Integrate the on-line data acquisition with the knowledge base and inference mechanism.
10. Integrate the recovery strategy and other control outputs with the actual control devices.

Figure 1 illustrates the functional components of a system developed via this process.

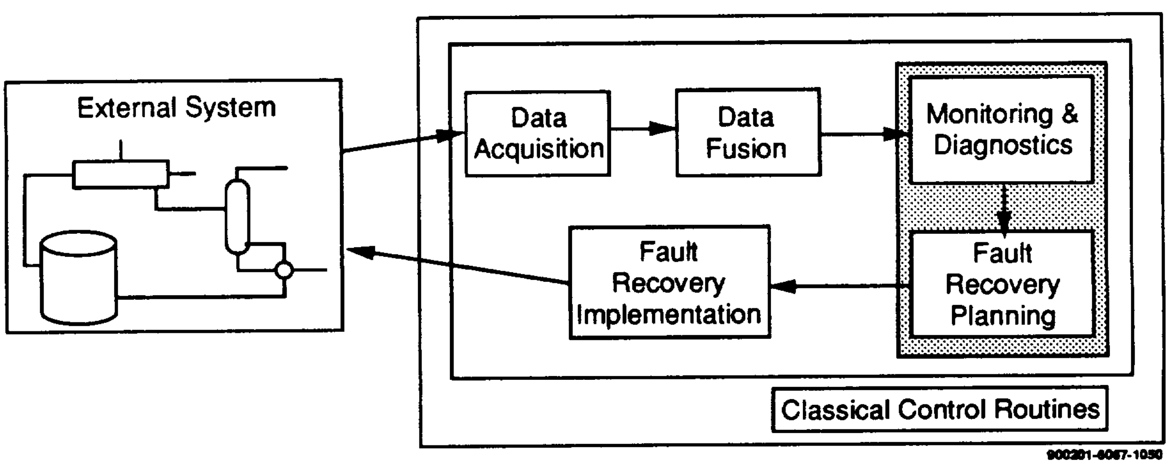

Figure 1. Intelligent Control System Top Level Structure

This process indicates that knowledge base construction is just a part of the overall development. Resources must also be committed to the test and validation of the knowledge base. As mentioned previously, the area of knowledge base testing and validation has not been extensively researched. For current research efforts, the author uses a combination of system modeling and iterative integration. Figure 2 illustrates this development process. A graphical simulation tool (developed in-house) is used to generate test scripts and to simulate system components. These simulated system events and components are used in three ways:

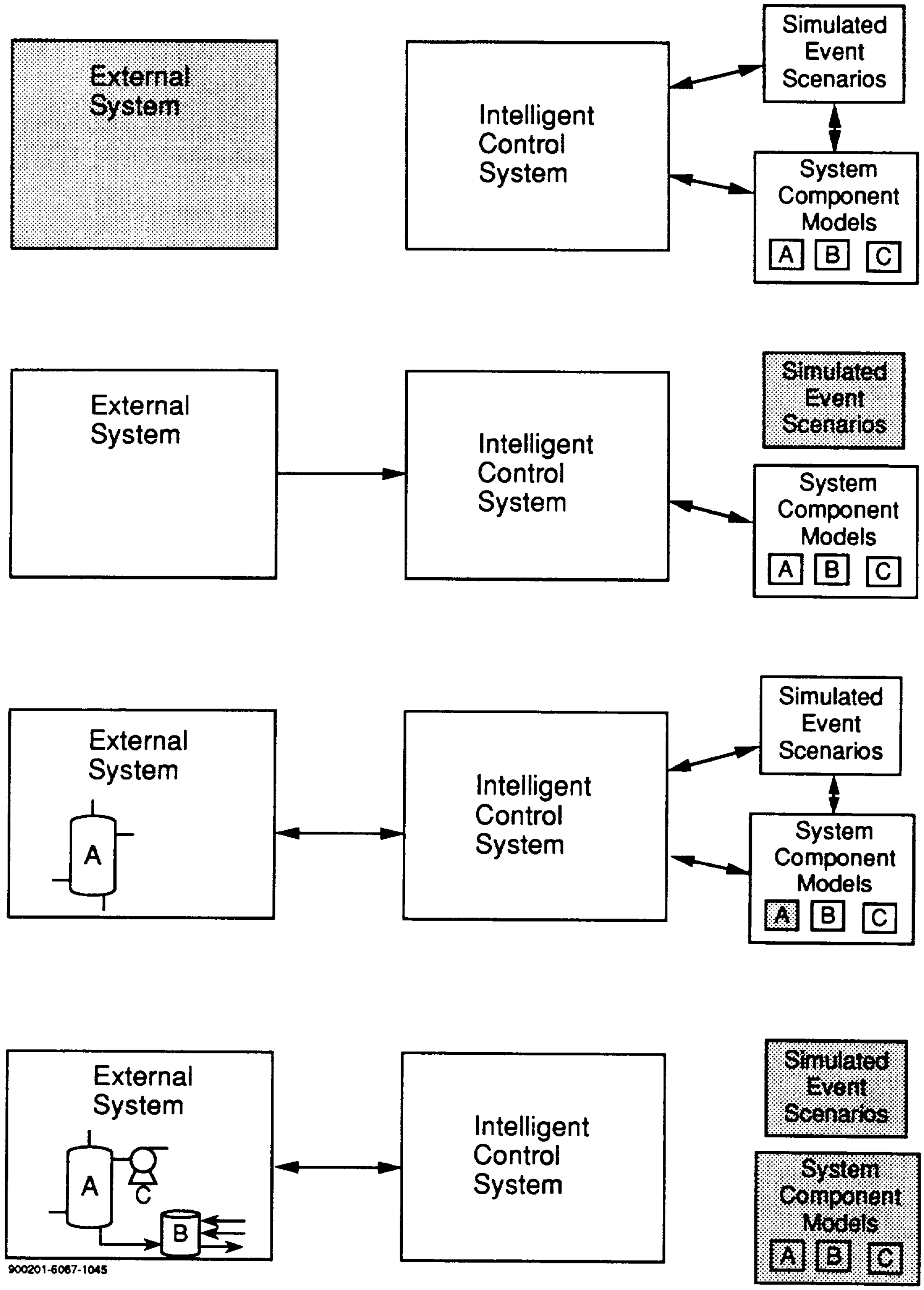

Figure 2. Step-Wise Development and Integration

1. To allow the control system developer to test various system event sequences during knowledge base construction.
2. To test different recovery strategies and their impact on the individual system components as well as the overall system.
3. To test actual in-line system components individually during system integration.

The scenario generation tool is integrated with the knowledge base as well as the system model component in order to allow interactive, dynamic determination of scenario events. For example, if the knowledge base does not diagnose the correct fault given a certain series of events, the scenario generation would stop to allow the developer to correct the problem. Otherwise, the scenario would continue. Probabilistic branching in the scenario path can be used to introduce random events into the test sequences.

Once the knowledge base has been fully validated, the process of integration must begin. This, too, can consume considerable resources. First, the hardware and/or software links must be developed for accessing the real-time data. This often involves integrating specific data acquisition routines with the inference structure. SRS has utilized the open architecture of the Nexpert OBJECT (from Neuron Data Corporation) expert system development shell to integrate data acquisition and direct memory access hardware with the intelligent control knowledge base. The ability to incorporate user defined external routines is also important for a commonly overlooked link in the overall system: the data fusion link. Often, the data obtained directly from sensors is not in a form amenable to the knowledge base. In these eases, external filters, statistical analysis, or other data fusion algorithms are used to abstract higher level information from the raw data.

The output links are even more critical to an integrated, in-line system. These routines must translate a knowledge base output to control hardware inputs. Any errors in the output routine definitions can jeopardize the integrity of the system. The simulated system models can also be used during this final stage of development since actual components can be integrated and tested individually to ensure that heuristically derived control outputs produce the desired system response.

4.0 Conclusions

This paper has presented an overview of some general issues involved in developing control systems utilizing embedded knowledge base processing. Although significant research has been conducted in the application of heuristic processing to system monitoring and fault diagnostics, further research is required in the areas of knowledge base testing methodologies and integrated, in-line systems. The use of scenario generation and system modeling tools for knowledge base testing was presented as a currently used approach. Also, the issues of integrating the knowledge base with the external systems were presented.

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