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A FRAMEWORK FOR REAL-TIME DISTRIBUTED EXPERT SYSTEMS: ON-ORBIT SPACECRAFT FAULT DIAGNOSIS, MONITORING AND CONTROL

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ABSTRACT

Control of on-orbit operation of spacecraft requires retention and application of special purpose, often unique knowledge of equipment and procedures. This information must be available for application in controlling routine as well as critical operating conditions. Expert or knowledge-based systems technology offers the capability of retaining this valuable knowledge under a variety of conditions. Even current expert systems (ES) have limitations however. A real-time, distributed intelligence system is a highly complex, human-machine system where an artificially intelligent component operates the system and the human manages it. Real-time distributed expert systems (RTDES) permit a modular approach to a complex application such as on-orbit spacecraft support. One aspect of a human-machine system that lends itself to the application of RTDES is the function of satellite/mission controllers; the next logical step toward creation of truly autonomous spacecraft systems. This system and application is described in this paper.

INTRODUCTION

Numerous complex and sophisticated human-machine systems exist which are beyond the scope and capability of current applications of artificial intelligence (AI) technology, yet these systems could significantly benefit from the application of some form of machine intelligence. This potential forms the basis for the application of AI and ES technology to real-time problems and distributed problem solving in development of RTDES. No one of the domains (real-time applications, distributed AI and expert systems) are sufficient for future autonomous systems as independent entities. One approach which embraces these domains in system development mimics the real-time problem solving ability of a human operator, using real-time paradigms in a heuristic structure.

Distributed AI is the technique by which several physically or logically separated AI programs cooperate to achieve a system-wide goal [4]. Distributing the decision-making AI programs in a real-time application has the potential to achieve the following benefits:

1. Allow autonomous operation of field units
2. Greatly enhance system fault tolerance
3. Allow modular increases in system capability

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4. Significantly decrease communications required between field units and a central decision maker.

The application of a distributed intelligence system provides a transition from totally manual to totally automated systems; a hybrid system of sorts.

DIFFERENT METHODOLOGY

The methodology and structure used to create autonomously operating individual AI programs in a nondistributed environment differs from the methodology used to produce AI programs that have to interface with one another. A decision-making program operating in a nondistributed environment is usually structured to achieve a specific goal or set of goals using a limited number of plans to reach these goals. These plans operate in response to input events and actions occurring in the environment. AI programs in a distributed environment dynamically modify their goals and plans in response to decisions made by other AI programs in the system [7].

In a distributed AI system, decisions made by each AI program (which could be considered a "module") depend on decisions made and actions taken by the other modules in the system. Both concurrent and non-concurrent events affect other events. Each AI program cannot have a knowledge base that provides for all combinations of occurrences that might happen system-wide. Each individual intelligent module must have the capability to dynamically alter its course of action based upon inputs from other modules. Each intelligent module must also have some degree of knowledge regarding the types of objects and events (i.e., new information) by the other modules. A critical issue yet to be solved for distributed AI is coordination of distributed AI modules.

Perhaps the most important feature of having AI modules reside within the individual entities (or sites) is the ability to intelligently determine what information should be transmitted to a central control center. If site intelligence were not available, entire streams of data would be transmitted each time new information was sensed at the individual sites. This selective information is shown as compressed data in Figure 1. The local intelligent sites are "intelligent" only in terms of local decision-making, and do not possess any mission or system strategies. Figure 2 depicts a distributed AI adaptation of the centralized control scenario. This distributed architecture places the greatest emphasis upon mission performance.

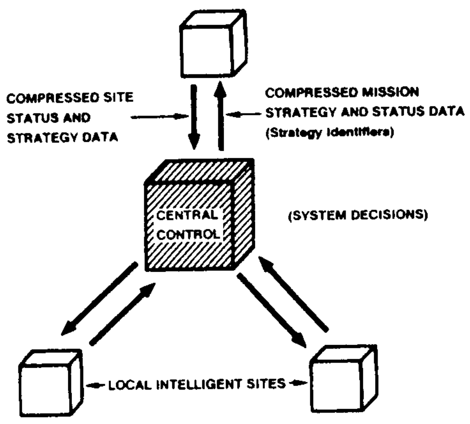

Figure 1. Centralized Control Structure

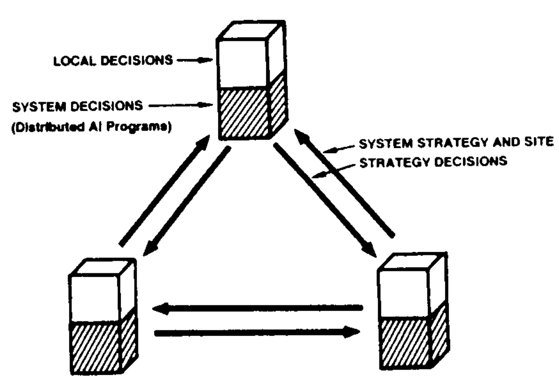

Figure 2. Distributed AI Control Structure

It is clear that diagnostic problems tend to make good applications of ES techniques [5]. This is because many diagnostic problems that are fully understood cannot be written algorithmically. For example, if the analysis is limited only to single component failures (as in even the simplest spacecraft system), there are still too many permutations for all cases to be deciphered explicitly. This combinatorial explosion is avoided in expert systems since the search tree is built at execution time and explores only the most promising branches.

SPACECRAFT OPERATION AND CONTROL

While an expert system can be used to consolidate a number of functions that analyze and monitor data during spacecraft passes or normal on-orbit operation, inherent limitations still remain. These limitations form the basis for the application of different structures and methodologies.

On-orbit spacecraft operation, including fault diagnosis, requires special purpose knowledge. This body of knowledge is acquired over decades, and is one of the most valuable resources of any large-scale program [6]. Unfortunately, this knowledge is most often lost with human attrition. ES technology offers the capability of retaining this knowledge, and in addition performing critical tasks faster and more reliably than humans, such as battery reconditioning, launch operations and resolution of anomalies.

The facilities and methods established for satellite command and control are quite basic and reliable. Raw data (telemetry) acquired via the assigned or scheduled tracking station is transmitted to a control center for processing. The "housekeeping" data is processed within a multisatellite data processing (DP) hardware and software complex for ultimate display to a spacecraft controller console. A variety of interfaces are available (e.g., CRTs, computer graphics, strip chart recorders, etc.). The "payload" data is processed specifically according to mission user requirements and disseminated appropriately. Processing of this data is usually affected off-line and incorporates the necessary corrections due to attitude and orbital influences [1, 3]. Alarm conditions triggered from digital and analog parameters exceeding pre-defined limits usually invoke a manual response.

A human-machine system such as satellite operations is an outstanding candidate for an RTDES application, based upon the telemetry, tracking and command functions described above. The advantages of this application include autonomous site operation, a high degree of fault tolerance, the ability to increase system capability modularly, and a decrease in real-time communications (due in part to data compression) between a central unit and local sites. The incorporation of one or more AI modules into such a system could enhance operational success because the controller would be freed from his/her time-sharing responsibilities, and thus have more time available to deal with a variety of more difficult, complex problems which might develop. This implementation process is evolutionary and iterative in nature, and could be a step towards the eventual elimination of a satellite control center.

It has been postulated that the definition of real-time processing is application dependent [2, 4]. Real-time in a satellite control application might be considered to be a data processing response on the order of hundreds of milliseconds. It is this sort of high-level real-time application that must be addressed.

PERFORMANCE EVALUATION

The overall effect of incorporating one or more AI modules into a complex system can enhance system performance. One effect which can cause this result is the application of AI modules which makes the human's job easier.

Design of RTDES by incorporating artificially intelligent components into portions of a human-machine system does not guarantee enhanced system performance with the same or less input. The humans who remain involved with the resulting RTDES must be adaptable to work with the new creation. There are also a number of other compatibility considerations which must be addressed in the design phase, all beyond the scope of this paper.

Another consideration is that of cost effectiveness. It may prove difficult or impossible to isolate which subtasks can be supported by AI modules. This seems likely since it can be difficult to extract valid data on controllers regard for each subtask as part of the overall task. This difficulty arises because some subtasks are not independent but highly interrelated with other subtasks, and cannot be analyzed separately [7].

Overall communications requirements in RTDES are greater because system strategy decisions made by each site or unit must be relayed and coordinated with all other units.

CONCLUSION

Although significant progress has been made in artificial intelligence and expert systems technology, workable methods have not yet been developed for sophisticated real-time distributed AI-based systems.

The use of artificially intelligent local modules in a complex, distributed, real-time system offer the potential for significantly reducing the communications required to and from a centralized decision-maker, as shown in Figure 2. These modules can also provide a high degree of fault tolerance [2, 4, 7]. The associated benefits as a result of this application were outlined in the introduction and mentioned throughout.

The AI technology required to perform the communications, coordination, and control between the distributed AI modules is in the early research stage and many researchers in distributed AI are not addressing the real-time nature of systems [4] such as presented in the satellite control problem. Technology transfer from various AI disciplines will be required as a base for developing methods to implement real-time distributed AI. There is a need for these applications in a variety of disciplines.

The design of RTDES and similar types of systems are in the developmental stage. A number of relevent research issues exist which should be addressed in the immediate future:

1. Now that AI and expert systems are maturing, primary emphasis should be placed upon real-time implementations.

2. Further investigation is needed into the problem of communication and coordination among distributed AI programs.

3. Similarly, investigation into the criteria used to intelligently determine what information should be transmitted to other AI components needs to occur.

4. Research is necessary into the isolation of subtasks to be supported by AI components and subsequent interrelationships.

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REFERENCES

[1] Barret, M., "Impact of Spacecraft Design on Remote Control of Satellite Operations", IFAC Automatic Control in Space, Noordwijkerhout, The Netherlands, 1982, pp. 563-7.

[2] Hawkinson, Lowell B., Levin, Michael E., Knickerbocker, Carl G., and Moore, Robert L., "A Paradigm for Real Time Inference", 1st Annual Artificial Intelligence and Advanced Technology Conference, Long Beach, California, 1985, pp. 51-56.

[3] Kornell, Jim, "A Satellite with a Good Attitude: An Expert System for Stationkeeping", Third IEEE Conference on Artificial Intelligence Applications, Denver, CO, December 1986, pp. 111-117.

[4] McDaniel, Bonnie G., "Interface Requirements For Real-Time Distributed Artificial Intelligence", Proceedings, IEEE International Conference on Data Engineering, Los Angeles, CA, April 1984, pp. 241-245.

[5] Mullikin, Richard L., "The Commercialization of Artificial Intelligence: Identification, Assessment and Implication of an Integrated Decision Support System and Expert System", Master Thesis, Loyola Marymount University, Los Angeles, California, 1986.

[6] Scarl, E.A., and Delaune, C.I., "LOX Expert System", Proceedings, 21st Space Congress, Cocoa Beach, Florida, April 1984, p. 2-16.

[7] Smith, Leighton L., "The Distributed Intelligence System and Aircraft Pilotage", Artificial Intelligence and Simulation, Simulation Councils, Inc., San Diego, CA, 1985, pp. 26-28.