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AN INTELLIGENT AUTOMATED COMMAND AND CONTROL SYSTEM FOR SPACECRAFT MISSION OPERATIONS

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ABSTRACT

The Intelligent Command and Control (ICC) System research project is intended to provide the technology base necessary for producing an intelligent automated command and control (C&C) system capable of performing all the ground control C&C functions currently performed by Mission Operations Center (MOC) project Flight Operations Team (FOT). The ICC research accomplishments to date, details of the ICC and the planned outcome of the ICC research, mentioned above, are discussed in detail.

INTRODUCTION

Beginning this year and extending into the foreseeable future mission operations personnel are being required to operate more complex ground systems with less flight operations team (FOT) personnel and lower budgets than in the past. The Intelligent Command and Control (ICC) system research is intended to provide the technology base necessary to solve these problems through automation and intelligent machine Case-Based reasoning and decision making. The need for the ICC is due in some cases to the fact that FOTs will be asked to command and control (C&C) more complex missions such as those of the Earth Observing System (EOS) and in others to the fact that FOTs will be required to operate several spacecraft concurrently from the same Mission Operations Center (MOC), such as in the case of the Small Explorer (SMEX) and the International Solar and Terrestrial Physics (ISTP) missions. These facts require that we develop an intelligent C&C system which is capable of acting as a cooperative assistant to the FOT, reduce the workload of existing FOTs, and reduce the cost burden of creating ever larger FOTs.

DEFINITION

The Intelligent Command and Control (ICC) System is designed to ultimately produce the technology necessary for development of a highly intelligent automated machine based C&C for Spacecraft mission operations which is capable of performing all the C&C functions currently performed by FOTs. While that is the ultimate goal, it should be noted that many very valuable interim products are being produced and will be produced which are and can be used to improve, automate, and reduce the cost of MOC operations.

This project was originally planned as a five year research project but, while interest in the ICC research is very high in the Space Ops and process control communities, funding has been halved and therefore the end-point of the ICC project is now 8-9 years out from the original start point of April, 1993.

A detailed description of the technology involved is provided later in this paper.

Program Objectives

The following are the objectives of the ICC research and development program:

1. To demonstrate that we can improve and simplify spacecraft MOC command and control by building and operating a real time Intelligent Command and Control (ICC) system utilizing AI, object oriented techniques, & animated graphical user interfaces.

2. To create a command and control system that can act as a cooperative member of an FOT.

3. To demonstrate that Mission Operations Center (MOC) Command and Control functions can be fully automated and that such a system can perform intelligent machine based decision making.

4. To demonstrate that such a system would show tremendous savings in both development and operating costs by:

* Limiting or reducing the number of FOT personnel.

* Intelligently automating spacecraft MOC functions to the point where management by exception can become a reality.

* Reducing operator error through more intuitive user interfaces, automation, the use of true machine decision making, and the application of standardized commands.

Technical Approach

The technical approach we have chosen to accomplish these objectives is as follows:

1. Establish a collaborative activity among the Mission Operations Division's (MOD) technology and operations groups, academia, and private industry.

2. Survey and evaluate existing advanced technology products available for possible use in the ICC.

3. Select and use an existing command and control system as a baseline with which to compare the ICC.

4. Prototype & evaluate the ICC using reiterative validation and development techniques.

5. Perform a side by side evaluation of the ICC and the baseline C&C.

Completion of ICC Research

Successful completion of the ICC research project is defined as completing a successful side by side test of a working ICC prototype and the baseline C&C. The comparison of the baseline C&C with the ICC will involve five steps:

1. Collecting data on the current or baseline C&C.

2. Turning off the baseline C&C and taking over all C&C functions with the ICC prototype for at least one pass.

3. Collecting data on the ICC prototype.

4. Turning off the ICC prototype and returning command and control to the baseline C&C.

5. Steps 1 through 4 above will be repeated until sufficient data on the performance and reliability of the ICC prototype has been collected to establish the results and conclusions of the ICC research.

Significance and Benefits

The following benefits potentially apply to all future NASA missions. Specific and strong interest in the ICC research, its results and products have been received from the following projects and organizations: ISTP, SMEX, Hubble Space Telescope (HST), EOS, and the Network Management and Operations Support (NMOS) Flight Projects Support Division, and the European Space Agency (ESA).

Expected benefits of the ICC research are:

1. Reducing operator error through more intuitive user interfaces, automation, and selection of standardized commands.

2. Lowering system supervisory costs through the use of management by exception.

3. Limiting or reducing the number of FOT personnel.

4. Faster, more cost effective and robust spacecraft system status, and operations simulators and models.

5. Simplified and reduced cost of training through the use of a command and control system which is both more generic, or standardized, for all missions, and internally more flexible (i.e. easier to modify for specific missions).

Accomplishments

Accomplishments to date are as follows:

1. Completed technology survey.

2. Completed 1st Transportable Payload Operations Control Center (TPOCC) Task Analysis (SMEX).

3. Completed ICC Prototyping Plan .

4. Completed Operator Function Model.

5. Completed initial ICC MOC Simulator which accepts actual TPOCC data as input .

6. Completed Task Analysis of Anomaly Detection and Correction Processes.

Deliverables and Future Accomplishments

The deliverables and accomplishments expected for the remainder of the ICC research project are as follows:

FY '94

7. Develop Case-Based+ Reasoning Tools for ICC.

8. Develop Advanced Tutor-Aid Paradigm for use in ICC (described below).

9. Complete Automation Analysis for implementation of control center management by exception.

10. Complete Second Task Analysis (ISTP).

11. Complete initial, basic research ICC Prototype.

FY '95

12. Conduct reiterative redesign and reevaluation of basic ICC prototype.

13 Complete detailed architecture (both structural and functional) of the ICC Inference Engine.

FY '96

14. Construct robust ICC MOC Simulator.

15. Begin construction of ICC inference engine.

FY '97

16. Complete Construction of ICC inference engine.

17. Conduct reiterative Integration and Testing (I&T) of ICC components.

18. Assemble ICC components into robust ICC prototype.

FY '98

19. Conduct reiterative I&T, evaluation, and redesign of complete robust ICC prototype.

20. Conduct sided-by-side test of ICC and baseline C&C.

Item Twenty (20.) marks the end of the research phase of the ICC project.

Technology Description

Functional Description:

Downlink Telemetry Handling:

The completed operational ICC when fully integrated into MOD operations will reside in the TPOCC workstation accepting data from the Front End Processor (FEP) Data Server Task (DST) and consist of the following: An intelligent object oriented command and control system capable of accepting downlink telemetry in real time, and passing the telemetry (or database) updates to the ICC Reasoning Machine (RM). The RM, or inference engine using case based, and most probably a combination of AI machine reasoning techniques, will match the input with robust spacecraft and ground control system models/simulators and then decide what actions should be taken based on that information. The ICC will decide whether these actions are to be taken by the ICC directly, sent to the human operators (FOT) for further action, sent to other ground control systems (e.g., small Generic Systems Analyst Aid [GenSAA] built expert systems), or other users (e.g., Primary Investigators, or subsystem engineers) . What actions the ICC takes can be preset by the FOT, have default settings or be based on previous cases or extrapolations from such cases.

Uplink Commanding:

The Command side of the ICC will be capable of acting cooperatively as another member of the FOT. It will be capable of accepting and sending commands in real time, from a number of sources: default routine commands set by the FOT prior to the mission, commands set by the FOT for a given pass, Reasoning Machine ordered commands sent in response to electronic input. Whatever the source of the commands, it is currently envisioned that they will be converted from either operator graphically generated commands or RM generated commands into the Systems Test and Operations Language (STOL) commands that will be processed by the existing STOL Processor. That is our current plan, although we may find that the ICC can bypass STOL and go directly from machine generated commands or human graphically generated commands to a lower level language.

User Interface Description:

The user interfaces (UI) will be, mostly, graphical animated user interfaces. The guiding principle behind any UI design and the first question which will be asked in designing each user interface will be "What type of user interface most enhances task (and thereby mission) performance?" Therefore some user interfaces will be two dimensional graphical animated interfaces (such as those currently used in the operational Visually Inspectable Tutor and Assistant [VITA] training system [Chu, 1991]). Others will be real time interactive 3D graphical animated interfaces (such as those being developed for the 1997 Hubble Space Telescope (HST) Servicing Mission), some will use voice interactive interfaces, and still others will be alpha-numeric command line interfaces. The idea is to apply the most effective type of interface for the task to be accomplished and this will be determined by a reiterative process of prototyping and prototype evaluation using FOT personnel to conduct the evaluations.

Detailed Description of Conceptual Deliverables:

The following descriptions and discussions are derived primarily from work conducted under a NASA grant by Dr. Christine M. Mitchell of the Georgia Institute of Technology (Mitchell, 1994).

SAMPEX Operator Function Model:

The Operator Function Model (OFM) is a hierarchical-heterarchical decomposition of the FOT functions required to carry out real-time operations involved in satellite ground control. The OFM provides a detailed normative model specifying how operations are intended to be carried out. The OFM is hierarchical. At the highest level it specifies the components that comprise the overall real-time operations: pre-pass, on-pass, and post-past. It decomposes each function into its component activities that may be mapped to lower levels including sub functions, and tasks. At the lowest level, the OFM specifies operator actions, both, manual (e.g., issue this command) and cognitive (e.g., check the current state of the power subsystem) needed to carryout individual tasks. The OFM is both heterarchic and dynamic. Its components depict the concurrent activities typical of satellite ground control (e.g., execute and monitor a command to ensure that it is properly carried out at the same time as running procedures to up-load another command). The dynamic component provides the context:

triggers represent how new operator activities manifest themselves as a result of system events and previously executed operator actions.

SAMPEX Task Analysis of Anomaly Detection and Correction Processes:

This analysis is intended to understand how often and what happens when unanticipated events and anomalies occur. The study addresses events that occur post launch and early orbit (L&EO), i.e., examination of those events that are considered to have occurred during the SAMPEX nominal operations phase. In particular, the study documents for each anomaly (other than those identified by one of the SAMPEX experts as a peculiarity of the L&EO) the process of 1) failure detection (i.e., when, how, by whom was the anomaly first noticed?); 2) failure management (i.e., how long, and what happened, between the time when the anomaly is first detected, and when corrective action is initiated); 3) fault compensation (i.e., what was done, who did it (with emphasis on the decision maker's qualifications, e.g., spacecraft analyst, command controller). The study will include identification of time required to resolve the anomaly and distribute information to the FOT. This study will be coordinated with the SAMPEX OFM, particularly with respect to the issue of non-preplanned activities. Recall, the OFM will include comments on what actions are pre-planned (always, usually, sometimes), opportunistic (i.e., planned and executed on the fly without inclusion in the pass plan). In the latter case we will attempt to document the types of opportunistic activities undertaken and the personnel who formulate and execute them (e.g., lead analyst, spacecraft engineer).

Case-Based Reasoning for Real-Time Ground Control Operation:

Building a Knowledge Base of Experience of Real-Time Decision Making:

This component of the ICC project will investigate the use of case-based reasoning technology to accumulate a knowledge base of actual operations experiences and, subsequently, to use that experience as aid or advice in an intelligent decision support system. Initially such a system monitors real-time operations forming a knowledge base that reflects the range of nominal operations. As unplanned and/or anomalous events occur the case base grows, in fact it automatically learns, broadening its knowledge base to include operations experience accrued in managing these unanticipated events. Such a system uses case-based reasoning technology to build an extensive repository of operations experience--i.e., cases, that over time, can function as the knowledge base for an autonomous system. This project represents one of the first applications of case-based reasoning to real-time decision making and system control. It provides an alternative, and potentially richer, knowledge base than such applications as rule-based systems. Given the extent of operational experience that comprises the foundation of FOT expertise, a case-based system that can learn from skilled operators is a promising way to encapsulate and capitalize on human experience and subsequently make it available to both other operators and intelligent systems.

The Tutor-Aid Paradigm

This project builds on the highly successful VITA intelligent tutoring system as the first component of an integrated tutor-aid architecture. The tutor-aid paradigm proposes that an effective approach to operator aiding and training is the integration of aiding and training into one comprehensive system that differentially responds depending on the skill level of the operator. An integrated tutor-aid provides a great deal of assistance and guidance to unskilled operators, i.e., operators-in-training; as the operator skills increase the tutor becomes less active and transitions into a well-understood assistant. The tutor-aid paradigm promises to be very effective. An integrated tutor-aid system is cheaper to build and maintain. Functionally, a versatile and intelligent tutor is likely to evolve into a well-understood and trusted aid. The knowledge bases that support an intelligent tutor-aid system (e.g., system and task models of what to do, how, and when) are exactly those needed for more autonomous system operation and control.

ICC-TPOCC (A Real-Time Simulator of the Operator Interface to TPOCC-Based Ground Control Systems):

Another component of the ICC project is the development of a research/experimental testbed, the ICC-TPOCC testbed. In addition to research concepts exploring intelligent systems for operator aiding and training, the ICC project is concerned with proof-of-concept demonstrations and evaluations of these technologies. Long term, the intent is to provide a side-by-side demonstration comparing conventional operations with operations incorporating the proposed aiding systems. In the interim, the individual research efforts can be demonstrated and empirically evaluated in the context of the ICC-TPOCC testbed. The ICC-TPOCC testbed is a real-time simulation of the operator interface to the satellite ground control system. It is modeled after the SAMPEX TPOCC mission operations center operations. The testbed provides the ICC project with the ability to implement the proposed system, and using NASA operations personnel as subjects, conduct experiments that compare current and proposed systems.

Automation Analyses:

Two studies comprise the final component of the ICC: an in-depth analysis of the feasibility of a completely autonomous control center and a statement of working assumptions that underpin the belief that an autonomous control center is possible. The feasibility study will examine the existing facilities and procedures integral to satellite ground control, specifically focusing on impediments to a completely autonomous control center (why are operator's needed and what do they do). As impediments to intelligent automation are identified, the study will attempt to suggest technological alternatives to the impediments. The sets of impediments and technological alternatives define the basis of the second study. This study will articulate a set of working assumptions that define the operating practices (current or needed in the future) essential to moving to fully autonomous ground control operations.

State of the Technology

Current technology in operational use employs windows and some point and click interfaces but is still highly tied to alpha-numeric command line and telemetry display technology. Very little artificial intelligence (AI) and animated real time graphics is built into any of the current operational command and control systems.

The technical challenges to developing the ICC lie, first, in the area of developing the most intelligent inference engine possible, second, in determining the most intuitive and cost effective graphical animated user interfaces. The third area is that of developing robust spacecraft simulators/models. The fourth technical challenge is that of integrating the ICC with the TPOCC systems.

Research Team

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Operations

5. Orbit Determination

* *Presented in Poster Session*