

11124

SPACECRAFT COMMAND AND CONTROL USING EXPERT SYSTEMS

July 22, 1994

Scott Norcross and William H. Grieser
Storm Integration, Inc.
CIT Tower - Suite 502
2214 Rock Hill Road
Herndon, VA 22070
(703) 478-6200 FAX (703) 478-6670

S3-17
31944
P-6

INTRODUCTION

We are in the midst of a revolution in the spacecraft command and control industry. This revolution is driven by several factors. Traditional customers of spacecraft command and control systems (like the government) are now trying to do more with less money. Where in the past the government would be inclined to design and build a system from scratch, today they are looking for an off-the-shelf solution. Another factor contributing to the changes in spacecraft command and control is the advancing technology of spacecraft. Several commercial ventures are underway to exploit large constellations of relatively cheap satellites. These new commercial space opportunities create a need for more economical command and control systems to satisfy these bottom-line oriented endeavors.

Some of the changing requirements in the market include:

- The skill level required to operate the system on a day-to-day basis is lower than required by traditional systems.
- The number of human operators required per satellite is smaller.
- The user interfaces are becoming graphical, as opposed to the text-based interfaces of traditional systems.
- The amount of time to prepare for a spacecraft mission is decreasing, making it harder for satellite users to develop their own system from scratch.

This paper describes a product called the Intelligent Mission Toolkit (IMT), which was created to meet the changing demands of the market. IMT is a command and control system built upon an expert system. Its primary functions are to send commands to the spacecraft and process telemetry data received from the spacecraft. It also controls the ground equipment used to support the system, such as encryption and decryption gear, and telemetry front-end equipment. Add-on modules allow IMT to control antennas and antenna interface equipment.

The design philosophy for IMT is to utilize available commercial products wherever possible. IMT utilizes Gensym's G2 Real-time Expert System as the core of the system. G2 is responsible for overall system control, spacecraft commanding control, and spacecraft telemetry analysis and display. Other commercial products incorporated into IMT include the SYBASE relational database management system and Loral Test and Integration Systems' System 500 for telemetry front-end processing.

Use of Expert Systems in IMT

Spacecraft command and control consists of a repetitive sequence of planning, contact and evaluation activities. During these phases, events occur and information is gathered that determine subsequent actions required to control the spacecraft. Traditional control systems require system operations personnel and spacecraft engineers to manually determine the appropriate responses to these events. In addition, to respond to recurring anomalous conditions that can be overcome via procedural solutions, operators often document detailed system conditions in a log book or operations manual. These references are examined by operations staff to determine how to resolve specific system conditions. If these conditions are not properly documented and accessible, the operations staff must consult with the operations "expert" to determine the appropriate course or action.

Using IMT's satellite support plan functions in combination with the embedded expert system, complex system conditions and responses are captured within a system knowledge base. IMT identifies specific events and conditions and invokes rules, procedures or specific satellite support plans to generate appropriate system responses. In this capacity, IMT stores, recalls and implements the knowledge of the system operations staff. The system can automatically respond to specific events or present suggested actions based on system conditions. The following are particular examples of how IMT implements these principles.

Telemetry Analysis and Display

The G2 expert system can be used to analyze telemetry data emitted by a spacecraft and determine the state of the spacecraft. G2's inherent ability to model real-world objects supports sophisticated analysis of complex data. The data can also be displayed to the user through G2 objects, presenting the data in a format that is easier to understand than traditional text-based displays.

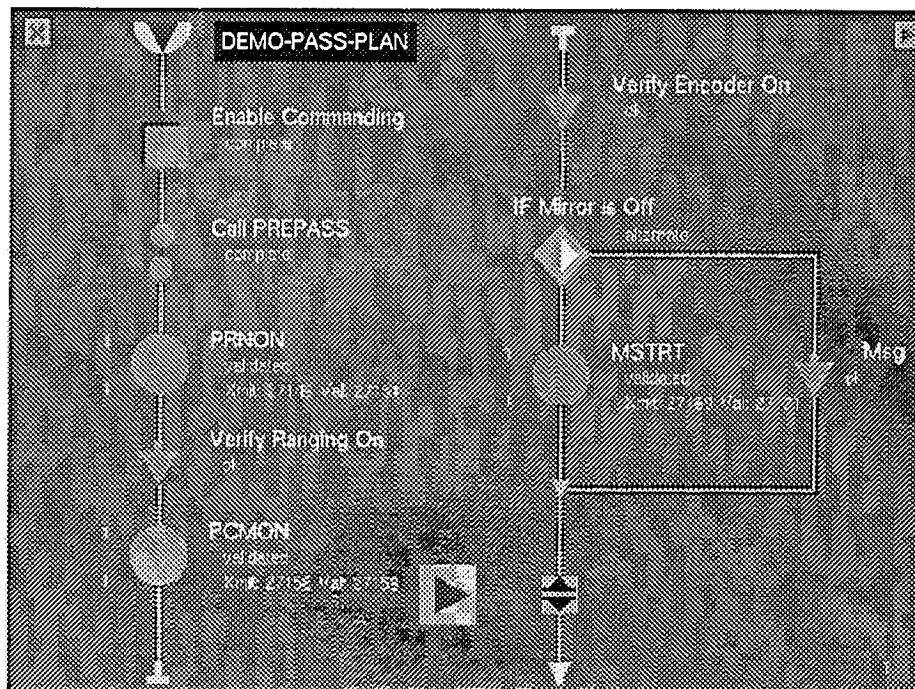


Figure 1 - IMT Graphical Pass Plan

Graphical Pass Plan

In IMT, a "pass plan" is a sequence of spacecraft commands and system configuration actions called "steps." IMT uses G2 to represent each step as a G2 object, and the flow of execution through the steps is indicated using the G2 connection facility. A graphical pass plan resembles a flow chart, which is more intuitive than the proprietary commanding languages used by other command and control systems. As the pass plan is executed, the current step is highlighted; status information about each step is presented along with the G2 icon for the object.

There are two ways to create pass plans. The first is to select commands from command palettes and connect them into graphical sequences to form pass plans. The second way to create a pass plan is to build an ASCII file using an off-line process (e.g. using an editor or the output from another tool). IMT's Pass Plan Import function is then used to convert the ASCII file into a graphical pass plan where it can be executed like any other pass plan.

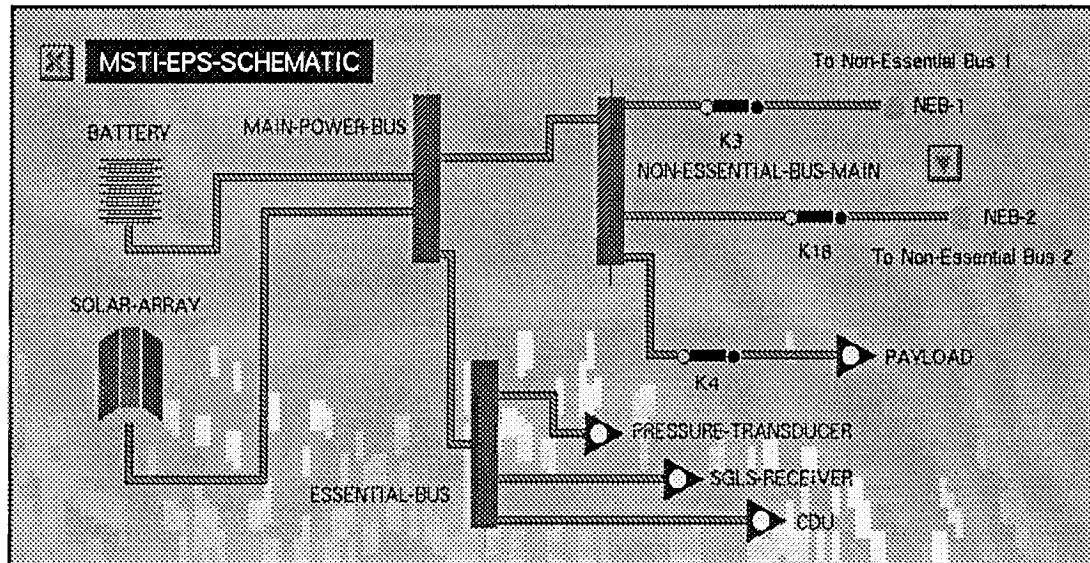
IMT supports two modes for pass plan execution: manual and automatic. Automatic execution provides the first step toward the complete automation of system operation. During automatic execution, command sequences are executed without operator intervention. Automatic execution continues until the sequence is completed successfully or until an anomaly is detected. Anomaly detection could be based on the inability to properly transmit the command from the ground system, a command rejection from the spacecraft, or the result of a complex set of rules developed to verify the command operation.

Logic in Pass Plans

Logic is provided through an "if step," which is analogous to an "if" statement in a high level computer programming language. When an "if step" is executed, G2 executes rules provided by the pass plan builder to determine which step should be executed next.

Interactive Telemetry Displays

IMT can be used to build "smart" interactive telemetry displays. These displays allow the operator to control the spacecraft by directly manipulating graphical representations of the system. For example, circuit diagrams representing portions of the electrical power subsystem can be created that contain graphical representations of subsystem components. The user could then click on the graphical representation of a switch to change the switch's position to allow (or prevent) current flow to the subsystem. This frees the operator from having to know the details of specific commands required to manipulate a system component (spacecraft or ground system) and creates a more "results oriented" user interface.



Command Verification

Traditional spacecraft command and control systems require manual examination of telemetry to determine the status of a spacecraft component or subsystem. Manual actions are initiated based on the examination of this data. For example, after transmission of a command, operators may continue to view telemetry data to determine if the spacecraft received the command and is responding as expected.

IMT uses expert system rules to automate the analysis of telemetry data, determine the status of the spacecraft, and identify necessary control actions. Specific control actions are captured in rules which are invoked after command transmission. Rules can be designed to examine specific data points and determine whether the desired reaction was achieved. Actions, as directed by the operations experts, can be initiated based on the results of the execution of these rules.

Commanding Constraints

Before a command is transmitted, IMT consults the knowledge base to determine whether it is acceptable to send the command. IMT allows the operator or engineer to specify command transmission constraints. To specify a constraint, a rule is written to which G2 backward chains during command transmission. These rules can refer to any available data to reach this conclusion. This includes telemetry data, system state, and even the person making the request to send the command. Using G2, it is easy to define constraints that can be turned on and off.

By defining a rich set of constraints, the end-users can customize their system to minimize the risk of using lower-skilled spacecraft operators.

Automatic Analysis of Pass Plans

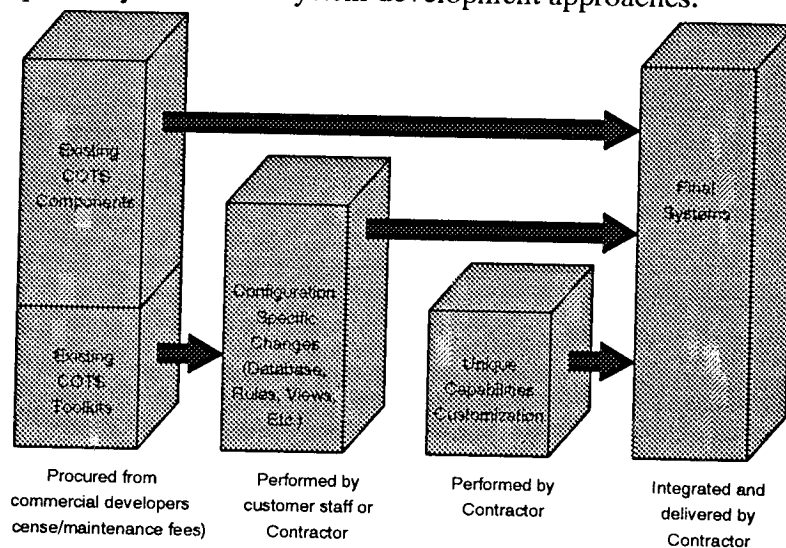
During mission planning, spacecraft operators determine the future activities of the spacecraft. The objectives of these activities are determined by vehicle maintenance requirements, overall mission objectives, and operations required to ensure the health of the spacecraft. Using IMT and the embedded expert system, mission objectives can be captured and applied during the planning process. For example, to ensure the health of a spacecraft, mission objectives might indicate that battery reconditioning must be performed at precise time intervals. These objectives can be stored as rules within the planning knowledge base.

As mission planners develop future contact support plans, this knowledge can be used to validate the proposed pass plans and command sequences. As system intelligence increases, this analysis can incorporate knowledge from previous spacecraft contacts. For example, suppose the last time the vehicle was contacted, a specific anomaly was detected. Using knowledge of this condition, along with the expert spacecraft knowledge captured by the system, the system could identify a proposed command sequence as ineffective or dangerous to the spacecraft.

THE TOOLKIT MODEL

IMT was designed specifically to support a dynamic system environment. The "Toolkit" model allows the product to be configured to satisfy a variety of mission unique requirements and ensures the system can evolve to meet changing system requirements.

The "Toolkit" Model emphasizes the use of COTS products as the foundation for final solutions. Rather than developing a complex system from scratch, the target system is developed by integrating commercial products - best suited for the target application - into a final solution. Mission unique requirements are implemented primarily through modifications to expert system knowledge bases and standard relational databases. In addition, many commercial products provide graphics rich tools that allow the system to be tailored to meet user specifications without extensive software development. This environment supports rapid system customization and reduces development, operations and maintenance costs. When development is required, the level of effort is significantly lower than that required by traditional system development approaches.



CONCLUSION

The Intelligent Mission Toolkit provides significant advantages to the implementation of a complex command and control system. The embedded expert system offers the ability to store and apply expert mission operations and planning knowledge using system knowledge bases. This information can be used to automate spacecraft command validation, control ground system equipment and apply intelligence to the entire mission planning process.

IMT's modular architecture and fully Object Oriented implementation addresses the complex requirements of modern command and control systems. The "Toolkit" model emphasis allows end-users to customize the product to satisfy unique mission objectives resulting in the most powerful and flexible commercial command and control system available.