I. Introduction

The Defense Meteorological Satellite Program (DMSP) weather satellite supports worldwide defense operations by the acquisition of global visual and infrared cloud data and other specialized meteorological, oceanographic, and solar data. In support of DMSP, prototypes are currently under development that will demonstrate the viability of expert systems, real-time graphics, and hypermedia-based information navigation for space vehicle monitoring & control.

The information navigation portion of this prototype depends on a highly integrated hypermedia environment. This hypermedia-based prototype’s design is predicated on a multiply connected information base of various media forms including video sequences, high-resolution photographs, schematics, engineering support documentation, and audio.

A program that would describe the actions of the spacecraft’s redundancy manager software was selected for the first expert system prototype. The prototype monitors telemetry from the spacecraft, then visually notifies and advises the operator if a malfunction in a redundant component occurs. The expert system interfaces to taped telemetry files generated by the DMSP high fidelity simulator. A real-time interface is currently being tested using a modem data line.

These prototype systems demonstrate capabilities beyond the scope of current systems at DMSP Satellite Operations Center. The goal of these prototypes is to provide concepts that can address the present military need for reduced manning, diminished contractor support, and improved data-handling techniques.
II. The Information Navigator:

A. Goals of the Information Navigator:

Improving the context of data presentation is one of the goals of the information navigator prototype. The context of presentation is a critical factor when turning raw data into information. To illustrate this point contrast a table of raw data with an associated 3-dimensional surface plot (see figure 1 and figure 2).

Both views represent the same data, yet the plot provides information or an awareness relating the magnitude of the data items relative to one another. When dealing with large complex data volumes as in our application, continuous visual inspection of the tabular data representation is both cumbersome and prone to error.

Orientation and presentation of data is made possible in the information navigator through the use of hypermedia. Hypermedia can be defined as the blend of multiple visual and audio presentation mechanisms that can be navigated in an intuitive fashion using easy-to-master user interface techniques. What this implies using today’s technology is a mouse/joystick “point & click” interface that ties together randomly accessible video sequences and high resolution still photographs from an optical disk, engineering drawings and system schematics on magnetic disk, hypertext, and digital audio segments. Each of these unique media forms is multiply linked with the others through a common application. In its current form this common application is HyperCard™.

Providing a graphically oriented repository for status information received from multiple systems is another goal of the information navigator. This activity presupposes that a well defined user interface that can demonstrate alternative relationships between prototyped user tools can be useful in defining the requirements for fully implemented versions of these tools. Different arrangements of the navigator interface can be compared and quickly interated with the user community. The results of this interaction materialize as descriptions that define diverse computational and display resource needs. In an attempt to better define these requirements the navigator prototype provides a platform for experimentation and test of user
interface concepts as well as tool development and integration.

B. Design of the Information Navigator:

The information navigator uses three CRT monitors for display of information. One monitor displays the HyperCard application. The primary screen within this HyperCard application is called the tools menu. This menu contains an array of small icons (small pictorial representations of the information or action taken when selected) that provide the user an index of the capabilities of the information navigator. This picture-based index technique provides a hierarchical structure of information that is easily traversable by the user. The highest level of the index represents the category of tools that can be initiated by the user. Once the user selects a tool, the specific action taken by that selection can remain transparent by the user. Only the final result need be presented to the user for further action. Consider the following example: The user wishes to view a high-resolution photo of a spacecraft sensor. The first selection made is the images icon in the tools screen. After this selection is made the user will specify via a keyword search, the specific photo required for viewing. After the keyword search is processed, the photo options are presented to the user. At this point the user makes the final selection and the image is displayed for viewing. At no time during this process was it necessary for the user to understand that a database program, image scanning program, and color graphics processing program were executed to develop the output for final viewing. Hiding the implementation (in this case the interaction of several applications) allows the user to concentrate on selecting an image rather than remembering how to and where to select an image. This process is shown in a graphical form in Figure 3:

The information navigator prototype complements existing data systems used in satellite support. The navigator is an evolving concept, and as such, the tools within the navigator prototype are in various stages of development. A subset of the tools (information access points) that exist in either conceptual form or partial implementation are summarized below with their respective icons shown next to each description:
This icon represents an access point for an expert system that addresses environmentally induced anomalies in the space vehicle. Access points for several expert systems are planned as part of the navigator prototype. One of the functions of the navigator is to provide a platform for visualizing the interaction between multiple concurrent expert systems. Within this context, the navigator can serve as a focal point for summary information made available by concurrent processes. The environment expert system is designed to establish a measure indicating probability that an anomaly registered on the space vehicle was due to disruptions in the space environment including but not limited to single event upset, bulk charging and surface charging. This expert system is currently hosted in a 286-based platform. An interface between the environment expert system and the navigator is planned at a later date.

This icon is selected for access to telemetry data files. In its current form it simply initiates a file transfer to a standard application for display. The evolved form will include network file transfers from remote hosts. In keeping with the theme of information abstraction, the implementation of this function will insure that the different between a local file transfer and a remote transfer is transparent to the user.

This is an access point for information relating to the space vehicles Ascent Phase Equipment (APE). This includes boosters, guidance & control for ascent phase, and telemetry descriptions for this phase. The type of information that will be referenced through this access point includes schematics, hypertext-based equipment specifications, still and motion photography, and software simulations. At the current time only hypertext-based equipment specifications and engineering drawings are available.

All forms of electronic documentation are accessible through this access point. Information available through this point is also connected to other points perviously mentioned. The purpose of this access point is to provide a simple method for looking up information. The technique for browsing information in the navigator is similar to perusing a library.
This icon interfaces to materials relating to the Command and Control Subsystem (CCS) for the space vehicle. The information referenced to through this access point is similar in form to the information referenced through the APE icon. Information specific to this access point includes diagrammed procedures for CCS access specific to the space vehicle requested.

This icon is the Equipment Status Telemetry Subsystem access point. The type of information accessible from this point includes user-definable views of telemetry as it relates to specific equipment selected by the user.

The Electrical Power and Distribution System provides descriptive information that can assist the user in understanding the interworkings of the various power subsystems within the space vehicle. Some of the areas covered through this access point include: power supply electronics, fuse box units, solar arrays, battery charge assemblies, power converters, and power budgeting procedures. These items are further broken down into their constituent parts. For example, the power budgeting procedures for a space vehicle are divided into the following categories: battery charge status, solar array output, battery load, mode control, and boost regulator.

In its final implementation, this icon will provide an access point to the status of the various ground stations that support the space vehicle. In addition to the status of these ground stations, the user may gain access to specific information for each ground station such as antenna sizes. The mechanism for navigating this information involves the traversal of a hierarchical structure of maps. Each layer in the hierarchy provides a more detailed view of the terrain than the previous level. Within this framework, the user can “zoom in” on the area of interest and see the projection of the space vehicle relative to the ground station’s coverage area.

This icon is an access point to one of the several tools contained within the information navigator that assist the user in graphical comparisons of data. Specifically, this tool compares a current data item (from a recently created telemetry data file) with historical curves. The historical curves are made available
through an on-line version of the orbit operations handbook for the space vehicle in question. The comparison takes both historical data and new data and overlays these items on a common grid for visual comparison.

This is the Attitude Control System icon. The information available through this access point begins with graphical representations of the space vehicle attitude control system. From this graphical representation, the user selects an area of the picture that coincides with the user area of interest. By clicking on this area of the picture the user is presented a screen that diagrams the area the user selected in more detail. Specific areas that are referenced through this icon include but are not limited to sun sensors, earth sensors, reaction wheels, electromagnets, rate gyros, and linear accelerometers.

Within the framework of the Information Navigator, expert systems can be viewed as specialized tools that are accessible through the navigator tools menu as is planned for the environment expert system. This does not constrain the operation of an expert system or even where the expert system is hosted (another computer platform for example), but it does suggest an architecture that addresses the transfer of information between the navigator and an expert system. The simplest form of communication between navigator and an expert system can be accomplished through a session dedicated to the transfer of high-level summary or assessment information. As part of the operation of an expert system, the processed conclusions can be made available to the navigator. Data that is provided through these individual communications sessions with the navigator can be deposited into appropriate containers (text fields & graphics) for display. It is also the responsibility of the navigator to organize and display information received from multiple sources. As yet this has not been implemented, but preliminary design work would suggest incorporating an expert system within the navigator to assist in defining priorities between information received from multiple sources. In its current form the navigator can provide easily accessible documentation that can augment the anomaly resolution processes developed using expert systems. Some sample screens taken from the navigator prototype are shown in Appendix B.
III. The Expert System:

A. Redundancy Management:

The operational system today

To insure the health of the DMSP spacecraft, many hardware and software components have both a primary and a backup configuration. In the event of an onboard malfunction in which one of the critical components becomes non-operational, reconfiguration of the vehicle occurs automatically, under the direction of the redundancy manager (REDMN) flight software. The remainder of this section outlines current methods of recognizing and handling such malfunctions and describes the role the expert system will take in alleviating some of the difficulties involved in failure analysis.

When DMSP satellite hardware reconfiguration occurs, Air Force command and control personnel must determine 1) that reconfiguration has occurred and 2) which failure has caused reconfiguration. What makes this difficult is that REDMN monitors internal variables that are unavailable to the ground operator. REDMN does not notify the user which component of the spacecraft has failed, or the nature of the failure.

In the operational environment, DMSP satellite controllers monitor lists of telemetry measurands presented alphanumerically on CRTs. During a pass of the satellite, the crews examine lists of subsystem telemetry to determine whether all subsystems are performing nominally. They look for trends from pass to pass which may indicate an anomalous condition. When a telemetry item exceeds a certain threshold, it is considered out of limits and the on-call engineer is notified. The engineer in making his/her analysis of the anomaly checks data from both onboard computers, then executes complicated procedures for restoring redundancy to the spacecraft.

All this is done manually by referring to operations manuals and cross checking the values against those listed in satellite analysis reports for telemetry. Since crew action is largely dependent upon engineering advice, the DMSP satellite operator would greatly benefit from online information concerning the actions of the redundancy manager.
and recommendations for returning to a nominal status if an anomaly occurs.

The prototype expert system offers the DMSP satellite operator a visual representation of the state of the spacecraft not available to him/her now. In the event an anomaly occurs, the function of the expert system is to notify the user which component of the spacecraft has failed and the exact nature of the failure, then guide the user through execution of contingency procedures when appropriate.

B. Failure Management with Expert Systems

The redundancy management flight software detects malfunctions in certain units of the Attitude Control Subsystem and the Electrical Power and Distribution Subsystem, but provides no direct information to the user regarding the reasons for reconfiguring those units. The DMSP Satellite Operator’s Assistant in Realtime (SOAR) expert system provides for the detection and diagnosis of nine anomalies on the spacecraft that provoke action by the redundancy manager, as well as recommendations for cleanup procedures for reconfiguration of the satellite from the ground. These nine anomalies include all the possible failures on the spacecraft that may provoke action by the redundancy manager. When it becomes apparent through telemetry indicators that the redundancy manager has taken some action, the expert system determines exactly which component of the spacecraft has failed and the nature of the failure. The satellite operator is notified of the subsystem failure and provided online information necessary for returning to a nominal status, if possible.

SOAR incorporates an expert system, a graphic interface, and a real-time telemetry processor, which work together to assist the user in diagnosing anomalies. The expert system consists of a supervisor knowledge base, subsystem knowledge bases, and cleanup procedure knowledge bases that mimic the cleanup procedures recommended within the DMSP operations manuals. The supervisor knowledge base consists of rules and objects that check for out-of-limits telemetry points indicating failure of one of the nine redundancy manager tests. The values contained within the telemetry points offer insight into the type of anomaly that has occurred. Rule conditions become true according to out-of-limits telemetry values, triggering additional rules in a forward
chaining fashion. Additional knowledge bases are loaded into computer memory when the supervisor determines in which subsystem an anomaly has occurred.

The DMSP high fidelity simulator provides telemetry for input to the expert system. One simulated anomaly, the Solar Array Drive (SAD) hangup, has been successfully tested with the SOAR system. The Solar Array is the source of all satellite power. It is the job of the SAD to maintain the orientation of the solar array towards the sun and to transfer power to the satellite subsystems. During normal mission operations, the array rotates continuously about the spacecraft. If the SAD becomes non-operational, power loss will occur. REDMN detects an error and switches to the redundant side of the solar array electronics. The expert system, detecting this side switch, notifies the user of the switch and continues monitoring REDMN actions. Analysis of the problem is automatically provided in realtime by the expert system. Without the conclusions of the expert system displayed visually on the user interface screens, the satellite operator would have no option but to search the lists of telemetry data for indications of REDMN actions. SOAR provides the pertinent telemetry automatically, and the user can verify the validity of expert system recommendations by checking these telemetry values.

C. SOAR System Architecture

The DMSP SOAR system utilizes three separate processes for performing realtime analysis and display of telemetry data. Each of the processes operates independently and communicates information via message passing. The processes are shown in Figure 4. Telemetry measurands are indicated TM1 through TMn.

There are three main advantages to this architecture:

1) The three processes can be run on either a single processor, in which case the processor is timeshared, or on three separate processors, where each process runs concurrently.

2) The Inference Process has complete freedom from input/output worries; its limiting factor is the processing power of the CPU on which it is resident.
3) Because the processes are loosely coupled, maintenance is simplified. A process can be modified or replaced with minimal impact on the rest of the system.

Two knowledge representation paradigms, provided by the shell (NEXPERT Object™), were used to design the knowledge bases for DMSP. A hierarchy of both classes and objects defines the satellite subsystems in terms of their associated telemetry parameters. Objects are telemetry measurands with their associated values from the satellite telemetry stream. These objects are organized into three major classes, which are analog signals, bi-valued discrete signals, and digital CPU telemetry. Each telemetry object also belongs to a subsystem class such as attitude control or electrical power. The second scheme reasons about the knowledge contained in the object base using if-then rules. DMSP rule bases are organized into three types of rules: rules of observation, rules of interpretation, and rules of communication. Rules of observation, or level-1 rules, have telemetry mnemonics as rule conditions and derived telemetry objects as rule conditions and derived telemetry objects as rule conclusions. Level-1 rules are evaluated when the rule conditions receive values from the telemetry server process (described below), either through a polling procedure or through a request for a particular telemetry parameter. When level-1 rules fire, rules of interpretation (level-2 rules) are evaluated in a forward chaining or backward chaining fashion until a diagnosis of an anomalous condition is found. Rules of communication, or level-3 rules, provide information to the user through message passing to the User Interface Process (see below). A network of level-1 and level-2 rules for observing and interpreting an Earth Sensor Assembly reconfiguration (ESA_side_switch) is shown in Appendix A “Expert System Rule Network”.

The telemetry server receives real or simulated telemetry data from ground station computers either via modem or from a telemetry data file and broadcasts changed telemetry to the Inference and User Interface Processes. Telemetry mnemonics and their values are input to the knowledge base.

The user interface process provides visual feedback to the operator about the health and status of the vehicle (Refer to Appendix A “User Interface Main Menu”). Subsystem status blocks, critical telemetry status charts, and user options are located on the perimeter of the screen. A working window in the center of the screen supports the following user
functions: 1) display of telemetry in alphanumeric or realtime graph form; 2) display of warning messages and information from the inference process; 3) hierarchical schematic diagrams animated in realtime; 4) browsing of diagnostic conclusions and recommendations; and 5) browsing and execution of command procedures to clean-up or resolve anomalous conditions. Warning messages received from the inference process are color coded based on severity: green (less importance), yellow (moderate importance), and red (urgent). All messages are stored in a monitor log for later viewing. Schematic diagrams are updated in realtime to reflect the current state of the on-board hardware. Switch icons are bound directly to telemetry parameters and reflect true switch states. The schematics are structured hierarchically and the user may browse the various levels by clicking the mouse on appropriate component icons. Anomalous components within each level are highlighted in red. Clicking on selected lines of a schematic brings up graphs of the telemetry associated with the line. The user interface was designed using the DataViews™ graphics development system.

IV. Conclusions:

These prototype systems represent information processing capabilities that can enhance current systems within the DMSP Satellite Operations Center by demonstrating the viability of expert systems, real-time graphics, and hypermedia-based information navigation for space vehicle monitoring & control. The information navigator can enhance the capabilities of the satellite operations support staff by providing access to information in a variety of forms. This navigator prototype effort is made possible through the integration of multiple information technologies including hypermedia, expert systems, data base, and procedural languages. Expert systems prototypes can improve the current data system through intelligent monitoring of telemetry data. By integrating telemetry data with output from the expert system via a modifiable graphics display, the users understanding can be improved. This can reduce the operator errors that could result from dealing with large data volumes. Future extensions of these efforts will be influenced by interaction with the satellite control user community and the DMSP Satellite Operations Center.
References:

Defense Meteorological Satellite Program, Block 5D-2 OPS Manual 41.

Notes:

VAX is a registered trademark of the Digital Equipment Corporation, NEXPERT is a registered trademark of Neuron Data, DataViews™ is a registered trademark of V.I. Corporation, Macintosh and HyperCard™ are registered trademarks of Apple Computer Corp.

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Figure 1: Tabular Data
Figure 2: Graphical Data

The Images icon is located in the tools menu by the user.

Figure 3a: Images icon
After clicking on the images icon, the user is prompted for keywords that are used by the system to structure a database query and retrieve the image.

**Figure 3b:**
Cutout View of Tools Menu

**Figure 4:**
SOAR Process Architecture

- **INERENCE PROCESS** - analyzes dynamic telemetry data by means of forward and backwardchaining rules.

- **TELEMETRY SERVER PROCESS** - gathers incoming telemetry from data files and broadcasts changed values to requesting processes.

- **USER INTERFACE PROCESS** - provides the user with messages, warnings, diagnosis, advice, realtime animated schematics, and realtime telemetry graphs.
Appendix A

Expert System Rule Network

User Interface Main Menu and Typical Block Diagram
Appendix B: Information Navigator Sample Screens