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OPERATOR ASSISTANT TO SUPPORT DEEP SPACE NETWORK LINK MONITOR & CONTROL

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ABSTRACT

Preparing the Deep Space Network (DSN) stations to support spacecraft missions (referred to as *pre-cal,* for pre-calibration) is currently an operator and time intensive activity. Operators are responsible for sending and monitoring several hundred operator directives, messages, and warnings. Operator directives are used to configure and calibrate the various subsystems (antenna, receiver, etc.) necessary to establish a spacecraft link. Messages and warnings are issued by the subsystems upon completion of an operation, change of status, or an anomalous condition.

Some portions of pre-cal are logically parallel. Significant time savings could be realized if the existing Link Monitor and Control system (LMC) could support the operator in exploiting the parallelism inherent in pre-cal activities. Currently, operators may work on the individual subsystems in parallel, however, the burden of monitoring these parallel operations resides solely with the operator. Messages, warnings, and directives are all presented as they are received -- without being correlated to the event that triggered them.

Pre-cal is essentially an overhead activity. During pre-cal, no mission is supported, and no other activity can be performed using the equipment in the link. Therefore, it is highly desirable to reduce pre-cal time as much as possible. One approach to do this, as well as to increase efficiency and reduce errors, is the LMC Operator Assistant (OA). The LMC OA prototype demonstrates an architecture which can be used in concert with the existing LMC to exploit parallelism in pre-cal operations while providing the operators with a true monitoring capability, situational awareness[1] and positive control[2]. This paper presents an overview of the LMC OA architecture and the results from initial prototyping and test activities.

BACKGROUND

The Operator Assistant (OA), a multi-year applied research project currently in its second year, is investigating the application of Artificial Intelligence (AI) based automation techniques to ground data systems operations. The problem of introducing automation into an existing operational system is a complex one, requiring a thorough understanding of the problem domain [1]. There is an almost overwhelming temptation to attack automation piecemeal, attempting to "fix" individual problems, rather than to view the system as a whole.

Our approach to automation was to first perform an in-depth systems analysis: identify the functions performed by the current system, identify problems characteristic of the existing system, identify desired new features, and develop and evaluate various functional breakdowns (human vs. computer), and then

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1. Knowledge of the true state & status of the system at all times
2. a. For all control actions, there exists a means of positively verifying that the given action occurred as desired; b. the human can, at any time, return the system to manual control.

develop an architecture capable of supporting the future system.

PROBLEM DOMAIN

NASA's Deep Space Network (DSN) is a world-wide network of large (26 to 70 meters) antennas and telecommunications equipment dedicated to the support of interplanetary spacecraft. The monitor & control systems for the network and the individual Deep Space Stations (DSSs) have evolved continually since the DSN was commissioned in the 1960's. However, the underlying architecture, which depends heavily on human operators, has changed little.

After an evaluation of DSN monitor & control (M&C), the first area chosen for application of automation technology was the DSS M&C, and particularly the Link Monitor & Control (LMC) functions.

In DSN terminology, the *Link* is the string of equipment, starting with the antenna, necessary to communicate with spacecraft. The DSN is a bent pipe which enables the spacecraft controllers to command their spacecraft and receive telemetry from the spacecraft. Each spacecraft requires a unique configuration of the DSN equipment in order to establish the link. The LMC operators are responsible for knowing which configuration is needed to support a particular spacecraft, any special test procedures or calibrations, and the sequence in which to perform the necessary actions.

During the configuration period (which can last anywhere from 45 minutes to several hours), the LMC operators are responsible for identifying, parametrizing, and sending over a hundred operator directives to several different sub-systems and subassemblies, and monitoring several hundred messages, responses and warnings to determine the health, status, and performance of the link. During this time, the station and equipment is not available to support any other activities. For some types of operations, the amount of time spent performing pre-cals (2 hours) dwarfs the actual data collection time (15 minutes). The goal of the Link Monitor & Control OA is to reduce the overhead associated with pre-calibrations and to increase operator efficiency.

The operator's job is difficult due to: 1) the lack of on-line access to procedural, schedule, and general purpose information; 2) an LMC architecture which does not allow operators to query subsystems and subassemblies for parameter values; 3) an architecture which decouples the monitor data from the display data so that there are inconsistencies between the two; 4) a keyboard-only input system which is both slow and error-inducing; 5) a directive vocabulary of over a thousand different directives without any form of standardization; and 6) an architecture which is so overladen with false-alarms that system warnings are often ignored.

Many of these deficiencies are the targets of on-going DSN upgrade activities. Therefore, the automation architecture developed for link monitor & control has to look beyond existing discrepancies, although it must take them into account for near-term implementations.

ARCHITECTURE

The LMC Operator Assistant architecture consists of five main processing modules, as depicted in Figure 1: 1) Parameter Selection; 2) Dependency Network; 3) Display Generation and Interface Management; 4) DSN Interface; and 5) Reactive Monitor, Diagnosis, and Control. Each of these modules performs specific functions which are an integral part of LMC operations. These modules are supported by several data and knowledge bases and secondary processes such as logging and report generation. The main components of the OA are discussed in the following sections.

Support Databases

As with most AI-based systems, a substantial amount of effort must be devoted to interfacing the support information and transforming it into a computer-readable and usable format [2; 3]. For the Operator Assistant, this required creating and organizing data and knowledge bases to contain the information currently used by the operations personnel. For example, the operators now

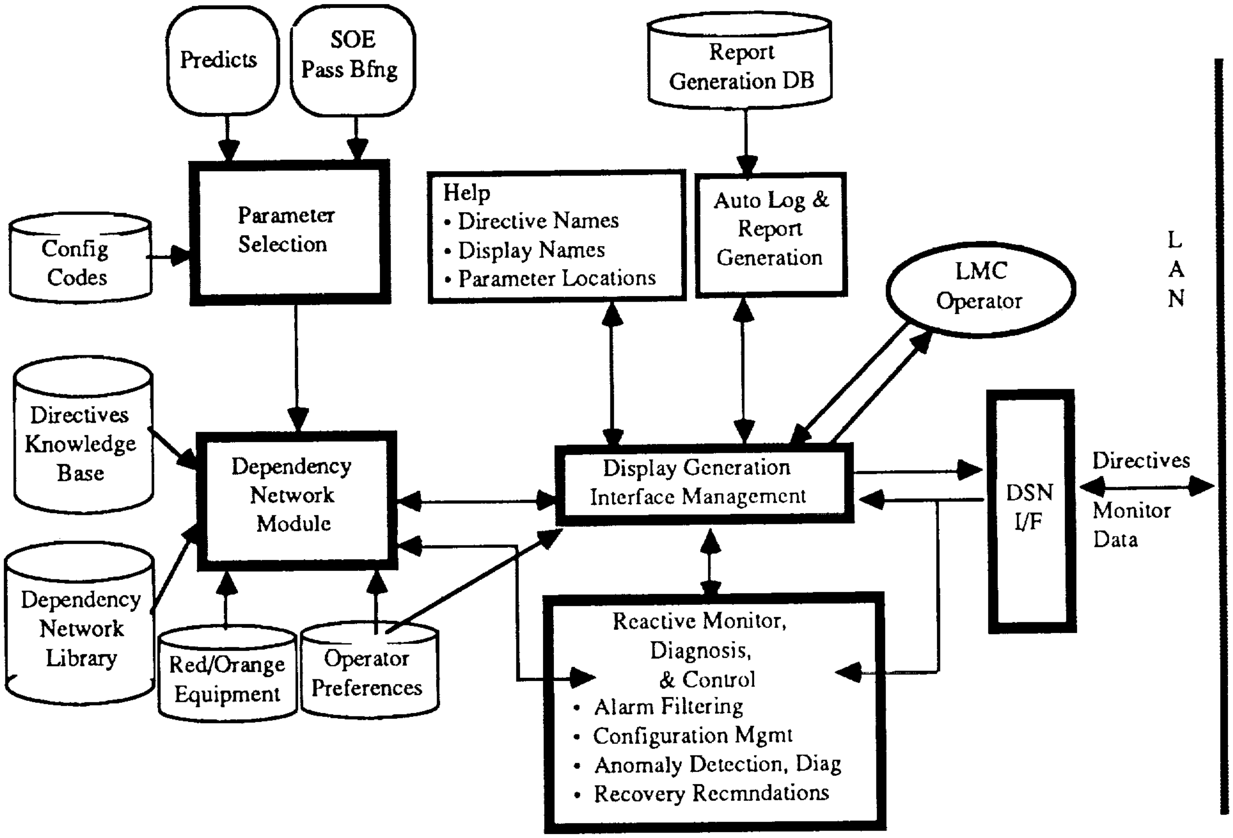

Figure 1: LMC OPERATOR ASSISTANT ARCHITECTURE

use a variety of inputs to determine exactly how they will perform a given activity. These inputs include daily schedules which identify what and when to perform activities, Sequence of Events (SOEs) which give detailed sequencing information and time critical information (e.g. *Acquire the spacecraft at time t=day::hour:min:sec*), and Predicts, which are specific predicted values necessary to communicate with the spacecraft (e.g. position, transmitter frequency). Currently, this information is available to the operator primarily in hardcopy format -- with little or no capability to edit, sort, filter, or transfer it on line. This results in the operators often having to manually enter large tables of data. Future upgrades are looking at making this information available on line. However, part of the OA architecture is to define a preferred representation format for this data.

Knowledge Bases

The key knowledge bases in the OA architecture are the Directives Knowledge Base (KB) and the Dependency Network Library. The Directives KB identifies each of the directives used to communicate with the subsystems and subassemblies. The basic information includes the directive name, description, parameters and directions for filling the parameters, expected responses, associated monitor functions, and time-out & clock information.

The individual dependency networks, stored in the Dependency Network Library, contain the information to configure, calibrate, test, and operate the link. Each network is comprised of operator directives, the post- and pre- conditions associated with a particular pass, and the predecessor and successor relationships between nodes.

Dependency Network Module

The Dependency Network Module initializes the dependency network defined in the library. First, temporal constraints are overlayed on the network resulting in a Temporal Dependency Network (TDN). The Parameter Selection Module then sets the values of directive parameters based on the most up-to-date information available. Finally, the TDN is passed to the Monitor, Diagnosis & Control Module for execution.

The contents of each node in the network include the sequence of directives needed to accomplish the node, the values of any parameters which are predetermined by the type of choice of activity, preconditions, postconditions, and predefined contingencies.

The TDN is a logical representation of the activity. It includes all of the required steps, and also identifies optional/desired steps, and sub-optimal operating conditions. It is a standardized, yet flexible representation of a DSN activity which incorporates the knowledge of the operations, engineering, and science personnel.

Reactive Monitor, Diagnosis & Control

The Reactive Monitor, Diagnosis, and Control Module is the centerpiece of the Operator Assistant architecture. It is responsible for scheduling the execution of the TDN directives, queuing them for execution, spawning the monitor and timing functions associated with each directive, collecting and distributing responses, detecting & diagnosing anomalies in TDN execution, recommending repair strategies, and replanning TDN execution when necessary.

This module was implemented using a blackboard architecture, as shown in Figure 2. The scheduler, queue manager, monitor manager, response and directive classification and disbursement, and clock manager functions have all been implemented as part of the blackboard.

The blackboard paradigm is a general-purpose architecture which can support a number of different types of applications including monitoring and diagnosis [4; 5], problem solving [6], and intelligent tutoring [7]. For the Operator Assistant, we used the blackboard not only to exchange knowledge about the system in order to support monitoring and diagnosis, but also as a mechanism for controlling the link equipment and interfacing to the DSN.

Display & Interface Management

The Display Generation Interface Management module is responsible for ensuring that the human operators see the information needed to perform their functions in the system. The goals are to 1) ensure that the human operator at all times can determine the health, status, configuration, and performance of the link, and 2) ensure that the human operator can at any time intervene in an operation in progress and return it to manual control.

DSN Interface

The DSN Interface module is the communications interface to the DSN Local Area Network (LAN) for monitor & control. This module is responsible for 1) acquiring information off the LAN, formatting it, and delivering it to the Operator Assistant, and 2) performing the inverse functions to allow the Operator Assistant to send control information across the LAN.

STATUS

The Operator Assistant Prototype, Version 1.0, was developed on a Macintosh II system, using Common LISP. The five primary modules and the portions of the supporting knowledge and databases required for the demonstration domain were implemented, integrated and tested in a laboratory setting. The diagnostician is currently being designed and will be incorporated into the next version of the OA prototype, to be released in September 1991.

The laboratory test of the Operator Assistant was accomplished using a SUN 3 computer running a subsystem response simulator which

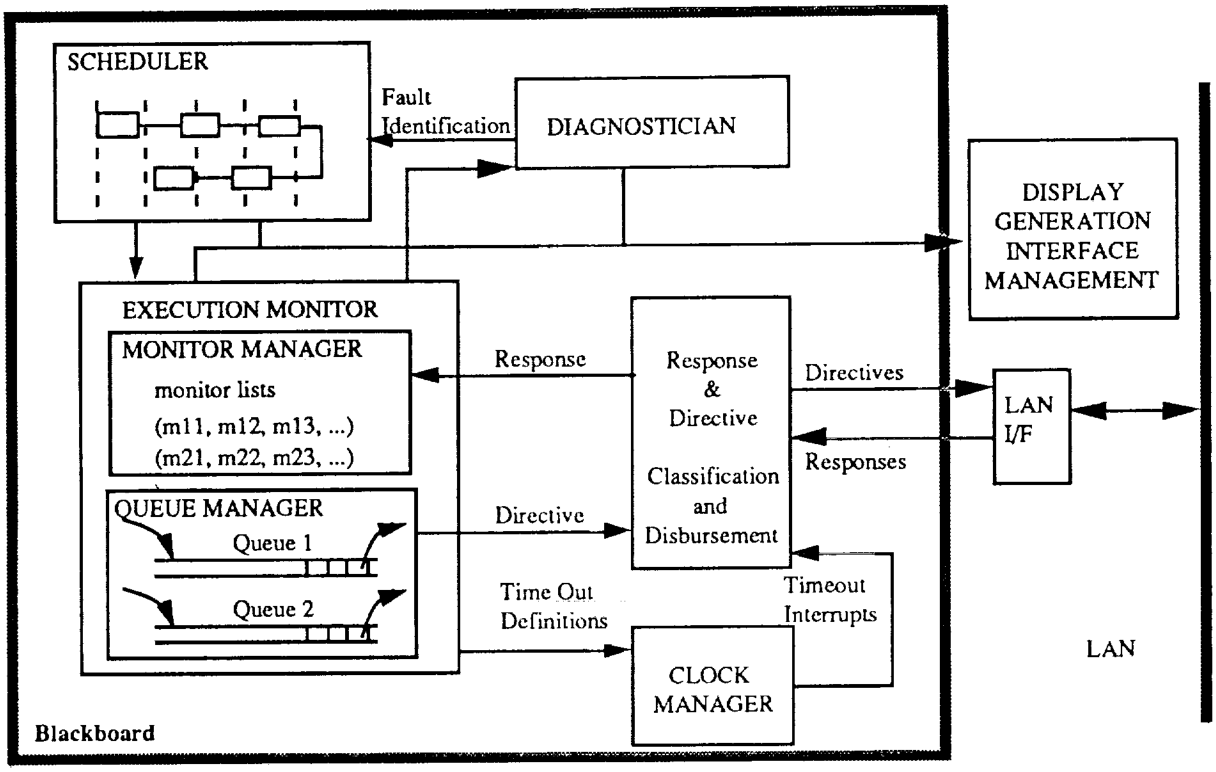

Figure 2. MONITOR, DIAGNOSIS, & CONTROL BLACKBOARD

was written in C. The Operator Assistant and Response Simulator were connected using Ethernet running TCP/IP. The tests demonstrated that the OA Prototype Architecture was appropriate and would meet system requirements. However, the test also highlighted some networking and memory management problems which will be addressed during the transition to the next version of the OA Prototype.

DEMONSTRATION DOMAIN: VLBI

The Operator Assistant was demonstrated for the Very Long Baseline Interferometry (VLBI) domain. VLBI is essentially a positioning technique which uses triangulation techniques to very accurately determine spacecraft velocity vectors. To perform a VLBI track, the DSN must configure two Deep Space Stations (located a continent apart) to the exact same configuration. Using differences in the phase and timing parameters of incoming signals, the VLBI scientists use differencing techniques to extract the desired data type.

VLBI operations are extremely difficult for operators because 1) they are not performed often, 2) they require the link equipment to be configured in a way different from standard telemetry and commanding activities, and 3) the underlying scientific theory for VLBI is difficult to understand in the context of operational options. Because of these characteristics, and the user-documented need for improving in VLBI performance through operability enhancements, the VLBI domain was chosen to demonstrate the OA.

The TDN for a VLBI[3] pass was developed. It incorporated procedural information gathered

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[3] Specifically, a VLBI Delta-DOR (Double Differential One-Way Ranging) pass for the Galileo spacecraft using the 70-meter antenna (DSS-14) at the Goldstone Deep Space Communications Complex. The TDN would be slightly different for other spacecraft, other antennas, or for other types of VLBI science activities.

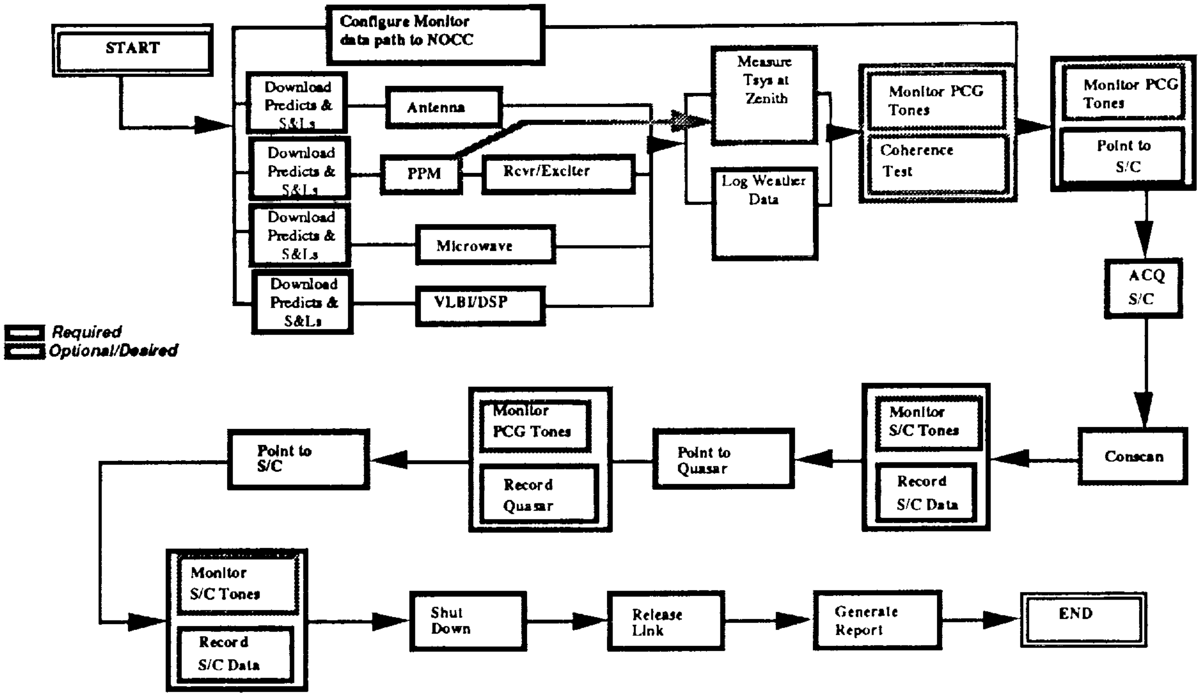

Figure 3. VLBI TEMPORAL DEPENDENCY NETWORK

from the published documentation, the link operations personnel at the Goldstone Deep Space Communications Complex, DSN systems and subsystems engineering personnel, and the VLBI scientists. The TDN shown in Figure 3 is a high-level overview of a VLBI pass. It represents the first time that all of the different components of a operational procedure were collected in the same place and the constraints, dependencies, and desired features explicitly stated.

CONCLUSION

The Operator Assistant prototype concept & architecture was the result of an in-depth analysis of how AI-based automation techniques could be incorporated into DSN operations. DSN operators, and specifically LMC operators, are part of a complex human-machine system which places a heavy burden on the human portion of the system to make it all work. The Operator Assistant is the first step in creating a new functional distribution between the operators and the systems they control and use. In this environment it is very difficult to improve monitoring without first improving the underlying control structure -- we have attacked the problem from both sides to address the issues of situational awareness and positive control. The resulting system has been demonstrated in a laboratory setting and is currently being upgraded to be demonstrated in a real-time operational environment.

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