EMBEDDED PARALLEL PROCESSING BASED GROUND CONTROL SYSTEMS FOR SMALL SATELLITE TELEMETRY

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ABSTRACT

The use of networked terminals which utilize embedded processing techniques results in totally integrated, flexible, high speed, reliable, and scalable systems suitable for telemetry and data processing applications such as Mission Operations Centers (MOC). Synergies of these terminals, coupled with the capability of terminal to receive incoming data, allow the viewing of any defined display by any terminal from the start of data acquisition. There is no single point of failure (other than with network input) such as exists with configurations where all input data goes through a single front end processor and then to a serial string of workstations.

Missions dedicated to NASA's Ozone measurement program utilize the methodologies which are discussed, and result in a multi-mission configuration of low cost, scalable hardware and software which can be run by one flight operations team with low risk.

KEYWORDS

Embedded parallel processing, Ground systems, Transputers, and Total mission concept.

1. INTRODUCTION

At the SPACEOPS '92 conference [5], it was shown that PC's could be used to control spacecraft and were capable of high throughput and performance if embedded processor methods were used [1]. Control centers using embedded serial processors were implemented for Nimbus 7 (N7) and the Meteor3/ TOMS (M3/T) missions, and have operated flawlessly since their inception in 1987 and 1991 respectively.

In 1991, development of embedded systems using parallel processing components based on transputer technology was begun. In 1992 we were tasked to develop a totally integrated control center using one Flight Operations Team (FOT) to operate N7, M3/T, and the Total Ozone Mapping Spectrometer - Earth Probe (TOMS-EP) missions. This facility is the TOMS Mission Operations Center (TMOC), and is leading the trend of combining similar missions with similar systems into multi-mission, single FOT facilities.

The trend in modern space mission control systems is moving towards standardizing telemetry systems design [9] as is evidenced by the move towards the adoption of CCSDS standards. These systems make use of the rapid advances in workstation or PC technology and contribute towards making the multi-mission Mission Operations Center (MOC) a reality. This paper will discuss the TMOC configuration utilizing embedded processing systems suitable for TOMS and other missions as shown in figure 1.

2. EMBEDDED PARALLEL PROCESSING : SCOPE AND BENEFITS

For the most part, telemetry processing is a bit oriented, repetitive, series of operations which are usually implemented in a serial process. Throughput gains are attained either through hardware implementation of repetitive software processes or the use of higher speed processors such as the DEC Alpha chip. Most telemetry processing for today's spacecraft can be handled in a serial manner, especially if we confine our functions to engineering or command matters.

The rapid advance of very large scale integration (VLSI) technology, and the

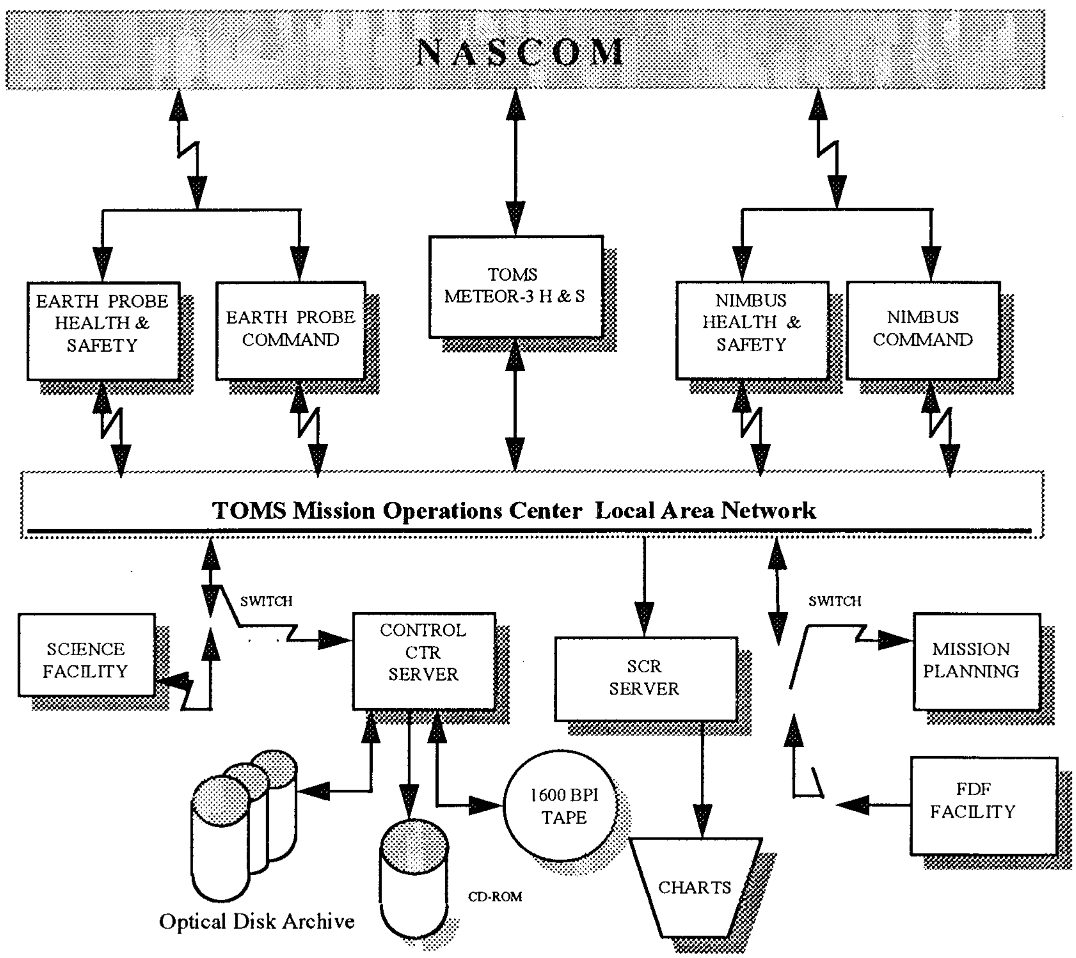

Figure 1: TOMS Mission Operations Center (TMOC) Configuration
Three missions are shown to interface to the NASCOM interface which provides inputs to the TMOC. All mission terminals and redundant ones (shaded) are connected through an internal LAN. All servers are switchable from the internal LAN to the NASA ethernet for security purposes.

availability of low cost processors have made it feasible to develop high performance, cost effective, and efficient parallel computer systems utilizing more than one processor, while maintaining a software design for implementation. These parallel methods lend themselves to bit and computationally intensive operations such as telemetry analysis, orbit and attitude analysis, and science processing and result in systems which are scalable, low cost, high performance, flexible, and reusable.

These systems [4,5,6,7] are based on the use of transputers as the parallel processing device. Transputers feature a built-in hardware scheduler which permits more than one concurrent process to share the processors time, and four DMA links to provide highly efficient inter-processor communication and data transfer. Hence, if the computation to communication ratio of component processes is considerably high, and the task allocation is uniform, multiple processes can be executed efficiently in parallel fashion. This strategy can be extended in dealing with future requirements by adding extra processing modules. In other words, embedded parallel processing offers scalability and flexibility to the system.

For our telemetry and command applications, a large body of software has been developed which executes on the embedded processor, requiring no significant resources from the host operating system, with a shared memory capability. This sets the basis for doing bit operations on the embedded processor while the host serves as the man/ machine graphical interface. More details on the scope of uniting of PC's and transputers as embedded processors can be obtained from references [2-7]. The benefits of utilizing the embedded parallel processing technology are:

a) Flexibility - Systems can capture all downlinked data, and immediately begin initial processing or data distribution. Systems are small, truly transportable, and require only normal office surroundings with clock and signal as inputs. Standard and non standard telemetry inputs can be processed simultaneously while commands are being output in required formats and rates.

b) Data Throughput - Base throughput rates depend on the number and architecture of the components as well as the parallel programming design. Rates in excess of 10 Mbits are achievable on our TOMS-EP system with NASCOM deblock only. Other levels of decommutation utilizing software algorithms slow the effective real time rate down to about 50 Kbits sustained for full health and safety while simultaneously archiving input data at the 10 Mbit receive rate.

c) Efficiency - System modularity, reusability, and ease of implementation lead to low costs, rapid implementation, and high performance.

d) Scalability - Systems can be built or expanded according to the demand of jobs or tasks to be performed and the systems can be reused in whole, in part, or with additional processing modules.

In addition, the use of embedded parallel processing and transputer technology contributes directly toward enhancing the unique features of the total mission concept. Based upon the granularity of parallelism exploited in the design, the system can be expanded to achieve the flexibility, reliability, and performance desired in the total mission system. The Total mission concept will be discussed in section 4.

3. CURRENT CAPABILITIES OF THE SYSTEM

The system architecture utilized in the TOMS Mission Operations Center (TMOC) is based on commercial off the shelf (COTS) products. Low cost, reliable, upgradable, user friendly, multifunction, standardized hardware and software are just a few of the goals in the system design. The TMOC is entirely driven by Personal Computers (PC's) utilizing the Intel Processor family. Embedded parallel processing is added to critical systems where real-time processing and/ or high computational requirements may be needed, and hence eliminating the need for high cost workstations and related software, as well as separate, costly front end processors (FEP). The ability to selectively add special purpose parallel processing modules gives the total system great flexibility. At a relatively low cost, the system can be reconfigured to support many of the current and proposed NASA missions.

The major functional areas are shown in figure 2, which include Real-time Command and Control, Health and Safety, and Mission Planning. The individual control center systems are connected via a standard ethernet Local Area Network (LAN). This makes it possible to transfer data between major system functional areas, as well as between individual

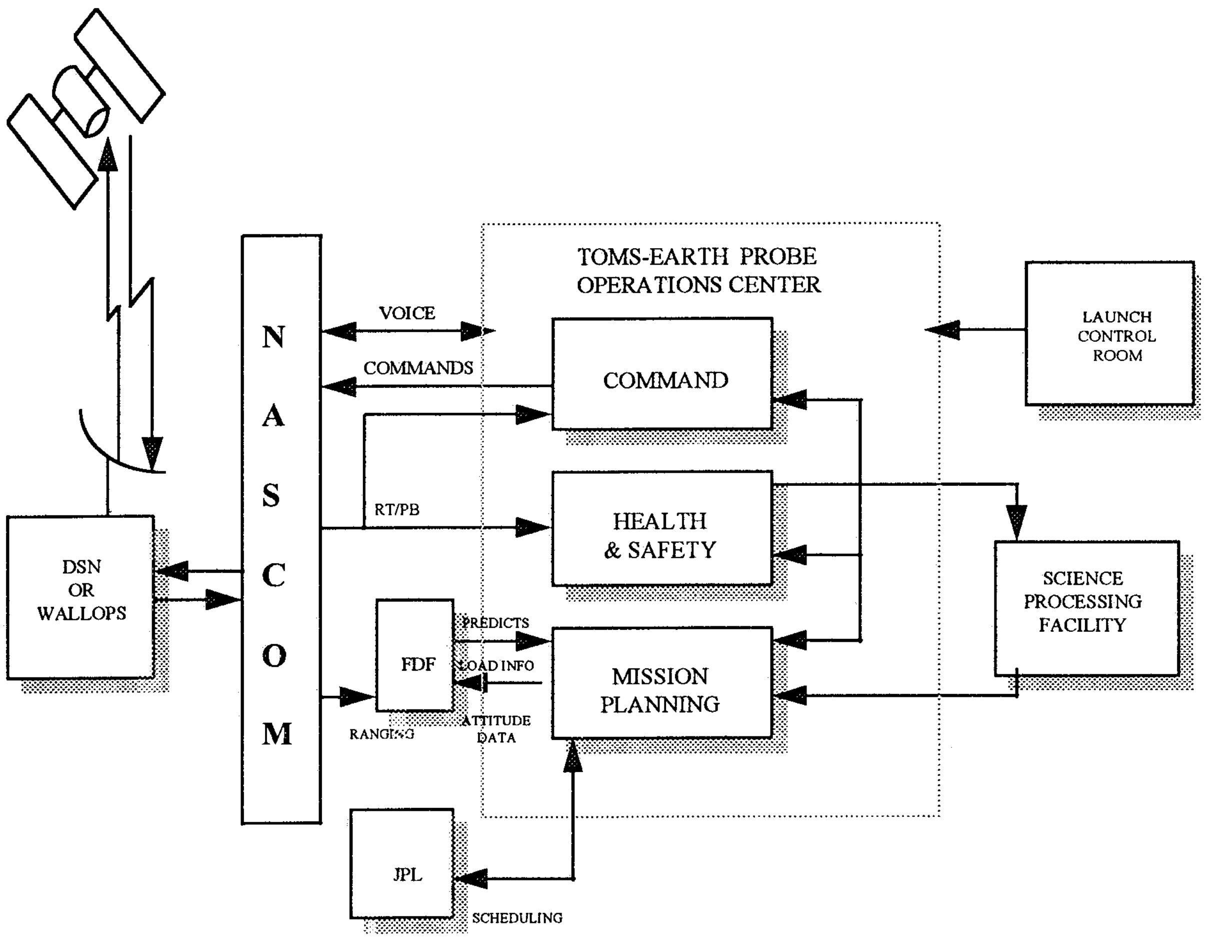

Figure 2 : An overview of the TOMS-EP mission system. The operations center exhibits its major operations -command,health and safety, and mission planning. The center interacts with the DSN or Wallops station via NASA communication network (NASCOM), and also with the launch control room, Flight dynamics facility (FDF), Jet propulsion laboratory (JPL) and Science processing facility during its telemetry operations.

systems. The TMOC interfaces with external components by several communication paths such as:

1. The Deep Space Networks (DSN) and the Wallops flight facility are utilized for support of command, telemetry, and tracking for the TOMS satellites. The NASA communications (NASCOM) network provides the interface between the DSN sites and the TMOC at the GSFC facility. The embedded parallel processor incorporates the FEP internally, making the single PC based workstation fully portable; the internal FEP is fully programmable for many packet formats received from TDRSS, DSN, MDM, IOS, or raw data from a bit synchronizer.

2. The Flight Dynamics Facility (FDF) provides the attitude determination and verification, as well as orbit determination support. The FDF products are transferred directly to the mission planning systems for incorporation into on-line databases. A standard ethernet network utilizing TCP/IP provides the interface to the mission planning systems.

3. The Jet Propulsion Laboratory (JPL) and mission planning coordinate and schedule all support for different components of the mission. Dialup/ dialback modems are utilized within the mission planning systems for the JPL interface. With the FDF data, JPL schedules, and instrumenter's command requests, command loads are prepared from the databases and transferred directly to the on-line Command systems.

4. The Science processing facility receives Level-0 processed TOMS data and further processes the data to create various products. The science facility receives data on a daily basis via standard ethernet using TCP/IP. Long term trending data is archived in the control center on CD-ROM media and furnished to the Science facility on an as required basis.

The on-line systems that are connected to the NASCOM network are all identically configured systems as shown in figure 1. For the TOMS-EP there are four systems on-line: a Primary Command system, a Primary Health and Safety system, a backup Command system, and a backup Health and safety system. Each on-line system has a UNIX Operating System (OS) with an X-windows based Graphical Users Interface (GUI) supporting the Motif X11R5 standard. All of the Command, Health and Safety, Level-0 processes, and analysis applications are written in C language using the Motif library. This standardized approach enhances the portability of the application source code to other platforms, as it may be necessary in future. Using UNIX and Motif also allows the system to incorporate NASA products such as Satellite Telemetry Operating Language (STOL) into the Command system. Since all of the on-line systems are identical, any one may execute the Command software or the Health and Safety software.

Currently, the TOMS-EP command system utilizes a command database specifically tailored for the EP satellite and TOMS instrument. The command system not only has Real-time command capability, but also full storage and forward capability. These features allow for frequent use of stored sequences of commands, and preprogrammed matrices that will be executed onboard the spacecraft at predetermined times. All commands transmitted are verified by echo blocks from the DSN site and further verified by the telemetry downlink. The telemetry downlink is in a CCSDS format and is fully decommutated in real-time in the internal FEP.

The TOMS-EP Health and Safety system provides a full analysis of both the spacecraft and the instrument in real-time. The screen format is set up as four quadrants, each quadrant may be customized by a satellite subsystem. In addition to the four quadrants, a general status panel is always visible at the top of the screen for a running summary of pass statistics. From a pull down menu bar and also hot keys, multiple panels are available for display by pressing of a button or clicking a mouse. Every telemetry point is in a database driven lookup table that is being updated in real-time through a shared memory interface. The embedded FEP does all the decommutation of the telemetry which places the processed data into the shared memory interface. Within the database, several things are occurring on each entry point such as calibration, floating point conversion, mode, event and alarm determination. The entry is then displayed based on a user defined display format. A row of subsystem buttons continually show the current status of each subsystem by changing the color. Green implies a normal operation, Yellow and Red indicate potential problems. By moving the mouse cursor on the subsystem button and clicking the mouse button, the event and telemetry panels associated with that subsystem are immediately displayed for analysis. In addition, there are X-Y plots that may also be configured in the display panels.

Along with the primary Health and Safety UNIX based systems, there are several standard PC's without FEP's. These PC's are configured as standard office systems running MS-DOS OS and Windows and are connected to the LAN. With an X-windows package, they are capable of running remote Health and Safety sessions in a client/ server configuration. The UNIX system becomes the server and executes the prime Health and Safety program. The DOS PC logs into the server as a client and executes a slave version of the same program. This configuration allows multiple screens of several subsystems to be viewed simultaneously. The DOS PC is used to transfer telemetry data points from the UNIX system and run trend analysis tools such as Quattro-Pro, Lotus, Excel or other packages that a user is familiar with. A note needs to be made at this point, with this type of PC environment, a relatively low cost control center can be put into full operation.

A localized LAN is being utilized for the control center communications. The bandwidth of the LAN can support the slave DOS client systems, mission planning, and an Astromed stripchart subsystem. The Astromed stripchart subsystem consists of four Astromed MT95000, 16 channel digital strip chart recorders. The four recorders are controlled by a front-end PC connected to the same LAN. The prime Health and Safety system sends raw telemetry directly to the 64 channel subsystem. The telemetry points, recorder speed and all controls are setup through a pop-up X-window during the pass. Any page on any terminal can be "popped" up on any other terminal on the network.

4. THE TOTAL MISSION CONCEPT

The TMOC control center architecture is designed for its missions and is self contained but can be expanded to include flight dynamics and science processing within the control center. The system is very modular allowing dynamic reconfiguration 'on the fly'. Figure 3 represents a Total Mission Concept that may be implemented within the TMOC requiring very little external support by adding the following functions:

1. Flight Dynamics

a. Integration of some of the Flight Dynamics functions directly into the control center. Several off the shelf products are now available from commercial companies such as

STORM Technologies and Integral Systems Corporation that make this feature doable now for attitude computation and mission planning products. It is assumed that precision 2-3 line elements are available.

2. Science Processing

a. The Level-0 product is already processed within the control center. The system can easily be enhanced by scaling up the system compute power by adding parallel processing nodes to provide Levels 1, 2, and 3 processing. These products could then be distributed to users and archived.

b. The addition of image quick look capability to verify data quality during real-time and playback data recorder dumps.

The Total Mission Concept for a control center can be implemented today in a very cost effective scenario. The same operations personnel could perform all the functions listed above from mission planning, through acquisition, analysis, data archiving, and the creation and distribution of science products. Multiple missions may be controlled by the same equipment and operations personnel by just selecting the mission type on

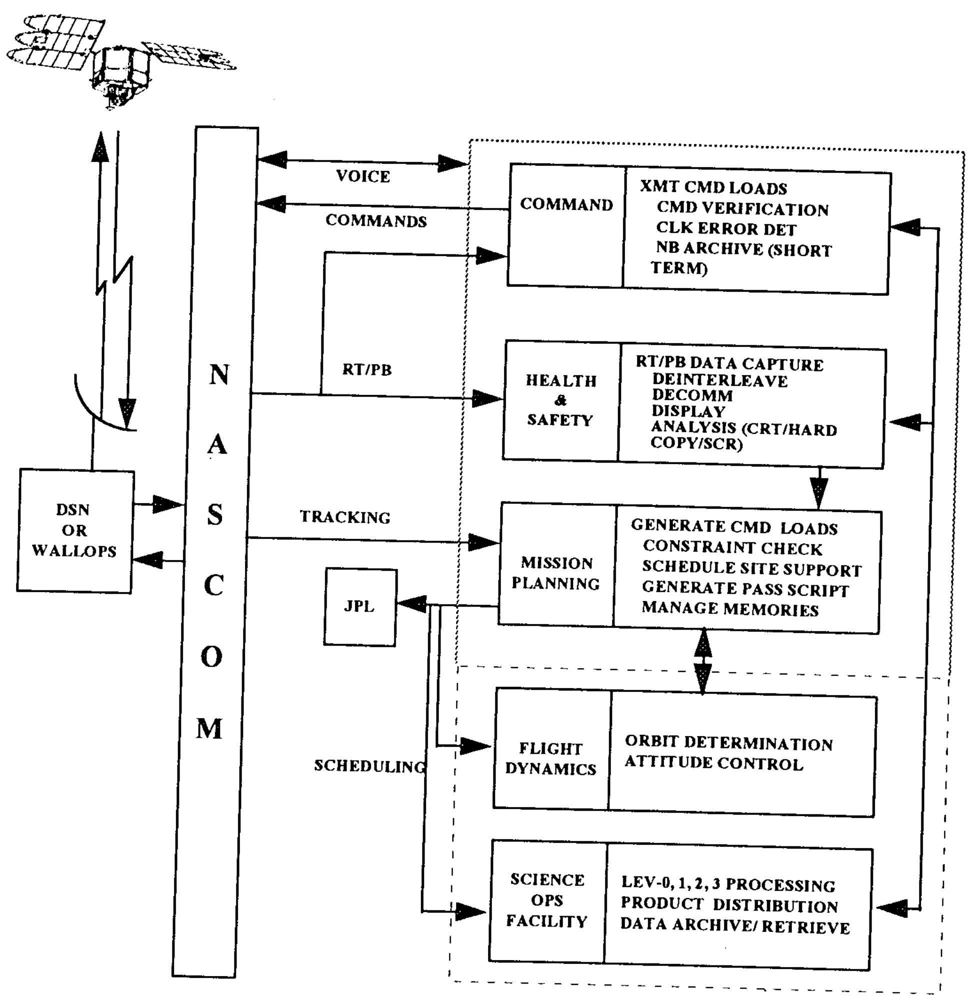

Figure 3: The Total Mission Concept implementation on the TMOC architecture. The dotted box exhibits the extension that can be added to achieve the flight dynamics and science processing capabilities to the system to perform orbit determination and level 1, 2, 3 processing.

screen. The nonreal-time DOS/ Windows systems are utilized in a multi-purpose mode from daily office operations to a client/ server based evaluation tool. All of this leads to efficient utilization of facilities, equipment, personnel and bottom line mission cost.

5. SUMMARY

The basis of using Transputers and Alpha chips in an embedded processing environment was to support the expansion of the Ground System from a simple command and telemetry analysis system to a system that supports spacecraft I&T, command & telemetry, and science processing and distribution. The cost effectiveness of this Total Mission concept and the ability to support multiple satellites simultaneously provides for a smaller operations staff resulting in an overall lower life cycle cost. In today's environment, this is a definite benefit when planning new missions.

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Bibliography

[1] Austerlitz, H., (1991), Data Acquisition Using Personal Computers, Academic Press.

[2] Cook, R., (1991,June), Embedded Systems in Control, BYTE, (pp.153-158).

[3] Ellis, G.K., (1989,Oct.), Data Acquisition and Control Using Transputers, Proceedings of The Second Conference of The North American Transputer Users Group, (pp.61-76).

[4] Forman, M.L., Hazra, T.K., Troendly, G.M., Nickum, W.G., (1993,Oct.), Applying PC-based Embedded Processing for Real Time Satellite Data Acquisition and Control, Proceedings of The Twenty Ninth Annual International Telemetering Conference, Las Vegas, NV, (pp.165-173).

[5] Forman, M.L., Troendly, G.M., Nickum, W.G., (1992,Nov.), High Performance Low Cost, Self-contained, Multipurpose PC-based Ground Systems, Proceedings of The Second International Symposium on Ground Data Systems for Space Mission Operations, (pp.733-737).

[6] Hazra, T.K., Troendly, G.M., (1994,May), Designing the Earth Probe Control Center for Telemetry Processing Utilizing Embedded Parallel Systems, Proceedings of The European Telemetry Conference, (pp.287-297).

[7] Hazra, T.K., Stephenson, R.A., Troendly, G.M, (1994,Oct.), The Evolution of the cost effective, high performance ground systems: A Quantitative Approach, To Appear in The Proceedings of The Thirtieth International Telemetering Conference.

[8] Muratore, J.F., et al, (1990,Dec.), Real Time Data Acquisition at Mission Control, Communications of The ACM, Vol.33, No.12, (pp.18-31).

[9] Sielski, H.M., et al, (1991), Modern Space Telemetry Systems, ITEA Journal, Vol. XII, No. 4, (pp.27-33).

[10] Sloggett, D.R., (1989), Satellite Data: Processing, Archiving, and Dissemination, Vol. I & II, Ellis Horwood.