Embedded Parallel Processing

For

Ground System Process Control

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ABSTRACT

Embedded parallel processing provides unique advantages over sequential and symmetrical processing architectures. During the past decade, the architecture of ground control systems has evolved from utilizing sequential embedded processors to modular parallel, distributed, and/or symmetrical processing. The concept of utilizing embedded parallel processing exhibits key features such as modularity, flexibility, scalability, host independence, non-contention of host resources, and no requirement for an operating system. These key features provide the performance, reliability and efficiency while at the same time lowering costs. Proper utilization of embedded parallel processing on a host computer can provide fault tolerance and can greatly reduce the costs and the requirement of utilizing high-end workstations to perform the same level of real-time processing and computationally intensive tasks.

KEY WORDS

"Key words: Modularity, Parallel Processing, Distributed Processing, Symmetrical Processing, Multi-mission Concept, Total Mission Concept, Ground System Process Control."

INTRODUCTION

The use of embedded processing techniques for telemetry processing systems leads to versatile system configurations which have low life cycle costs, are scaleable, and exhibit a high degree of reusability of both hardware and software. Previous papers have discussed embedded processing from the embedded processor viewpoint with emphasis on embedded parallel architectures utilizing transputers. [1-5]. Utilization of high speed processors such as the DEC Alpha, in a manner that makes the embedded processor's architecture look parallel retains the advantages of both serial and parallel embedded architectures. Some of these advantages are:

SCALABILITY: Systems can be designed to provide functions initially perceived as requirements. As the, requirements mature, change and increase, appropriate modules can be added for nominal costs, without loss of prior efforts. Of course, one can anticipate change and design beyond the initial requirements.

VERSATILITY: System configurations can operate in a standalone mode, and communicate with other systems which may be on the network. As an example, any number of individual systems for command, health and safety, and archiving can be on a network along with mission planning, orbit analysis, and science processing systems with each system receiving its own appropriate data. Systems can also be configured to run in a distributed mode where one front end receives and processes data for all systems on the network.

REUSABILITY: System software is reusable and may be recompiled for maximal task efficiency. Hardware can be upgraded as new, more powerful modules are developed, with minimal software changes.

RAPID PROTOTYPING: Since available modules are generic and no operating systems are necessary, reconfigurations for new or changing needs can be made in a short time.

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.

The primary thrust of this paper is to show how the use of embedded parallel processing improves overall system performance, functionality, capability, and low life cycle cost in a ground spacecraft operations scenario. Based upon the granularity of parallelism exploited in the design, the system can be scaled to achieve the flexibility, reliability, and performance desired in the total mission system.

SCOPE AND BENEFITS

Embedded parallel processing utilizes high speed processor modules which compliment host systems like Intel's 486 and Pentium, DEC's Alpha AXP, HP's 9000 series, or alternate workstations. These processor modules have specific functionality such as telemetry bit, word, and frame synchronization, decommutation, computation, networking, and real-time data archive. These modules are considered basic building blocks which perform the front end processing and other functions. The processors may share memory with the host system utilizing interprocessor communications, and several modules may be stacked on a single board. Communications between processors are on a point to point basis which eliminates bus contention. Meanwhile, the host performs other system management functions such as Graphical User Interface (GUI) management, client server task management and distributed processing over Ethernet. Thus the compute power for telemetry processing is not compromised by performing system overhead functions. A typical set of building blocks is shown in figure 1.

The packet modules have there own 32 bit processor onboard to provide control over the communications interface and to pre-process the data once the data is in a structured format. The interface supports Pulse Coded Modulation (PCM) data on both an RS-422 and TTL physical interface in full duplex mode. The interface is programmable to process several standard input and output data formats including:

NASCOM - NASA Packet Communications Protocol

CCSDS - International Packet Telemetry Standard

SGLS - Air Force S-Band Telemetry Standard

In addition, the interface can accommodate other formats incorporating variable frame and packet sizes.

The compute modules have 32 bit processors and memory configurations to support concurrent processing of data. As the data packets are broken down into sub-structures to represent various formats such as spacecraft data, payload data, command data and others, the compute modules can independently perform decommutation, calibration, alarm and limit checking. The results of each process is archived to disk and passed to the host for display processing through a shared memory interface. As processing needs increase, more compute modules may be added. Software processes must be analyzed and distributed across the compute modules to maintain a proper computational load balance.

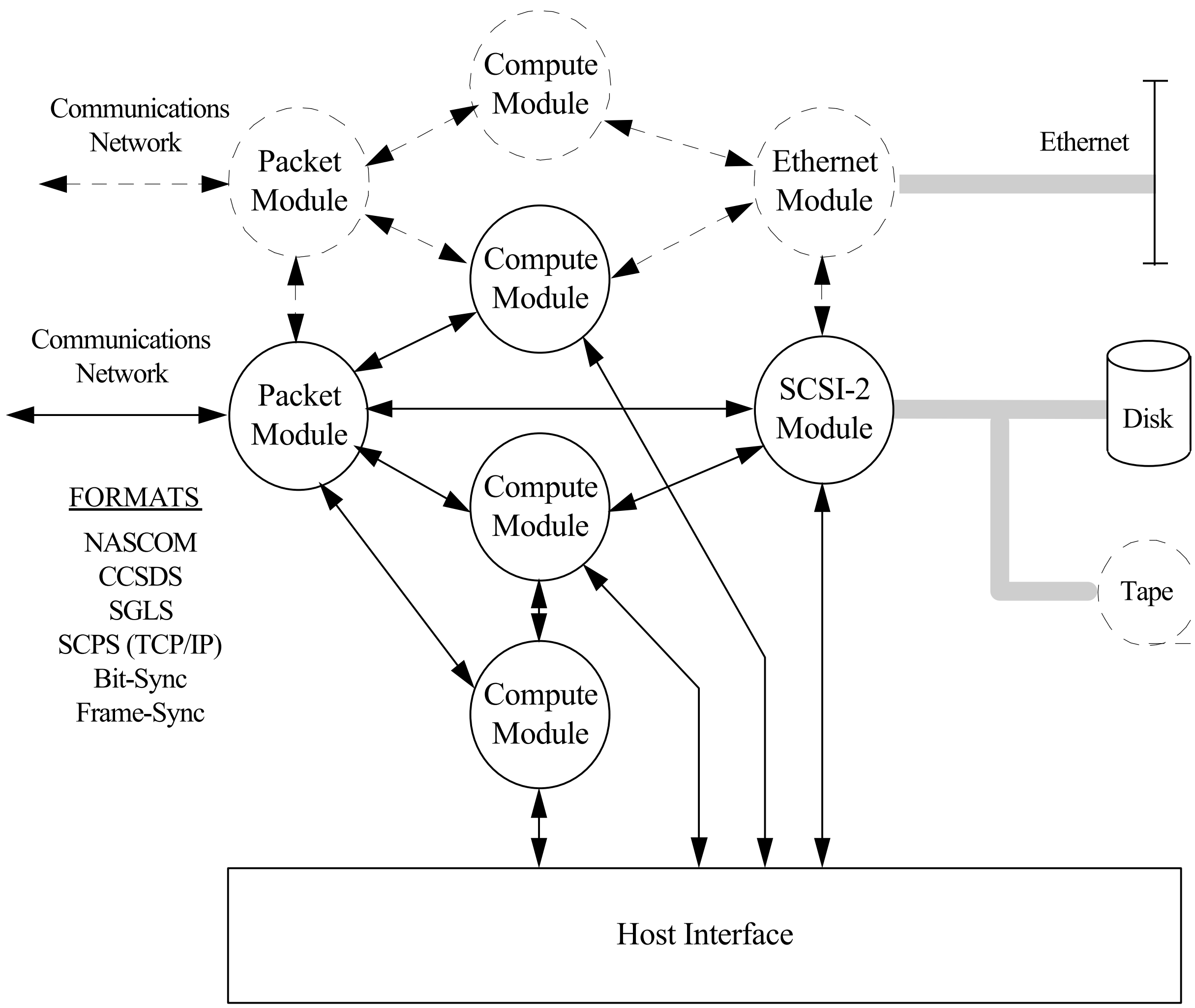

Figure 1 : Embedded parallel processing system is comprised of modules that communicate through interprocessor communications. System functionality is achieved by adding the functions needed; Packet modules for data I/O, Compute modules for computation and decommutation, Fast SCSI-2 modules for real-time data archive, and Ethernet modules to support TCP/IP and UDP over LAN systems.

The Ethernet module is primarily utilized to distribute selected processed data to application work stations for analysis and to a strip chart recorder server for hard copy signature of selected telemetry points. Commands are normally generated on the host, however the system software can be setup to accept commands from the distributed network, verify, packetize and transmit the command packet.

The fast SCSI-2 module is utilized for the real-time data archival of all input raw data from the packet module and all processed data from the compute modules. This allows for quick replay or reprocessing of any data sets that have been recently archived for evaluation and trend analysis. Data is moved from the real-time archive disks to a central server that writes all data to CD-ROM's for long term data archive.

With this scalability and modularity, a total mission concept can be implemented with a low mission life cycle cost utilizing an inexpensive personal computer platform. An overall functional diagram is shown in figure 2.

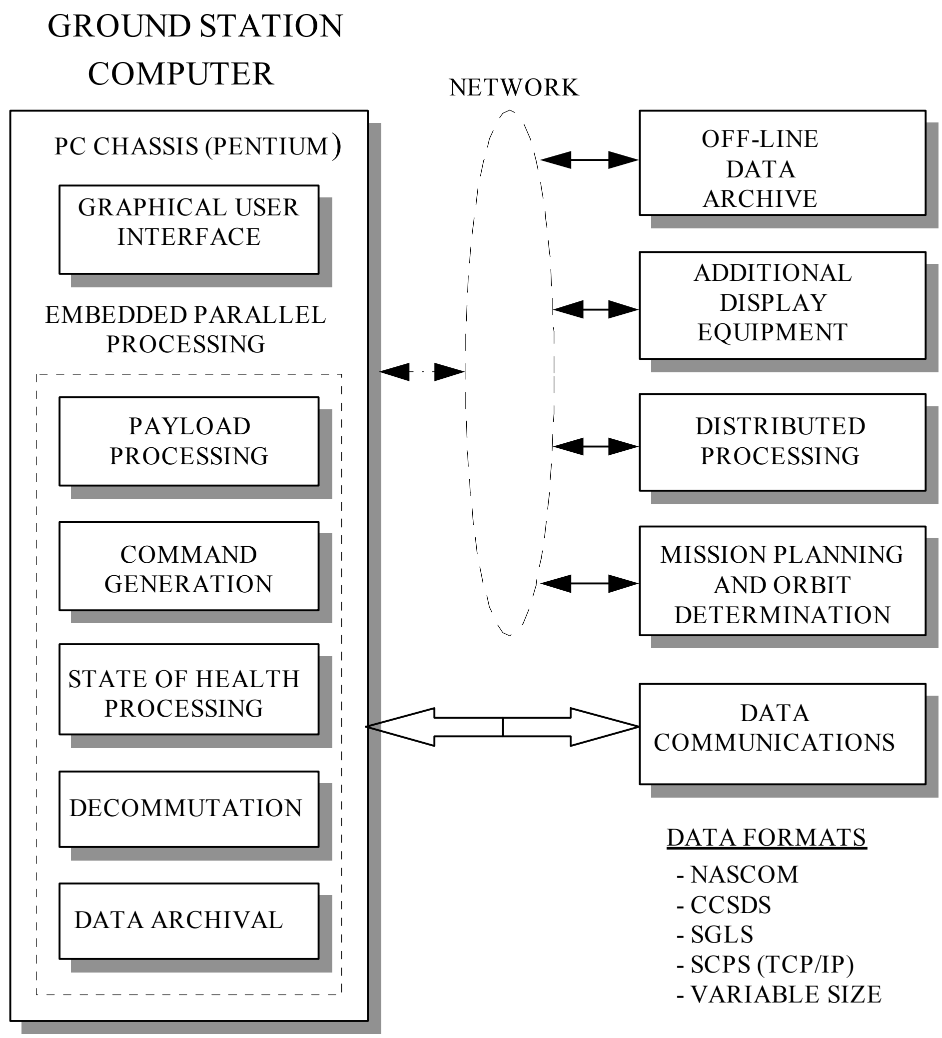

Figure 2 : Functional diagram of a PC based ground system with external components to create a Total Mission Concept.

TOTAL MISSION CONCEPT

An actual system utilizing this total mission concept is the Total Ozone Mapping Spectrometer (TOMS) Mission Operations Center (TMOC). The TMOC is based on Commercial Off The Shelf (COTS) products incorporating low cost, reliable, upgradable, standardized hardware and software. The TMOC is entirely driven by Personal Computers (PC's) utilizing the Intel 486 and Pentium Processor family.

Embedded parallel processing is added to systems where real-time processing or high computational requirements is needed. This reduces the need for high cost workstations and related software, as well as separate, costly front end processors (FEP). The ability to selectively add 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 TMOC functional areas are shown in figure 3. These include Real-time Command and Control, Health and Safety, and Mission Planning. The individual functional areas are connected via a local Ethernet Local Area Network (LAN). This local LAN is not accessible from external resources thus making the on-line systems safe from intruders.

The TMOC Command, Health and Safety systems interface directly with the Deep Space Network (DSN), Wallops flight facility, and the Air Force Satellite Central Network through the NASA Communications network (NASCOM). These sites are utilized for support of commanding, telemetry, and tracking of the TOMS satellites. The embedded system incorporates the FEP internally, making each single PC based workstation fully portable and independent. The internal FEP is fully programmable to accept raw PCM data, NASCOM packets or TCP/IP packets.

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 provides the interface to the mission planning systems. Several COTS products are now available that make integration of the Flight Dynamics functions into the control center possible.

The Jet Propulsion Laboratory (JPL) and mission planning coordinate and schedule all support for different components of the mission. The mission planning facility coordinates and schedules all support for the mission through a dial-up line to JPL using the FDF data, JPL schedules, and experimenter's command requests. Command loads are prepared from the databases and transferred directly to the on-line Command systems.

The Science processing facility receives processed TOMS data from the server and further processes the data to create various products. The science facility receives data on a daily basis via Ethernet using TCP/IP. Since Level-0 product is already being processed within the control center, the system can easily be scaled up to provide Levels 1, 2, and 3 processing. Long term data is archived in the control center on CD-ROM media and furnished periodically to the Science facility.

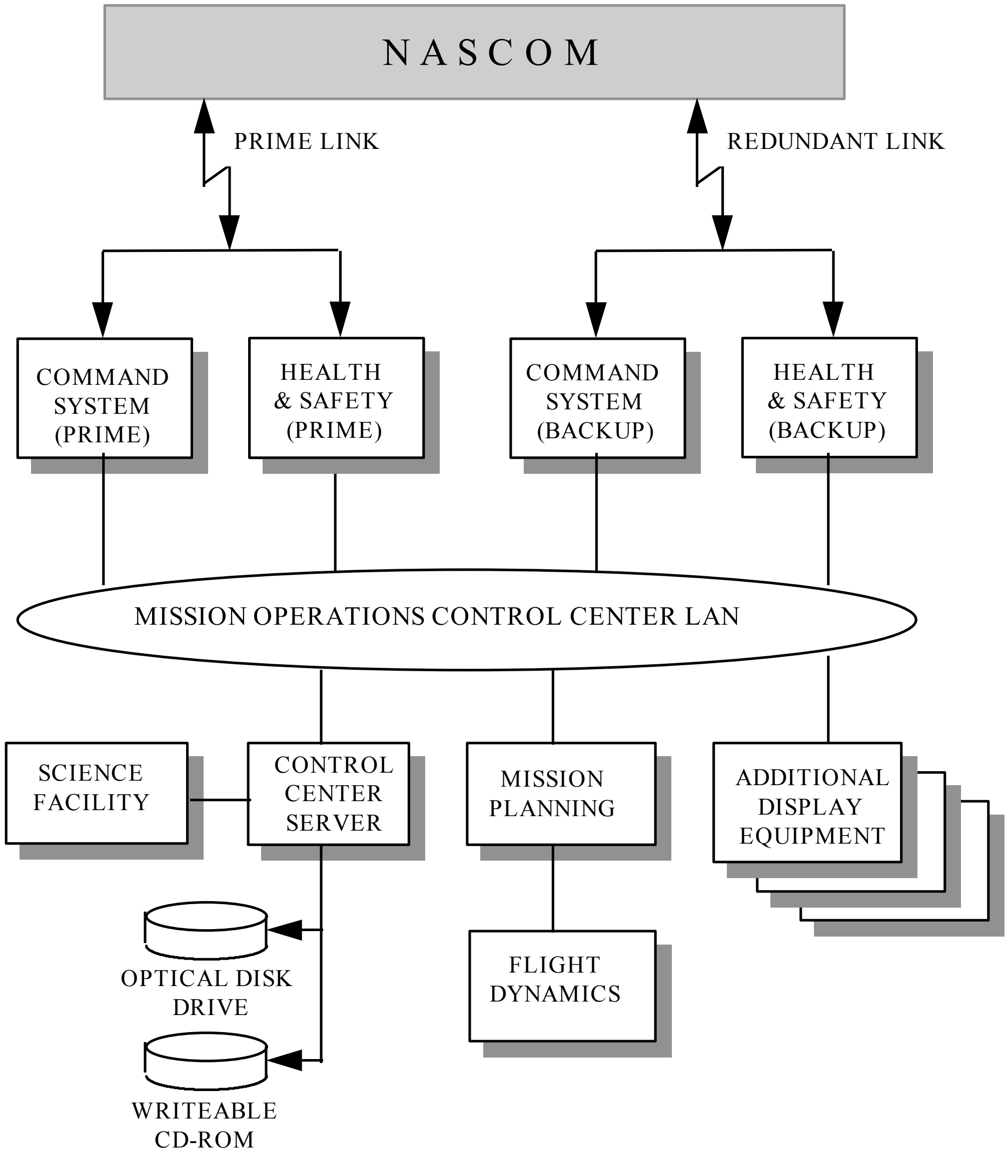

Figure 3: Major functional blocks incorporated in the TMOC: external functions such as science processing are connected to the Server by an external LAN preventing access to the internal LAN. Mission Planning also connects to Flight Dynamics by external LAN.

The on-line systems that are connected to the NASCOM network are all identically configured systems as shown in figure 2 and 3. 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 of the systems have a UNIX Operating System with an X-windows based Graphical Users Interface (GUI) supporting the X11-R5 standard. All of the Command, Health and Safety, Level-0 processes, and analysis applications are written in ANSI C language using the Motif library. This standardized approach enhances the portability of the application source code to other platforms. Since all of the on-line systems are identical, any one can execute the Command software or the Health and Safety software.

The command system utilizes a command database specifically tailored for the TOMS Earth Probe satellite and instrument. The command system not only has Real-time command capability, but also full store and forward capability. These features allow for stored sequences of commands that can be executed onboard the spacecraft at predetermined times. All commands transmitted are verified by echo blocks and by telemetry downlink. The telemetry downlink CCSDS format is fully decommutated in real-time in the internal FEP.

The Health and Safety system provides a full analysis of both the spacecraft and the instrument in real-time. From a pull down menu bar and 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 updated in real-time through a shared memory interface. The embedded FEP does all the decommutation, calibration, floating point conversion, mode, event and alarm determination. The FEP passes the processed data into the shared memory interface for display purposes. Each subsystem is represented by a button that is displayed as green, yellow, or red depending on the state and mode. Green implies normal operation, yellow and red indicate potential problems. By selecting the subsystem button and clicking the mouse, the related event and telemetry panels are immediately displayed for analysis. X-Y plots are utilized to represent trending analysis.

There are several standard PC's without FEP's that are connected to the LAN. These PC's are configured. as standard office systems running MS-DOS and Windows. With an X-windows package, they are capable of running remote Health and Safety sessions in a client/server configuration. This configuration allows multiple screens from several subsystems to be viewed simultaneously. The PC is used to transfer telemetry data points from the UNIX system and run COTS tools for trend analysis and anomaly resolution.

The Total Mission Concept as shown in figure 4, can be implemented today in a very cost effective scenario. The same operations personnel can perform all the functions discussed 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 screen. The non real-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.

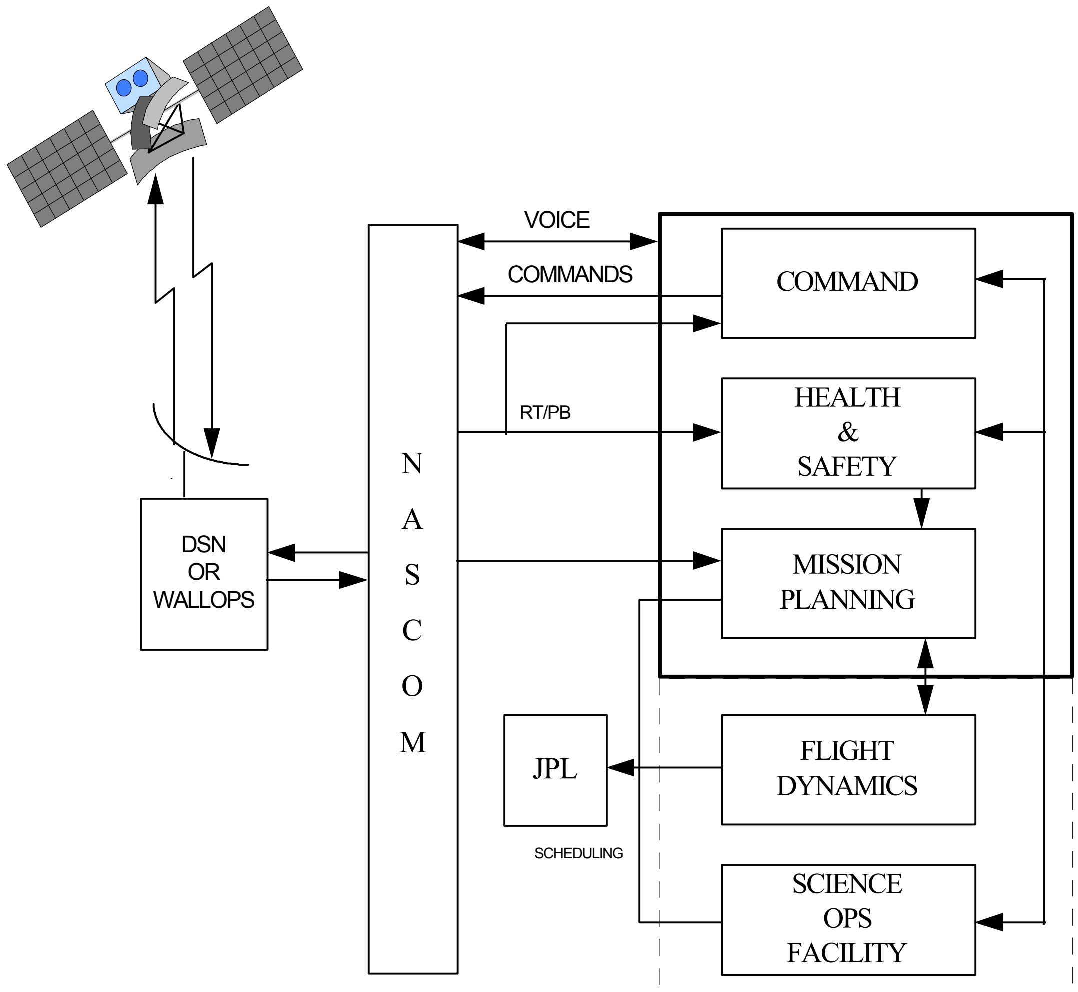

Figure 4: Total Mission Concept for TOMS Mission Operations Center. Adding Flight Dynamics and full Science processing will provide for a complete self contained entity.

ON-GOING EFFORTS

Modules utilizing the DEC Alpha processor (550 MIPS) are being merged into the existing embedded parallel processing architecture. These systems are being designed to conform to an Open Systems Architecture for interoperability with many COTS products. Computer systems from laptops to high end workstations can interface with it through a common Applications Programming Interface (API). A new packet module utilizing an Alpha processor will be added to provide dual channels at data rates up through 50 Mbps.

Several inference engine (rules based) products are being evaluated for automated emergency procedures, and command generation. Graphical representation of the state of all sub-systems of the spacecraft and payloads with hooks into the engineering values if needed. Adding full Relational Data Base Support will give the system a more generic mission profile that can be used to add mission profiles quickly. Addition of image quick look capability will provide data quality verification during real-time and playback data recorder dumps.

SUMMARY

Transputers and DEC Alpha processors are used in an embedded processing environment to support the expansion of the Ground System from a simple command and telemetry analysis system to a system that supports spacecraft Integration and Test, command, telemetry and science processing and distribution. The cost effectiveness of this Total Mission concept and the potential 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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