APPLYING PC-BASED EMBEDDED PROCESSING FOR REAL-TIME SATELLITE DATA ACQUISITION AND CONTROL

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ABSTRACT

The performance and cost effectiveness of embedded processing has greatly enhanced the personal computer's (PC) capability, particularly when used for real-time satellite data acquisition , telemetry processing, command and control operations. Utilizing a transputer based parallel architecture, a modular, reusable, and scalable control system is attainable. The synergism between the personal computer and embedded processing results in efficient, low cost desktop workstations up to 1000 MIPS of performance.

[Key Words: Real-time Command and Control, Telemetry Processing, Embedded Processing, Transputer, Parallel Architecture]

INTRODUCTION

The rapid advance of very large scale integration (VLSI) design during the early 1980's made it feasible to devise high performance, cost effective, and efficient computer systems which utilize more than one processor, i.e., a multiprocessor. In recent years, parallel processing VLSI devices have been developed which provide an efficient alternative approach to serve the demand of fast and intensive computing. The decrease in cost and increase in capabilities of parallel processing devices has led to their use in multiprocessor structures for real-time control applications, using embedded processing. We refer to these as embedded controllers. In general, embedded controllers are not reprogrammed while in operation, therefore, they do not require interrupts from the operating system to support standardized services.

We have found that the use of transputers for implementation of embedded processing in telemetry applications has several advantages. A wide range of transputer programs have been developed that are capable of being run in a standalone mode as embedded applications, and which require minimal or no support from the associated host operating system. A network of transputers, embedded in a conventional host processor can work as a highly efficient, multipurpose computing engine and is equivalent to an embedded controller. In this configuration, the conventional host (PC) performs the job of a front end to support user interface and display activities as well as other input / output operations. Computationally intensive tasks such as real-time data acquisition, command and control functions are performed concurrently on a network of embedded transputers. The host also provides the programming environment and program downloading capabilities for the embedded processing sub-system.

This paper describes current developments of a NASA sponsored ground control center utilizing desktop personal computers. PC's will be used for complete real-time spacecraft command and control, high speed data acquisition, telemetry processing, spacecraft health and safety evaluation, and data archival exploiting embedded processing and parallel methodologies. In order to provide a clear understanding of the system architecture, the events leading to the recent implementation of transputers as embedded processing tools are reviewed.

BACKGROUND

During the early 1980's, a new ground based system development was initiated for the flight operations control of the Nimbus 7 satellite. The design of the system focused on achieving the following goals: low cost, high performance, short development cycles, ease of maintenance and use, reusability of software and hardware, and maximal use of commercially available hardware and software. The preliminary version of the system was implemented on an IBM 8088 XT with a DOS operating system which housed a single embedded processor based on the Motorola 68000 series chip.

These systems have been upgraded to use Intel based 80486 type PC's with a network of transputers, the SCO UNIX Open Desktop operating system, and an OSF/Motif Graphical User Interface (GUI) to provide a multi-user, multitasking system. A typical system with embedded processing capability is shown in figure 1. The configuration of the system shown in figure 1 performs the following functions: it can acquire data transmitted from the satellite via the NASCOM data system at sustained rates in excess of 2 megabits per second; decommutates spacecraft data frames on a bit-by-bit or a byte-by-byte synchronization pattern search; carries out spacecraft health and safety analysis; executes all real-time command operations to the satellite, performs post pass analysis of all playback data (data recorded in the flight recorder of the satellite, while out of contact with the ground based system); distributes data for subsequent scientific analysis, and archives all spacecraft and processed data. All functions occur in real time or

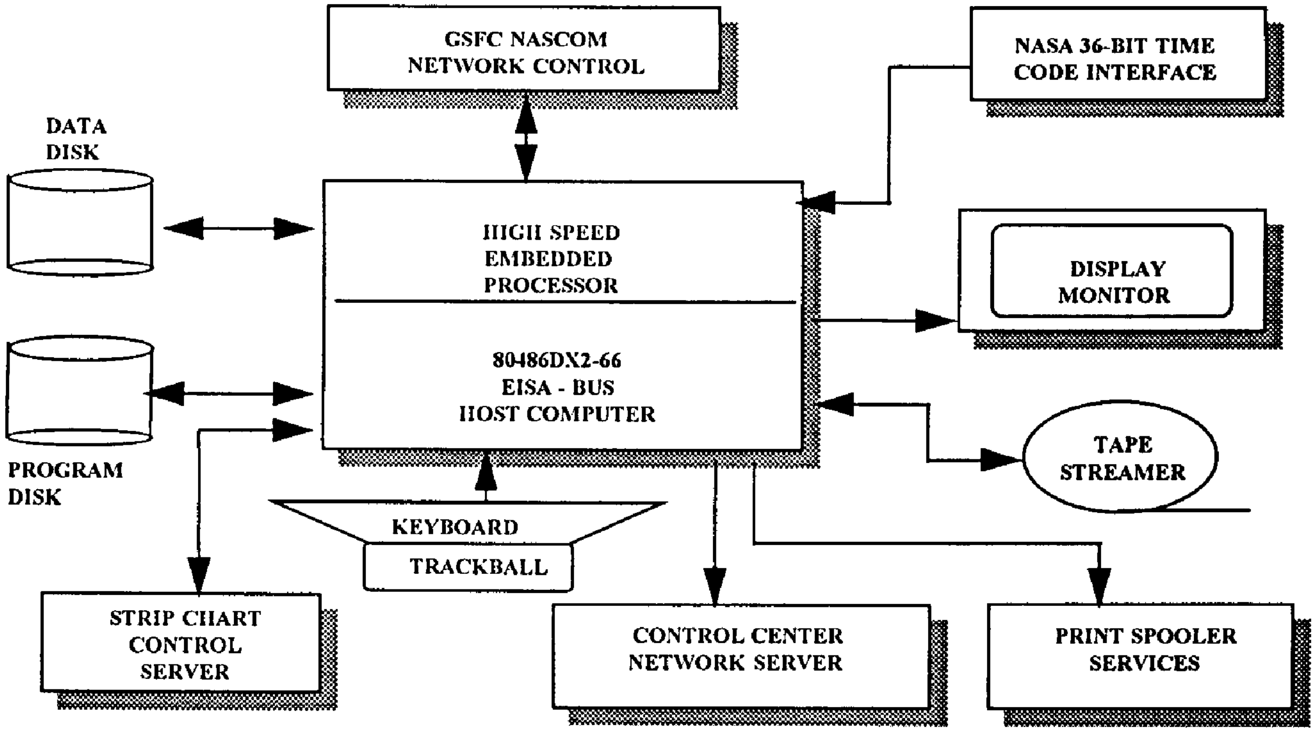

Figure 1 : The present model of the ground system exhibits its components for real-time data acquisition, display activities, user interface and other input / output peripheral interfacing
7 represents the direction of data flow , an d : represents bidirectional interface

within one hour of data acquisition. In practice, we may use two or more identical systems in a cluster mode to perform total spacecraft operations with full redundancy and they can be interchanged to perform any required function. In a typical application, the systems are connected via internal Local Area Network (LAN) to a mission planning system for command management and a file server for distribution of data to the desired science operations facility.

TRANSPUTERS IN EMBEDDED PROCESSING

A transputer is the basic building block for a PC-based multiprocessor system architecture. The transputer provides both computational power and communication links which makes it possible to transfer data in a non-bus mode. Transputers feature a built-in hardware scheduler which enables any number of concurrent processes to share the processors time and have well defined growth paths to future technologies.

This single chip RISC (reduced instruction set computer) microprocessor, makes a very powerful and versatile component for Parallel Processing [1]. Scalable communications bandwidth is an equally important feature for a parallel architecture. A transputer has four direct DMA link engines to provide highly efficient mechanisms for inter-processor communications and data transfers while avoiding the limitations of a shared memory design. These links and the ease of integration support the design of functional modules. The communications channels of the transputers allow modular design of the embedded controller on an EISA based interface board (figure 2) which in turn results in several tasks occurring simultaneously such as data ingest and archive, real time command and verify, and spacecraft health and safety checks.

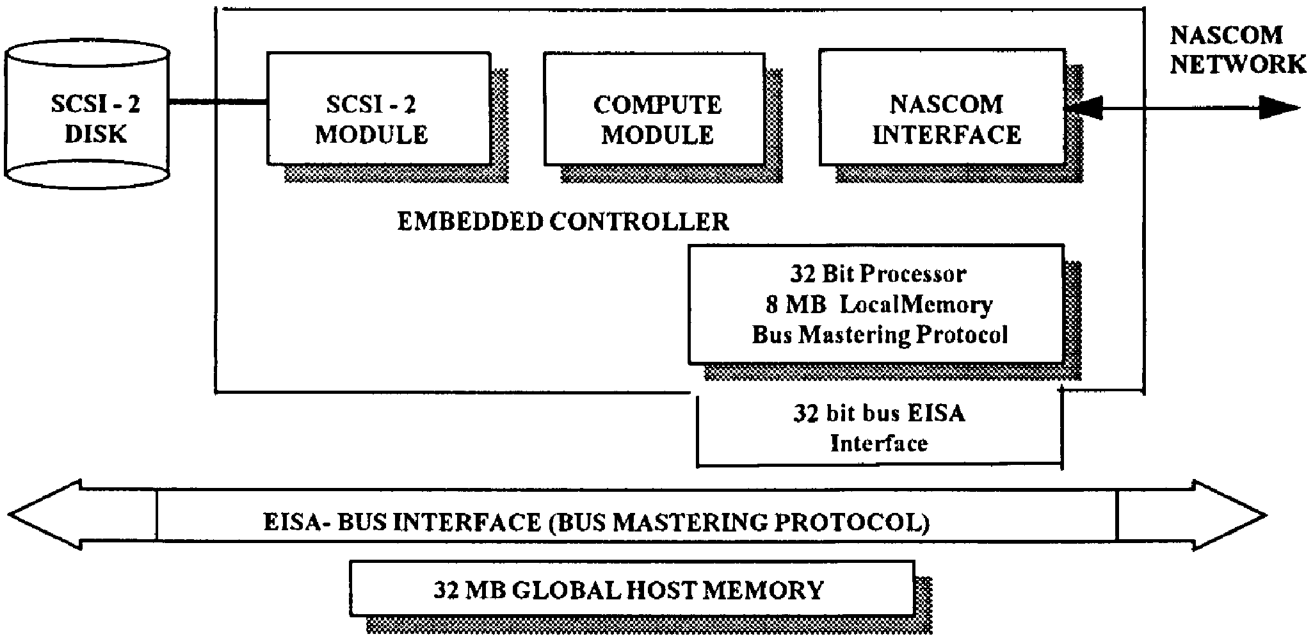

Figure 2 : The embedded controller consists of SCSI-2 data archive module, a compute module for intensive computing , and a Nascom interface module for communication. It also includes a 32 bit processor, and EISA-bus interface which allows sharing of data between the modules and other interfaces.

EMBEDDED PROCESSING IN THE SYSTEM

In Pc based systems, modularity is the key factor in developing a scalable, cost effective and reliable system. The modular processing employed in such a system can be exhibited as shown in figure 3.

Custom modules such as the NASCOM interface, Compute modules, and 'Fast' SCSI-2 modules are a few of the modular building blocks utilized in PC-based ground stations. The NASCOM module receives blocked data from the satellite via NASCOM, checks the block size and the NASA 22 bit CRC error, and buffers the data before passing it to the Compute module.

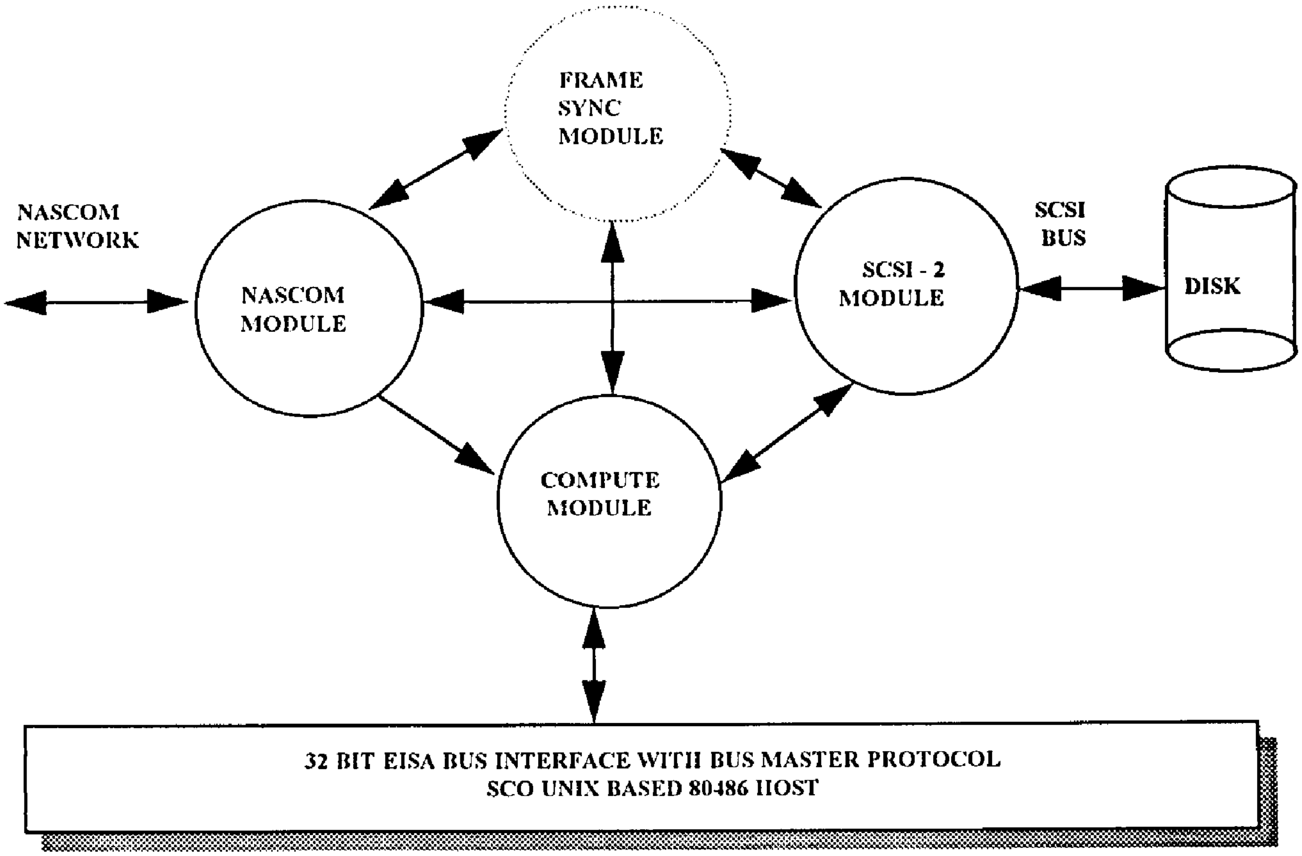

Figure 3 : Modular processing of the present system involves bidirectional message passing between the components : Nascom module, Compute module, SCSI-2 module, and optional Frame Sync module, as well as Nascom network, disk and EISA bus interface to the host. ----- represents the bidirectional data flow.

The NASCOM interface module is very versatile and has the following capabilities .

- Frame Synchronization Pattern size up to 128 bits in length
- Programmable frame packet size from 8 to 65536 bits
- Programmable correlation threshold
- Programmable clock and data polarity control
- NASA 22 bit CRC decoding and error detection
- Supports in burst mode 5 MBit / sec ingest data rate
- Six hi-speed DMA links connecting to EISA crossbar switch.

The Compute module performs intensive computing related to formatting the data and preparing the data for subsequent scientific analysis. The SCSI-2 module provides fast storage of processed or raw data to a SCSI disk or other SCSI devices.

RECENT DEVELOPMENTS IN COMPUTER ARCHITECTURE

During the past decade of development, three major technology issues have affected the progress to achieve the present status of the project. These issues are the evolution of the transputer, particularly with the recent introduction of the T9000 series, EISA bus mastering and 'Fast SCSI-2' interfaces supporting transputers. Before discussing the latest architecture of the ground based data acquisition systems, a brief review of the above-mentioned issues is in order. For further detailed information in any of these issues, listed readings [2], [3], and [4] can be suggested.

The T9000 is a new generation of the transputer series. The features of T9000 include: programmable memory interface; 4 Gigabyte physical address space; 16 Kbyte instruction and data cache; virtual channel processor; 200 MIPS and 25 MFLOPS performance (at 50 MHz.), and instruction set compatible with T800 [2]. Its packet-switched virtual communication channels support the routing of messages and reduces the communication delays to a few microseconds from that of hundreds of milliseconds in T800.
Today's transputers (T9000) having up to 200 Million Instructions Per Second (MIPS) peak [2] power, can be used for computationally intensive activities and high speed bit operations, while the Intel based host 80486 computer provides a programming communications interface to the transputer and controls graphic displays and data bases. The T9000 transputer [2] has just been made available. Although currently not implemented in our design, it can be used to compliment the T800 based modules for increased power without the need for major redesign of the existing system.

The concept of Extended Industry Standard Architecture (EISA) became available in late 1989 and was built around a 32 bit-wide bus architecture. A major feature of EISA is that any bus master interface controller can directly access memory and memory mapped peripherals in the system without host processor intervention. The EISA bus controller can adapt accesses from the host CPU, a 32- or 16-bit EISA master or an ISA bus master. They are capable of 32-bit burst transfers at a speed of 33 megabytes per second. This feature is extremely helpful in the data acquisition systems for handling high-speed LAN networks and feeding a fast disk drive.

The SCSI (Small Computer System Interface) is known as a parallel, multi-master input/output (I/O) bus. It can provide extremely fast I/O operations. The SCSI-2 evolved from the original SCSI specification, added features such as higher data transfer, greater compatibility and provides two optional enhancements towards increasing throughput: 'Fast SCSI-2' and 'Fast Wide SCSI\I-2'. The 'Fast SCSI-2' allows data transfer at a rate of 10 millions transfers per second over the SCSI bus.

SYSTEM ARCHITECTURE

Several systems developed since 1987 are reviewed in the proceedings of space ops '92 [8]. Our current system architectural concepts are:

1) The primary function of the host is to provide the programming interface to the embedded system and provide a graphical user interface. The user interface either utilizes a DOS/ Windows or UNIX/ X-Windows/ Motif environment depending on the applications requirements.
2) The embedded processor provides the systems computational power. Employing the T800 with 30 MIPS peak [1] processing rate per transputer, and capitalizing on the point to point direct communications channels, a network of processors operate concurrently. The embedded processor permits a flexible approach to data capture, health and safety analysis, commanding, and science processing all on the same system. As higher speed transputers become available, they will replace or compliment slower speed modules.

3) The use of Commercial Off The Shelf (COTS) hardware and software is maximized and that Industry Standards are utilized for all external interfaces.

The system architecture diagrammed in figure 1 provides a building block approach to ground system requirements whether it be a stand alone or distributed application. Typically in the stand alone system, one system is used for commanding and another for health and safety analysis. A hot redundant back up for each of the two prime systems prevents a single point of failure and low cost protection for data or commanding loss. Command management, scheduling, and spacecraft software image maintenance is performed on another system with redundant back up. All systems are networked together via ethernet for data distribution, data archive, and strip chart recording. This self contained, integrated system, provides spacecraft command and control capabilities on a desktop and uses standard office power and environmental services.

The use of commercially available software and hardware for databases and displays reduces documentation efforts and helps control cost. For example, Case tools are used in the development cycle, OSF/ Motif is used to develop displays and user interfaces, and FoxPro is used to generate the databases for database driven software. Use of these standard tools reduces learning time both for operators and designers. The small size does not mean reduced performance. During the pass, real time commanding and command verification based on telemetry returns occur while receiving and processing satellite data. All spacecraft systems are continuously checked and monitored. Icons using color to designate status change are continuously displayed and are selectable for full on screen viewing by a keystroke. Other features which add to this system performance are:

- The capability to do X-Y plots on any telemetry point for trend analysis.
- Highlighting status changes due to command or events on any display.
- Subsystem sorted chronological by event or mode list.
- Use of optical disks for long term data archiving.
- Level '0' science processing can be performed post pass or real time depending on the missions needs.

To convert a standalone system to a distributed system, both an ethernet module and compute module are added to the Embedded Controller board. Packets of information are distributed to numerous display terminals using a client-server mode similar to the X-Windows environment. This is well suited for multi-spacecraft operations or applications where multi-instrument displays are necessary to support scientist and experimenters.

A special purpose, full length, 32 bit Extended Industry Standard Architecture (EISA) board featuring Bus Mastering Protocol has been designed to provide support of parallel processing. The EISA board helps modules to support up to ten parallel processing modules as diagrammed in Figure 2. Up to four full EISA boards may be installed inside an Intel based 80486 host. Connections are provided to interface with external based Massively Parallel Processing (MPP) systems (scalable up to 800 Giga-Instructions Per Second (GIPS)) when greater computational capacity is required [3]. Industry Standard interfaces are utilized and include: 1) Small Computer Systems Interface (SCSI) ; 2) RS-422 and RS-232 ; 3) Ethernet IEEE 802.3 File Transfer Protocol (FTP), and Transmission Control Protocol (TCP/IP) as shown in figure 4.

PARALLEL PROGRAMMING OF THE SYSTEM

Embedded computers utilizing transputers feature a parallel architecture, which in turn provides the ability to expand (or scalability) the hardware configuration to suit the application. Parallel Programming of the system relies on the effective utilization of multiple processors for increased performance. In a PC based ground system, more computation time than time for interprocessor communication indicates a good fit for parallel implementations. Problems such as real-time control, monitoring, event determination, image, and science processing have already proven to be good candidates for Parallel Programming.

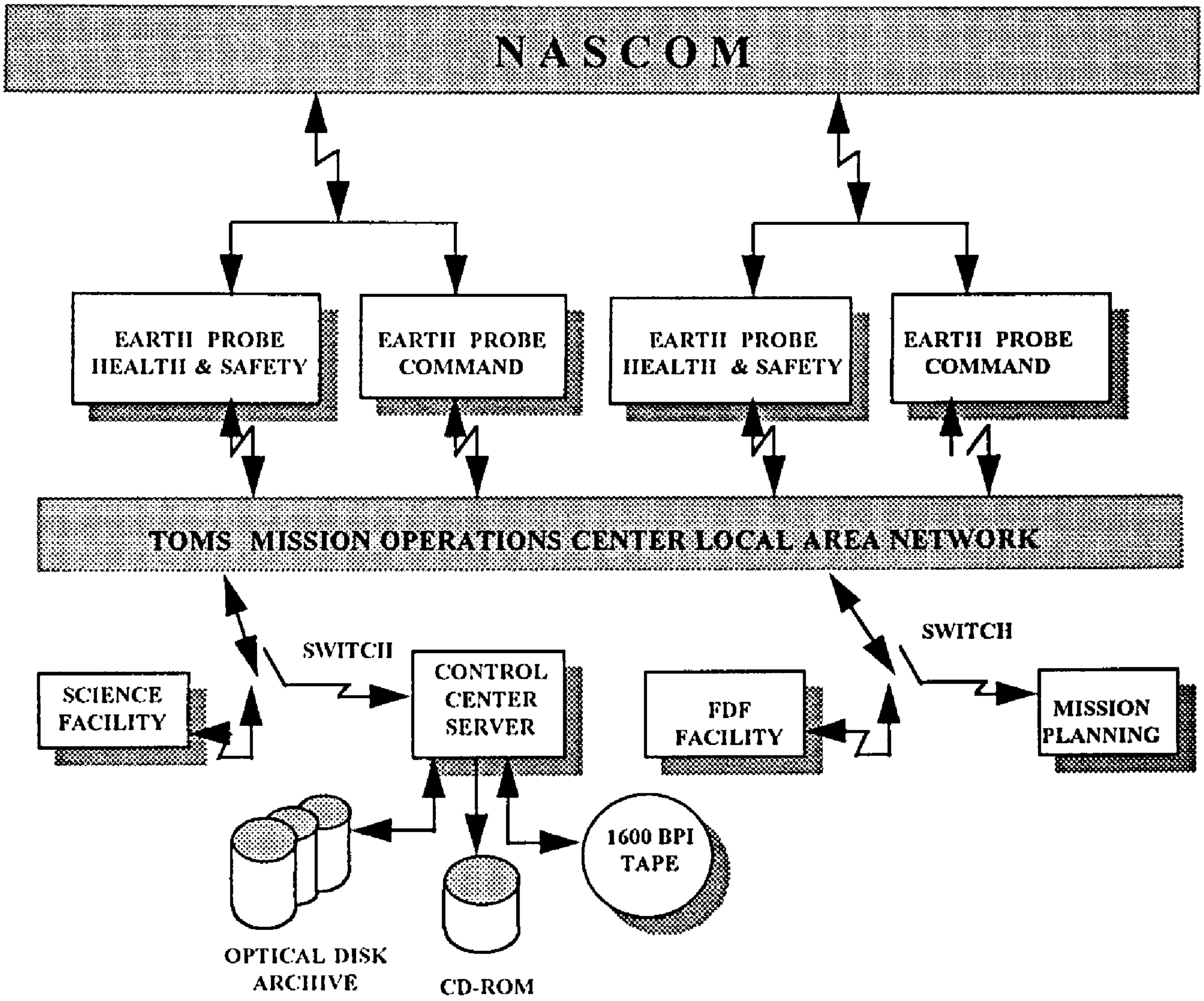

Figure 4: The Mission Operations Center of TOMS Earth Probe System is connected to external facilities such as science and FDF and internal operations such as mission planning and health and safety via wide and local area network.

In the present system, C and Occam are used as programming languages in developing parallel processing environment. The modularity of the system is supported meticulously using parallel language such as Occam. Occam processes act as building blocks of parallel processing in transputers. They allow the design of a complete modular, scalable software to be designed on a single transputer for initial testing, validation and helpful debugging prior to its implementation on a network of transputers. Transputers allow mixed language programming, which makes existing programming modules written in a conventional language such as C reusable with a minimal addition to or change in the source code.

The efficient and appropriate utilization of a multiprocessing system depends upon its configuration, associated overheads, and an understanding of load balancing, performance evaluation and the cost factor. Obviously it is not possible to give the same priority to each of these factors, and it becomes necessary to make a trade-off between these factors. In this case, the optional frame synch module shown in figure 3 can be cited as an example. This approach of parallel programming enhances the future modification or development plan, scalability, flexibility, reliability and easy usability of any future architecture without major redesign of the system.

OTHER APPLICATIONS OF THE SYSTEM

Although the preliminary version of the system has been developed and designed with the primary goals of the Nimbus mission in mind, the design methodology has improved over the years and proved to be highly efficient, cost effective, operational and adaptable to other missions such as Meteor 3/ TOMS and Earth Probe TOMS. The system architecture has been updated with the progress in present technology and modified to meet the challenging need for significantly increased performance and intensive computation. The present version of the system is capable of handling multi-spacecraft mission control and it can be scaled to meet new requirements with minimal changes in configuration and design.

The depth of the discussion has been centered around spacecraft telemetry processing, but the system should not be construed as limited to this application. The scalability of the system provides adaptability to radar, remote sensor telemetry, airborne imagery, seismographic, as well as science data processing. In fact, parallel processing is well suited to compute intensive data processing applications, both in real time and post processing applications.

SUMMARY

In summary, the use of personal computers in combination with high speed transputer modules provides a relatively low cost, highly versatile, workstation building block upon which satellite control centers can be built. In addition, the latest developments in the modern computer architecture, a few of which described in a previous section can help upgrading the performance of the presently described system.

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