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MIRAGE: THE DATA ACQUISITION, ANALYSIS & DISPLAY SYSTEM

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ABSTRACT

Developed for the NASA Johnson Space Center Space and Life Sciences Directorate by GE Government Services, the Microcomputer Integrated Real-time Acquisition Ground Equipment (MIRAGE) system is a portable ground support system for Spacelab life sciences experiments. The MIRAGE system can acquire digital or analog data. Digital data may be NRZ-formatted telemetry packets or packets from a network interface. Analog signals are digitized and stored in experiment packet format. Data packets from any acquisition source are archived to a disk as they are received. Meta-parameters are generated from the data packet parameters by applying mathematical and logical operators. Parameters are displayed in text and graphical form or output to analog devices. Experiment data packets may be retransmitted through the network interface. Data stream definition, experiment parameter format, parameter displays, and other variables are configured using spreadsheet databases. A database can be developed to support virtually any data packet format. The user interface provides menu- and icon-driven program control. The MIRAGE system can be integrated with other workstations to perform a variety of functions. The generic capabilities, adaptability, and ease of use make the MIRAGE a cost-effective solution to many experiment data processing requirements.

INTRODUCTION

This paper describes the overall design, major features, and possible applications of the Microcomputer Integrated Real-time Acquisition Ground Equipment (MIRAGE) system. The MIRAGE system provides a portable, self-contained unit capable of data acquisition, monitoring, analysis, archival, playback, and network transmission. The MIRAGE can acquire RS449 synchronous serial NRZ-formatted Spacelab downlink telemetry data transmitted from a High-Rate Demultiplexer Interface (HRDI) or as Consultative Committee for Space Data Standards (CCSDS) packetized data from a network interface. Analog input signals can be acquired and inserted into data packets. Meta-parameters are generated from the data packet parameters by applying mathematical and logical operators. Data parameters are displayed in text and graphical form in a Macintosh window environment. Selected parameters are output to strip chart recorders or other analog devices through a digital-to-analog interface. Experiment data packets may be transmitted through the network interface. The MIRAGE also accepts IRIG-A formatted time input through a Macintosh serial port. Data stream definition, experiment parameter formats, and other variables are read into the program from spreadsheet databases. The Macintosh user interface provides menu- and icon-driven program control. Experiment data acquisition and processing are supported during baseline data collection, experiment hardware bench testing, and real-time support of flight experiments. Archived data are played back and analyzed postflight. The MIRAGE can be integrated with other data acquisition and analysis systems to perform a variety of experiment data processing functions.

The MIRAGE is being used initially to support the Baroreflex experiment on the German D-2 Spacelab mission (STS-55) scheduled to fly in February, 1993. The objective of the Baroreflex experiment is to measure the sensitivity of the carotid sinus baroreceptor reflex during spaceflight to determine the effect of weightlessness on normal cardiovascular reflex control mechanisms. Principal Investigators at the German Space Operations Center will use a MIRAGE system for real-time data acquisition, display and analysis during the mission [1]. The MIRAGE will also be used in bench testing of experiment hardware, and during preflight and postflight baseline data collection. It will also be used to play back, analyze, and transform archived data.

OVERALL DESIGN

Design Considerations

The original design specifications for the MIRAGE system were created to support the Baroreflex experiment. During the early design phase, it became clear that by selecting the right hardware and using a modular, object-oriented approach to software development, the MIRAGE could become a flexible, powerful system capable of operating in a wide range of data acquisition environments. Some of the desired features of the MIRAGE system that were combined to meet this goal are listed below.

- Easy to use
- Easy to maintain and modify
- Possess real-time, multifunction capabilities
- Acquire data from several sources
- Support multiple experiment data streams
- Generic data displays to handle a wide variety of data
- Use preexisting software and off-the-shelf hardware where possible
- Provide real-time and post-time data analysis
- Provide data playback capability

Input Data Format

The original design specifications for the MIRAGE required that it support the acquisition and processing of a synchronous serial NRZ-formatted data stream generated by an experiment payload microcomputer at a minimum bandwidth of 32 kilobits per second. The data stream is formatted into High-Rate Multiplexer (HRM) frames [2]. In this format the data bits are formatted into 12 or 16 bit words. The words are grouped into minor frames. A minimum of four minor frames are grouped into major frames. Each minor frame begins with a standard 6-byte header. The first 32 bits of the header are a 24 bit sync word and 8 bit minor frame number used for frame synchronization. Data parameters are stored in the remainder of the minor frames. Data parameters may or may not be major-frame repetitive; ones that are not repetitive are indicated by bits set to indicate the presence or absence of particular parameters in the major frame. Upon acquisition by a ground system, major frames are grouped into packets of one or more major frame per packet. The MIRAGE system can be configured to acquire packetized digital data in other formats.

Up to sixteen analog channels can be input into the MIRAGE system. Samples of the signals are digitized and stored in digital data packets.

Hardware

The MIRAGE system was initially developed on a Macintosh IIfx platform. The MIRAGE software will run on any Macintosh with a Motorola 83020 or higher processor and at least 2 MB of internal RAM memory; however, at least five NuBus slots are necessary to install the boards required for a full-function MIRAGE system. Macintosh system software 6.0.5 or higher is required. A HRDI box is necessary to acquire Spacelab downlink telemetry data.

Digital and analog data acquisition and analog data output are supported with four NuBus boards manufactured by National Instruments [3]. An NB-DIO-32F is used to receive data directly from a HRDI. A slight modification to this board is made to provide handshaking capability with the HRDI. An NB-MIO-16L provides up to eight differential or sixteen single-ended analog input channels. An NB-AO-6 analog output board provides up to six channels of analog output. An NB-DMA-8-G provides Direct Memory Access (DMA) transfers to speed up the digital and analog acquisition processes and the analog output process. National Instruments provides low-level drivers for the boards.

An Ethernet controller card is used to support data acquisition and transmittal over Ethernet using DECnet protocol. An 8 bit, 256-color graphics video board and color monitor (16 inch or larger preferred) provide high-resolution graphics display. An internal hard disk is used as a boot disk, and also holds the MIRAGE software. An external, removable-cartridge Small Computer System Interface (SCSI) disk is used for data archival. A Graphtec WR7700 eight-channel analog strip chart recorder is used to provide hardcopy strip charts. Any printer connected to the Macintosh locally or on a Local Area Network (LAN) can be used for printed output.

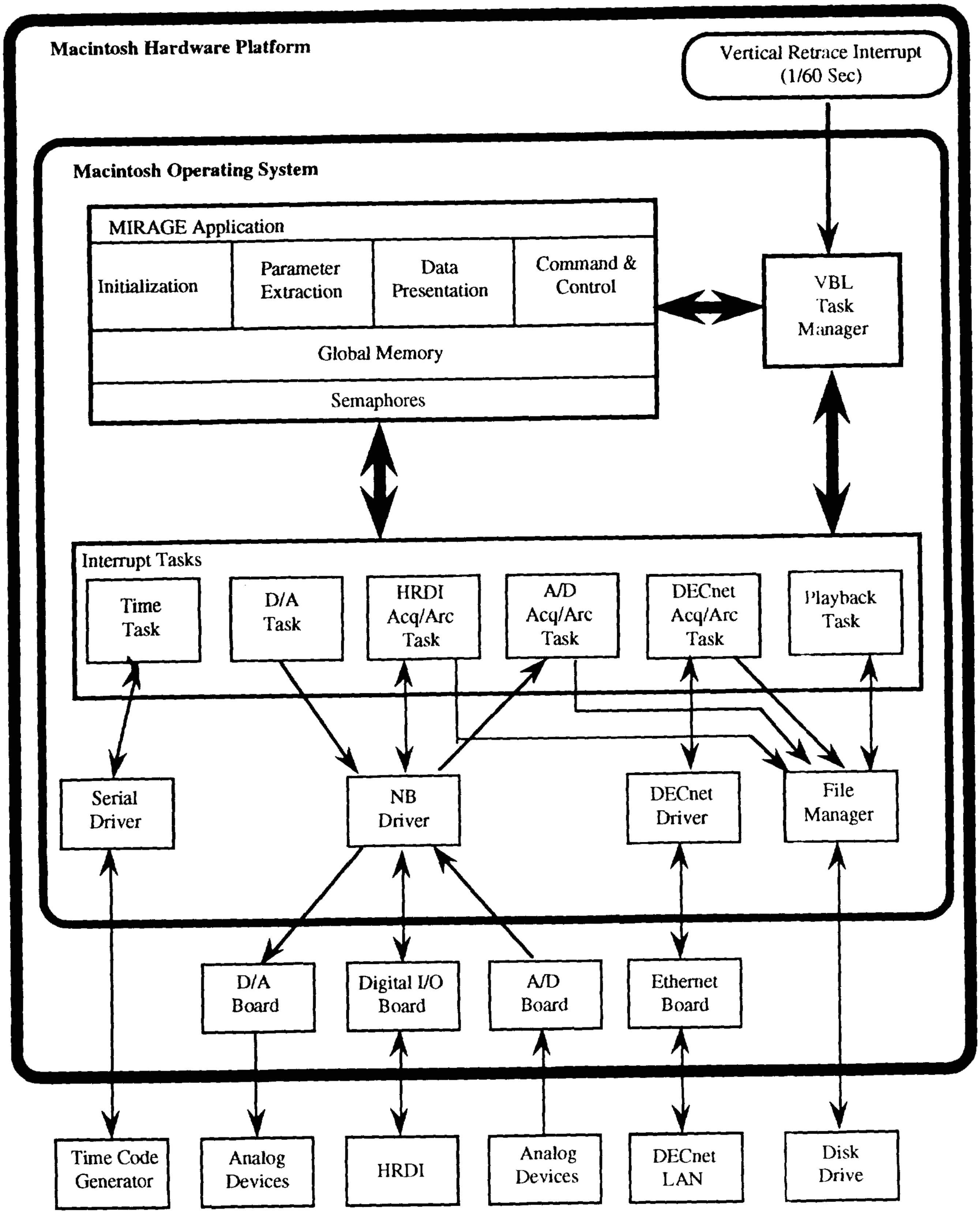

Figure 1: The MIRAGE System Architecture

Software

The MIRAGE system software was developed on the Macintosh platform using Apple's Macintosh Programmers' Workshop C. A modular, object-oriented approach to software design was used to assure ease of modifiability and maintainability. Necessary use of the Macintosh toolbox, however, means the MIRAGE software is not directly transportable to other systems such as DOS-based Personal Computers.

The MIRAGE software makes use of the vertical retrace interrupt service provided by the Macintosh toolbox to support real-time functionality. The MIRAGE software also uses National Instrument's library of function calls to control the NB boards. DECnet for Macintosh software is used to provide DECnet protocol interface to the Ethernet controller hardware. A third-party library of charting functions integrated with the MIRAGE software to provides X-Y plots.

See Figure 1 for an illustration of the MIRAGE software and hardware architecture.

Configuration Database

The MIRAGE configuration database is created using Microsoft Excel. The database consists of several tab-delimited text spreadsheets, arranged into folders on the disk the MIRAGE software resides on. The MIRAGE database is used to define the MIRAGE system defaults (fonts, colors, etc.), experiment-specific hardware configuration, data stream format (stream data rate, packet frequency, etc.), acquisition defaults, experiment parameter format (packet location, extract masking information, etc.), display format, and analog input and output characteristics.

Data Flow

Figure 2 gives a representation of the data flow through the MIRAGE system. There are three external sources: the Macintosh user interface, the experiment database, and the experiment data source. The user enters experiment stream, parameter, and display data into the experiment database. Through the Macintosh interface to the MIRAGE application, the user controls at runtime the experiment data source and other application functions. The user can choose the HRDI, DECnet, or analog acquisition functions. Data can also be played back from an archived disk file.

The data acquisition portion of the program reads data from the specified external data source and, based upon the contents of the stream database, extracts and stores the major frames in the primary buffers. If the user has the archival function turned on, the primary buffers are read by the archival process, a header is generated, and the data packet is written to the archive file.

The parameter extraction function then extracts the data values for each parameter specified in the display databases from the primary buffers. The parameter database is used to locate and process the data values. The extracted and processed data values are stored in the parameter buffers.

If analog output is enabled, the data values for the parameters to be output are extracted from the parameter buffers and stored in the analog output buffer. The buffer is then passed to the analog output process.

For each display and graph window defined in the display databases, the data values to be displayed are extracted from the parameter buffers and output in the specified window in textual or graphical form based upon input from the display databases.

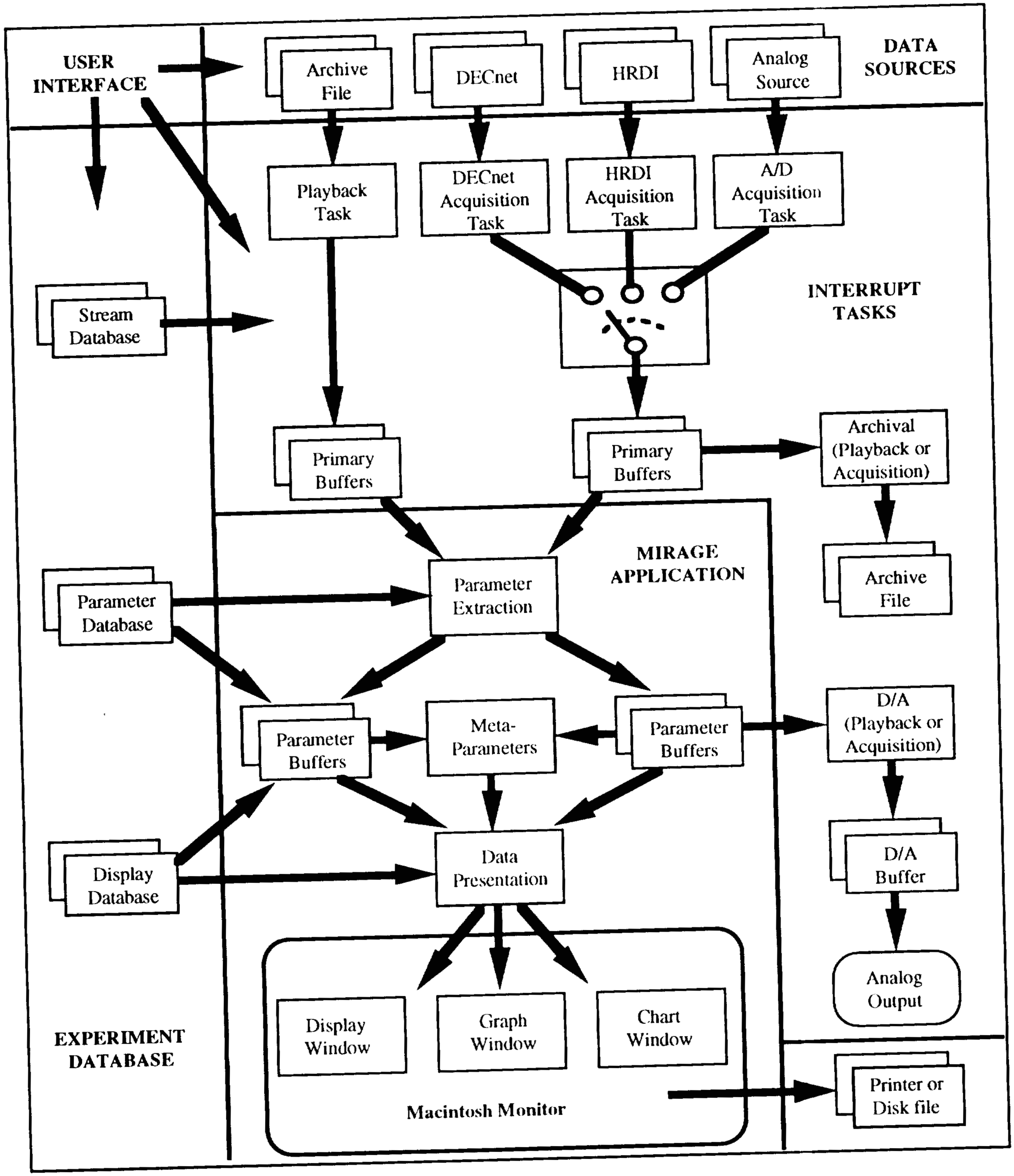

Figure 2: Data Flow Through the MIRAGE System

SYSTEM FEATURES

Acquisition

The MIRAGE system can acquire data from three interfaces: HRDI, DECnet, and analog.

HRDI Acquisition

The MIRAGE system uses the HRDI interface to acquire data during bench testing of Spacelab experiment payload microcomputers and during flight of a life sciences Spacelab mission. During flight, several data streams generated by experiment payload microcomputers are multiplexed to form the HRM Spacelab downlink telemetry data stream. On the ground, hardware external to the MIRAGE system demultiplexes this data stream into the separate experiment data streams, or channels. The HRDI interface can handle one of these channels at a time. During bench testing, the data stream generated by the experiment payload microcomputer can be connected directly to the HRDI.

The HRDI acquisition is achieved using an external HRDI box connected to a NB-DIO-32F input/output card via a 50-pin ribbon cable.

The HRDI is an interface board that resides in a box with its own bus and power supply developed with funding from the General Services Administration by GE Government Services at JSC [4]. The HRDI card receives balanced current serial signals and clock from the experiment payload microcomputer on two twinaxial cables. The line receivers compatible with this input are employed to convert current to standard transistor-to-transistor logic voltage levels. The input data is clocked into an Input Shift register whose length is 32 bits. This length is determined from the requirement to align itself to a 32 bit field (24 bit sync pattern + 8 bit frame count) for establishing and maintaining frame synchronization. The synchronization word for the experiment stream is set using thumbwheel switches. Some operational characteristics of the HRDI are preprogrammed by the host computer through a latched 16 bit Digital Output port. The HRDI board has an effective bandwidth of 512 kilobits per second.

All data transmitted by the HRDI flow through a 64 word first in, first out (FIFO) buffer (a 2K word FIFO buffer is currently available). The output from the HRDI is a sequence of 16 Bit words along with a transfer REQUEST signal. This REQUEST signal generates a DMA request for the host computer. The host acknowledges this REQUEST with a separate ACKNOWLEDGE signal, which also resets the old REQUEST signal.

The HRDI board requires two identical 40 pin ribbon cables compatible with the DEC DR11-W interface module. A Mac-to HRDI Interface board interfaces between the 50-pin NB-DIO-32F connector and the HRDI board.

The National Instrument NB-DIO-32F card is modified to interface with the HRDI board. The NB-DIO-32F is interfaced to the National Instrument Real-Time System Integration (RTSI) bus so that DMA transfers to Macintosh memory can occur using the NB-DMA-8-G. The 32 lines of digital I/O of this board are divided into four bytes, each of which can be programmed to function as input or output. The maximum transfer rate is 360K 32 bit words per second, more than adequate to support life sciences experiment data bandwidth. This card uses one DMA channel from the NB-DMA-8-G board.

DECnet Acquisition

During DECnet acquisition, a ground acquisition computer receives the HRM data stream, formats it into CCSDS packets, and transmits the packets to the MIRAGE node. The data transfer between the ground acquisition computer and the MIRAGE is accomplished over an Ethernet LAN using the DECnet transparent task-to-task communication services.

The MIRAGE system can acquire network packets transmitted over Ethernet using DECnet protocol. An Ethernet controller card in the Macintosh allows it to connect to thinwire or thickwire Ethernet media. Digital's DECnet for Macintosh supplies software support for the DECnet protocol.

The link between the MIRAGE system and the ground acquisition computer can be initiated in two ways. When the MIRAGE network acquisition is in MASTER mode, the MIRAGE network software searches for a designated object on the LAN and, upon finding it, initiates the link. In SLAVE mode, the MIRAGE system registers itself as a network object and waits for the ground acquisition computer to link to it.

Analog Acquisition

The MIRAGE can acquire up to eight differential or sixteen single-ended analog signals, extract samples from the signals at different frequencies, and pack the samples into experiment major frames. Analog acquisition is used in preflight and postflight baseline data collection for Spacelab life sciences experiments.

A National Instruments NB-MIO-16L board is used for analog-to-digital conversions. The board handles up to sixteen single-ended or eight differential 12 bit analog channels at a maximum sampling rate of 100 kHz. The NB-MIO-16L is interfaced to the RTSI bus so that DMA transfers to Macintosh memory can occur using the NB-DMA-8-G.

After the acquisition of each buffer of analog input signals, the buffer containing the samples is demultiplexed and packed into an experiment major frame. Each channel will represent one analog parameter for the experiment. The MIRAGE parameter database maps the samples of the different parameters into the major frame.

Other parameters necessary for the processing of the experiment major frame are inserted into the major frame after the analog data has been acquired. Locations and values of these parameters are derived from the MIRAGE experiment parameter database.

Data Displays

The Macintosh user interface is used to display digital and analog experiment parameters and the MIRAGE status parameters in a window environment. The MIRAGE displays are database-configurable. The display control interactive user interface allows the real-time modification of the data display windows. Some operations allowed are zooming in and out on graphs and charts, changing display colors, and changing fonts and font sizes. See Figure 3 for an example of a MIRAGE display window.

Each MIRAGE display window will have a number of items, or objects, used to display data in one of three formats: text, graph, or chart.

Text objects display discrete data in alphanumeric format.

Graph objects display analog experiment parameters in scrolling strip chart format. Each graph object will have one or more channel objects. One or more analog parameter trace is drawn to each channel. X- and Y-axis labeling is provided.

Chart objects display X-Y plots of selected parameters in real-time. Plots can be point-only or line plots. Recurring plots can be overlaid or cleared before replotting.

Data Analysis

The MIRAGE system provides several tools to aid the experiment scientist in data analysis. Some data analysis is performed in real-time.

The experiment meta-parameter database defines parameters that are derived from experiment parameters in the major frame. Meta-parameters can also be constants to use in the derivation of other meta-parameters. A meta-parameter definition consists of a type declaration, an operator, and a set of one or more operands. Meta-parameters can be 8, 16, or 32 bit integers or 32 bit real numbers. Several mathematical and logical operators are available including add, subtract, divide, multiply, logical AND, and logical OR. Meta-parameter operands may include experiment parameters or other meta-parameters. Meta-parameters are displayed in text, graph, or chart display objects.

The chart function, as noted above, allows for the plotting of X-Y plots during real-time.

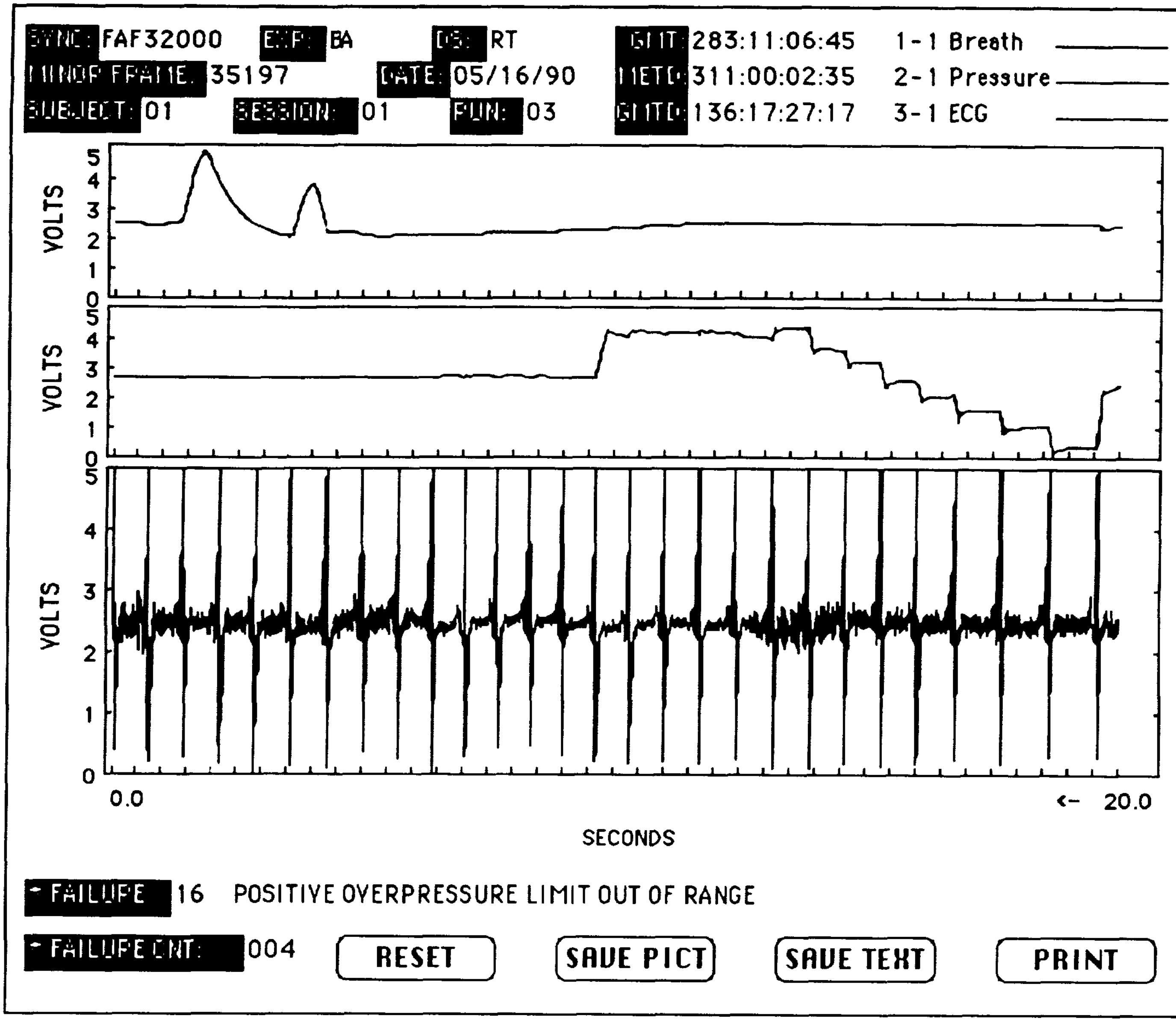

Figure 3: Typical Display Window with Graph

The information on displays can be saved in either Pict or text spreadsheet files for post-session analysis.

The MIRAGE can output selected parameters in digital packets over the network or as analog signals using the NB-AO-6. Other workstations or analog devices can receive and process this data.

Analog Output

Analog output of selected parameters is available through the NB-AO-6 analog output card. Up to six single-ended output channels are available. The NB-AO-6 is interfaced to the RTSI bus so that DMA transfers to Macintosh memory can occur using the NB-DMA-8-G.

During life sciences experiment support, the output signals are routed to a strip chart recorder. The strip chart recorder presently being used is a Graphtec WR7700. A Macintosh Serial port is connected to the recorder's RS232 port for periodic data time annotation. The serial port connection is also used to program the operational characteristics of the recorder such as speed, channel setup, etc. The output signals can be received by other workstations or analog devices to perform waveform analysis in real-time.

Archival

Experiment data streams acquired from any source can be archived to any disk drive connected to the MIRAGE system. Packets are archived exactly as they are received except for the addition of a 90-byte header. Archival can be suspended and resumed. Markers can be interactively inserted in the archive file to mark significant events during the run of the experiment.

As noted above, displays can be saved in Pict or spreadsheet file formats when updated.

Playback

The MIRAGE can play back previously archived data streams. Playback can be controlled interactively. Some of the interactive control capabilities of the playback system are speed, reverse, and jump to a frame or mark.

User Interface

The Macintosh system software gives the MIRAGE a menu-and-icon-driven graphical user interface. The user can control many aspects of a MIRAGE session by selecting menu items, clicking the mouse button on icons or windows, and typing text into window text items.

Event Logging and Status Displays

Significant events that occur during a MIRAGE session are displayed in an event window and written to a MIRAGE session log file on disk. Status windows display the status of acquisition, archival, playback, and analog output in real-time.

Adding New Experiment Data Stream Support

The MIRAGE system can be customized to support most experiment data stream formats and displays. To add support for a data stream, the experiment databases and data display windows are created. The databases are created as Excel text spreadsheets. A copy of an existing experiment database can be used as a template. Display windows are created using ResEdit, a graphical resource creating and editing program provided by Apple. A small library of experiment-specific functions written in C is created, compiled, and linked with the MIRAGE software. These functions can often be copied from existing experiment function libraries and modifed for the new experiment. Since the MIRAGE system supports a wide range of generic data display and analysis functions, custom functions are necessary only for unique data display and analysis requirements.

APPLICATIONS

The MIRAGE system is designed to support the acquisition, archival, and processing of Spacelab life sciences experiment data streams in HRM format. The considerations that went into the design of the MIRAGE system make it adaptable to a wide range of applications and data formats. For instance, the NB-DIO-32F can be used to acquire almost any 8, 16, or 32 bit parallel digital data stream. Frame synchronization can be ignored during acquisition to eliminate the sync word requirements. The MIRAGE system can be customized to acquire network data packets in a variety of formats.

Another useful feature of the MIRAGE system is its ability to transform data received from any source and retransmit the data in either packetized digital form over the network interface or as up to six analog output signals. This ability of the MIRAGE system to act as a standalone data acquisition and analysis system or to work in conjunction with a variety of other systems give it a wide range of applications. Some of the possible applications are listed below.

- Experiment support
- Analog data acquisition workstation

- Data analysis and transformation
- Network playback
- Analog output system
- Archival system

CONCLUSION

The MIRAGE system has met or exceeded all of its original design requirements. The system has been used in the NASA Space and Life Sciences directorate in a number of experiment ground support roles and has performed beyond expectations.

In March of 1991, NASA presented the MIRAGE development team with its Public Service Group Achievement Award "in recognition of their outstanding contribution to the design, integration, test, and fabrication of the technologically advanced portable MIRAGE system."

The MIRAGE system concept continues to grow. Future enhancements of the MIRAGE system may include GPIB and RS232 data acquisition, expanded data analysis capabilities, and support of other network protocols (TCP/IP, FDDI). DOS, UNIX, and VAX workstation versions of the MIRAGE system are also possibilities.

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