DISTRIBUTED, REAL-TIME, HIGH-RESOLUTION COLOR GRAPHICS DISPLAY SYSTEM FOR TELEMETRY

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ABSTRACT

Dramatic increases in telemetry data rates and sources require test engineers to view and digest real-time data in order to make cogent decisions about whether to continue or modify flight tests. Traditional telemetry systems offer limited insight through a myriad of strip charts and alphanumeric displays. Attempts to improve this human interface employed expensive central superminicomputers and display systems. Although these methods have been successful, development and procurement costs and delays have limited their deployment. Recent advances in low-cost standard display, processing, and network technology have led to the development of the System 500.

The System 500 employs a distributed architecture. Independent, relatively low cost, high-resolution color graphics workstations connect to the data acquisition and processing subsystems via Ethernet.* Each station is independent, requesting and then receiving only data for display. The combined ability to physically display and update only a few hundred parameters, each at relatively few samples per second makes Ethernet and standard upper layer protocols ideal for this application.

The state-of-the-art human interface lets users select or mix a variety of methods to create and modify display contents, including: choosing from a list using arrow keys or a mouse, moving a scroll bar to pan through parameter files, or entering commands via keyboard where response anticipation reduces keystrokes to those uniquely defining a choice. A repertoire of graphic window displays is available to present real-time and static data concisely in analog and alphanumeric formats. Window size, location, and color have been chosen to focus attention rather than beautify. Standard windows and accent colors direct user attention to specific areas without cluttering and distracting.
INTRODUCTION

During a survey of telemetry centers across the nation, a need became apparent for affordable mechanisms to improve the presentation of raw and processed telemetry data. Existing systems frequently included paper strip charts driven by telemetry front ends or host computers, which were also consumed with driving alphanumeric monochrome or character-oriented color displays. The host’s resources were often limited by data processing and data management activities or were shared by peer organizations. The host’s central processor periodically transmitted data to each terminal from the contents of a current value table (cvt) that was in turn updated from the system’s front end. Additionally, the host processed selected raw parameters and placed results in an expanded cvt. This centrist architecture limits the number of parameters observed and terminals supported, restricts real-time parameter analysis, and reduces flexibility in modifying system setup. The almost simultaneous advent of relatively inexpensive Local Area Networks (LAN), color graphics workstations, human interface techniques, standard graphics development tools, and very high performance microprocessors made possible the next generation of display system technology that is incorporated in the System 500.

SYSTEM ARCHITECTURE

The System 500 is a distributed architecture, real-time telemetry data acquisition, processing, and graphics display system. Data transfer from point of capture, to decommutation, to real-time processing by traditional or user-created algorithms, and finally to the display subsystem or to storage on very high performance media occurs via a single high-speed logical bus specifically created for the uniqueness of telemetry applications (Figure 1). This is the MUXbus, a parallel data flow bus, that transmits each parameter as a single token consisting of a 16- or 32-bit data word and a 16-bit tag uniquely defining its source. The overwhelming majority of acquisition devices produce single word values, thus a perfect match of bus structure to data. In those applications requiring multiple data words, multiple tokens are employed. Receiving devices on the MUXbus simply acquire multiple unique tagged tokens to construct the complete measurement.

The MUXbus is also a broadcast bus; any device on the bus can be set to acquire specific tokens. Multiple devices acquire data simultaneously (Figure 1). This can be compared to traditional computer buses moving data through memory from or to a single device (Figure 2). Separate transfers are required to move the same data to multiple locations. The System 500 philosophy is to include the entire device as one or more cards in its chassis. Bit syncs, decoms, quantizers, analog and digital ports, MIL-STD-1553 bus interfaces, or interfaces to the display subsystem’s network and many other devices are on the MUXbus.
and housed in the same chassis. Only large mass storage and display devices are relegated to the outside.

Data manipulation and reduction are accomplished in one or more Field Programmable Processors (FPPs), each incorporating a high-performance RISC architecture numerics microprocessor with a matching floating point processor. Each set produces a peak throughput of 8 times the performance of a VAX+ 780 FPA (as per the Whetstone benchmark) or over 25 times the LINPACK benchmark. Applications assigned to the FPPs include data compression, decommutation of asynchronous embedded or packetized (e.g., Daniel 90) data, wild data point removal, traditional signal processing (i.e., FFT and filtering) and maintenance of the system’s current value table.

Three programming alternatives are available to develop application suites: (1) selecting one or more standard algorithms from a large repertoire; (2) defining algorithms through algebraic notation, including use of transcendental functions and parameter names; and (3) using high-level languages such as C and Fortran plus assembler for the utmost single processor throughput. Multiple processors may be employed as throughput increases. Source independence makes the application of parallel processing an elementary task, since the path of algorithm computing is independent. Pipeline processing is another parallel processing technique for increasing computing power. Here multiple processors are logically connected in a pipeline (i.e., intermediate results are produced as tokens, with new tags, for acquisition by the next processor). As intermediate results are output for the next processor, the first processor can begin work on new data.

One of the Field Programmable Processors is dedicated to maintaining the current value table in addition to processing algorithms. An FPP can also be dedicated to large display networks. Thus the reliance on a host computer is diminished by distributing the acquisition, processing, and display functions.

Individual color graphics workstations are dedicated to presenting independent information to the engineers and analysts monitoring the test. Each workstation is equipped with a 19" color display, mouse, disk storage, and Ethernet interface. The workstations and System 500 chassis are tied together via a standard Local Area Network - Ethernet. Although only 30% of the 10 Mbit/sec speed of Ethernet LAN’s theoretical throughput is typically attained, it is more than adequate, for only compressed display data is presented to each terminal. Each chassis subsystem includes an Ethernet Processor to capture data requested by the workstations for display and to receive module setup instructions. The network also provides access to share expensive or relatively unused resources such as printers.
HUMAN INTERFACE

The robust color graphics workstations now available make an ideal platform for the human interface. Extensive employment of a mouse as a pointing device, multiple windows, and pull-down menus make setting up the entire system and viewing data virtually intuitive. Operators of each station can view data and function independently as befits their function. A general display format optimizes information recognition for operators circulating among the data center’s terminals. The top 20% of the screen contains annunciator panels presenting current values for key parameters and/or subsystems status. Background color determines the relative state of each parameter and stream. For example, blue, amber, and red indicate parameters are within limits, caution (approaching limits), and out of limits, respectively. Blue, amber, orange, and red backgrounds are indications of decommutator status: in lock, verify, check, and search, respectively. Parameters and streams displayed can be predefined and stored as part of system setup or individually changed at any time. Clicking the mouse (moving the mouse so its screen cursor covers the desired area and pressing its button) over a panel brings down a menu listing of the parameter base. (Of course only a small portion of the data base is displayed, one can scroll through the entire base or move quickly to an area of interest.) A click selecting the new parameter and a second click confirmation replaces the contents of the panel. Figure 3 portrays status of parameters and data streams. The upper right-hand corner contains the terminal user’s name, test being performed, and time (e.g., wall clock, time of test, elapsed time, or unique variable recorded in the data stream). The size and distribution of this area are easily changed to reflect the system’s configuration.

Immediately below the status panel is the command line used to set up the display and view the overall status of data alarms and system errors. Clicking on the command window (the left side of the command line) creates a menu of possible commands; clicking on the choice of interest executes the command or brings the next level or portion of the command into view. These “clicks” continue until the entire command is created and executed. Alternately the keyboard can be employed to create the same command. The use of type-ahead logic limits keystrokes to only those required to define the command uniquely. Inappropriate keystrokes are immediately met with an audible negative feedback.

The remaining two thirds of the command line are divided between data alarm and system alarm status. Each of these two areas show whether they are armed (i.e., will the system report or ignore the existence of an error or alarm) and how many alarms or errors have occurred since the file was purged. A separate display window lists parameters exhibiting alarm conditions (created since the previous reset) can be called up at any time. The user can view alarms by scrolling and sorting contents. A history of each parameter indicates condition, number of occurrences, and first and last occurrences.
The remaining screen contains up to four visible windows for displaying data, defining or setting up the system, developing algorithms, or analyzing data using workstation resources. Other windows may be hidden (or stacked) ever ready to be brought on top for display. Visible windows can be moved about via dedicated keys as desired. Thus a predefined window presentation may be brought quickly into view. The window types developed include:

**Strip Charts**

Four electronic versions of the ubiquitous paper output medium. These may be used to depict slowly sampled data (less than 200 samples/second). One version displays up to four signals, each contained in a separate horizontal band; smaller bands within this larger one define unique tolerance limits. A double window width version of the same display allows viewing of twice the data without changing scale. A third version fills the entire viewing area with up to 10 signals. Like the paper strip charts, all monitored parameters move at a uniform speed, which can be changed at any time. Similarly, each window is equivalent to another recorder that can be independently set to reflect the characteristics of the parameters. Figure 4 is an exploded view of the time plot or multichannel strip chart (where each “pen” can ramble across the entire field much like a chart produced by a flat bed plotter). The color is different for each parameter being plotted.

This presentation typifies the philosophy of the System 500 graphics windows. At the top, a subcommand line enables the user to define the contents of a display window previously opened via the command line. The central portion contains the analog data. The width of the line or selectable color specifies the parameter displayed. The x axis defines absolute time values scrolling across the screen in synchrony with data or in a relative format as shown in the figure. Clicking the small panel at the right of the axis controls the time scale. Graphic displays can be frozen, scrolled to-and-fro, or cross-hairs can be brought into play to obtain differential or absolute measurements, or time can be displayed. Color is user selectable and envisioned to highlight abnormalities, analogous to the annunciator panels.

**Gather n**

For data greater than 200 samples per second. Here a defined number of samples are collected and then displayed. Due to the speed of the signal, only a periodic sample of data is viewable. Reviewing all data would require extended time, perhaps after the test. Alternatively, certain predefined conditions could initiate saving data to a file for review. The Power Spectral Density (PSD) algorithm employs a version of this display. Hear the sample axis is replaced with the frequency spectrum. The small panel at the right end of the abscissa controls the number of samples collected.
Cross Plot

Two parameters are compared, each occupying a single axis. This display also incorporates the ability to freeze the presentation and move two cursors to determine exact values and differences on both axes.

Alphanumeric Displays

Scrolling (viewing current and previous values) or displaying (current value only) parameters alphanumerically, plus a variety of system setup and administrative function.

Bar Chart

Appears as eight vertical gauges, each showing the current value as the proverbial bouncing ball. The color of the bar denotes limits. The range and units of each chart are also listed.

Annunciator Panels

This is at quadrant size equivalent to the status panel. It allows viewing of the maximum number of parameters simultaneously. The background colors instantly inform users whether the data is within predefined limits.

Parameter Display

Continuously presents the current values of selected parameters in a tabular format. The values are presented in both engineering units and binary form.

Alarm Display

Presents a list of all parameters that have exceeded preset boundaries since the previous clearing (zeroing out) of alarms. Information displayed for each affected parameter includes initial and current out-of-limit values and occurrence, and the number of occurrences of the alarm.

Define Parameter Display

An example of processed parameter definition appears as Figure 5. These linked displays define those prime parameters required to create the resultant parameter and which modules will acquire the resultant data. This is the mechanism for defining and linking the processing algorithms, including those called from a library or created in algebraic
notation, specifying upper and lower values for each limit level and the colors associated with their presentation on displays.

**List Parameter Display**

Allows the rapid perusal of the thousands of parameters that may be defined for a test. It provides the ability to sort parameters by name, number, source, and type. A scroll bar offers fast review of the entire data base.

**Configuration Display**

As part of the power-on system diagnostics, a file is created to verify proper configuration and operability of the System 500. The display presents this information in a tabular format.

**Administrative Displays**

Administrative displays include system setup, defining user security levels, audit trails to enable posttest critiquing of information and operations utilized during a test, setting the system clock, and access to the operating system.

In addition to the window manipulation via the mouse and keyboard, user-programmable keys recall macros to reproduce keystroke sequences.

Security is a vital issue in the daily operation of the system, whether to prevent accidental destruction or modification of a data base or to limit the ability to scrutinize data. Five privilege levels attached to each user’s logon control access. The lowest limits operation to the use of function keys while the highest is relegated to a “super user” with access to all nonencrypted files.

**IMPLEMENTATION**

Implementation and future enhancement of the System 500 was expedited through the use of standards and off-the-shelf components. The numerics microprocessors manufacturer supplied and supported standard compilers and development tools. UNIX, perhaps the most transportable operating system, is employed on the workstations. The graphics software tool X Window System tremendously accelerated the display and the “human interface” applications development and virtually eliminates the task of transporting the system to other types of workstations employing the same tools. Ethernet, as a display and system control local area network, permits attachment of external computers to the system. Finally the VMEbus, serving as the administrative and display data bus in the hub chassis,
offers the opportunity to incorporate relatively slow, standard off-the-shelf controllers for such tasks as magnetic tape storage and mass storage.

CONCLUSION

The System 500 enhances the state of the art in user interfaces. It is an ideal platform to meet testing requirements today and can readily be expanded to meet planned, or even unexpected, growth tomorrow.

* Ethernet is a registered trademark of the Xerox Corporation.
+ VAX is a registered trademark of Digital Equipment Corporation.

Figure 1. System 500 Data Flow Bus Architecture with Separate Control and Display Bus

<table>
<thead>
<tr>
<th>Module</th>
<th>Function</th>
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<tbody>
<tr>
<td>PCM</td>
<td>Data Compression</td>
</tr>
<tr>
<td>PAM</td>
<td>Engineering Unit</td>
</tr>
<tr>
<td>Digital</td>
<td>Conversion</td>
</tr>
<tr>
<td>DMA</td>
<td>Limit Checking</td>
</tr>
<tr>
<td>MIL-STD-1553</td>
<td>Derived Parameters</td>
</tr>
<tr>
<td>ARINC 429</td>
<td>Simulation</td>
</tr>
<tr>
<td>Analog</td>
<td>FFT</td>
</tr>
<tr>
<td>Time</td>
<td>Filters</td>
</tr>
</tbody>
</table>

Disk       Analog Ports
Tape       Digital Ports
DMA        MIL-STD-1553
ARINC 429  PCM
Figure 2. Traditional Flight Test System Architecture

Figure 3. Color Graphics Workstation Display
Figure 4. 4 Pen Strip Chart (Quarter Screen)

Figure 5. Processed Parameter Development