Multimission Telemetry Visualization (MTV) System
A Mission Applications Project from JPL's Multimedia Communications Laboratory

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I. ABSTRACT

This paper describes the Multimission Telemetry Visualization (MTV) data acquisition/distribution system. MTV was developed by JPL's Multimedia Communications Laboratory (MCL) and designed to process and display digital, real-time, science and engineering data from JPL's Mission Control Center. The MTV system can be accessed using UNIX workstations and PCs over common datacom and telecom networks from worldwide locations. It is designed to lower data distribution costs while increasing data analysis functionality by integrating low-cost, off-the-shelf desktop hardware and software. MTV is expected to significantly lower the cost of real-time data display, processing, distribution, and allow for greater spacecraft safety and mission data access.

II. INTRODUCTION

As the leading NASA center involved in unmanned space missions, JPL has a long and distinguished scientific record of achievement in collecting, analyzing, distributing, and archiving data and images from planetary exploration missions. To manage its multi-scientific and engineering operations connected with the exploration of the Solar System, JPL has developed extensive local area communication networks for linking its user community in clusters of cooperative workgroups. Utilizing this infrastructure of networked desktop workstations and PCs as display platforms, MTV was developed to provide an easy, plug-in access to real-time mission data using local and wide area networks. Registered MTV users now have convenient access to key telemetry data channels from a variety of platforms and graphical user interfaces (GUIs) from almost any location. MTV data distribution and display ergonomics have increased the electronic exchange of engineering and science data by allowing principal investigators, scientists, engineers, and managers worldwide access to real-time data, anywhere, any time and seamless transport of data into other analysis, spreadsheet, word processing, or other software tools.

Recent technology advances in multimedia communications hardware and software have provided MTV users with a wide range of concurrent processes beyond telemetry viewing. Now audio and video services can be requested during MTV sessions, thus providing mission operations personnel with new processes for distributing and displaying high resolution photographs, conducting point-to-point video conferencing, shareware, and digital television monitoring/capturing. This paper also briefly outlines the role of the MCL in developing low-cost multimedia communication tools for JPL and NASA scientists, engineers, and managers on a wide variety of projects.

The following MCL capabilities will be discussed:

(1) Prototyping and demonstrating network distribution of real-time mission data using networking, i.e. Institutional Local Area Networks, TCP/IP, FDDI, and telecom, i.e. standard 9600 baud telecom lines, Switched 56 and ISDN. This activity serves as a proof-of-concept function for the MTV project.

(2) Testing and evaluating promising technologies, applications and implementation strategies associated with distribution of bandwidth-intensive multimedia mission data types which are compressed and distributed over networks currently installed or planned at JPL, i.e. desktop video teleconferencing, groupware, image and video servers, multimedia electronic mail and remote telepresence over Ethernet, ATM and FDDI optical fiber interfaces.

(3) Analyzing and predicting the productivity impact of multimedia computing and communications on organizational effectiveness, and communications within and between scientific and engineering workgroups including multilingual communication for international spaceflight workgroups.

(4) Developing a five-year institutional strategy and implementation plan for integrating multimedia workstations with networked supercomputers, the National Information Infrastructure (NII), and High Definition Digital Television (HDTV) for space mission applications.

(5) Designing, developing, and implementing interactive, digital applications using interoperable workstations and PCs for supporting technical and management presentations, large group video teleconferencing, and on-line, interactive training for ground and mission operations.

(6) Development of multimedia productions for Internet Mosaic Home Pages including hypertex, full-motion video, and interactive CD-ROMs.

As the technologies of multimedia platforms, software, and subsystems enter mainstream computing and communications, the JPL MCL team evaluates promising commercial, off-the-shelf (COTS) technologies and products as they are released from developers. Those products which, after test and evaluation in the MCL, are found to contribute to cost-effective mission operations and add value to JPL's institutional processes, will be considered for service within our flight operations groups. MTV was the first such product. As with any technology involving the widespread distribution of images and audio over networks, there is potential to reshape the way spacecraft data is viewed and shared. Multimedia communications is opening many new avenues for cost-effective, innovative processes which support the national space program. Further, it is expected that MTV will find application as a dual-use system in the commercial sector. Real-time medical monitoring, industrial and environmental monitoring and process control are a few promising applications under consideration for technology transfer.

III. ANALOG VERSUS DIGITAL SYSTEM

For twenty years JPL has relied upon an analog TV telemetry distribution system for viewing up to 3500 possible telemetry channels. After telemetry data is received by the Deep Space Network (DSN) and decommutated at JPL, it is converted to an NTSC video signal and distributed to a large switch for delivery to video monitors scattered throughout JPL's primary flight operation facilities. The system allows only viewing of the desired channels which the user may select for his/her mission. The Digital Television System (DTV) as it is called is not a digital system in the true sense, but was given this designation presumably because it displayed digits! The system has served JPL's telemetry data analysis users well and still has many proponents. But with the advent of desktop computers, the DTV system became an antiquated liability with little flexibility in the era of cheaper, better, and faster.

After reviewing the costs vs. capability of the DTV, it became clear that use of desktop PCs and workstations connected to the JPL Institutional Local Area Network (ILAN) and Internet could perform the primary DTV functions with greater flexibility. Enhanced telemetry visualization, a rich set of data analysis tools, including automated alarming of data streams by use of set points, were compelling reasons for a new system. Further, users could access the system from remote sites-globally. This feature is attractive for missions involving domestic and international partners with remote command centers.

IV. MTV PROTOTYPE DESCRIPTION

The development of an MTV prototype was started by the Multimedia Communications Laboratory (MCL) in January 1993. After quickly abandoning the concept of continued broadband distribution of the DTV analog signals, except for video display on desktop platforms, it was decided by the designers to interface a Unix server with the Galileo spacecraft data stream, separate and condition the data channels, and distribute the data to remote PC clients and workstations using JPL's ILAN.

The initial prototype, which used a 486 PC running MS Windows™ 3.1 with a network interface, was demonstrated to several of JPL's mission teams. From this demonstration, experimental users were identified for testing MTV and the system was installed at several sites. These experimental sites were used to debug the system and to gain insight into user requirements. User's suggestions and comments were solicited and the design team made several enhancements to the MTV (GUI) as a result of this prototyping. The architecture of the MTV prototype is shown in Figure 1.0 below.

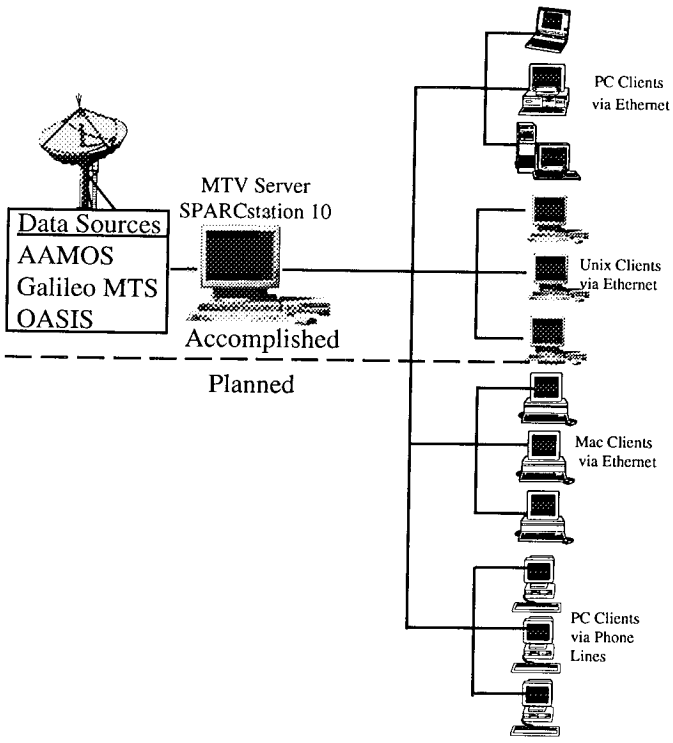

Figure 1.0 MTV Network Architecture

Samples of MTV display windows are shown in Figures 2.0 and 3.0 below.

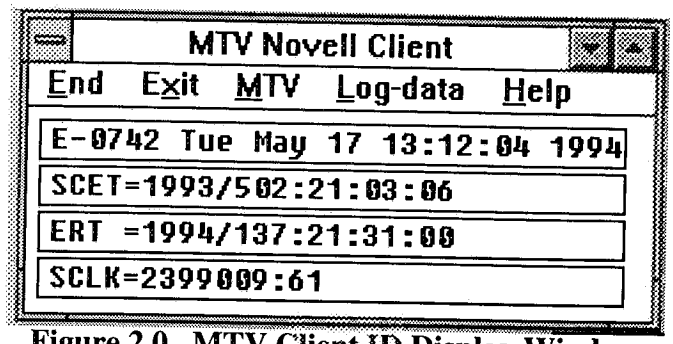

Figure 2.0 MTV Client ID Display Window

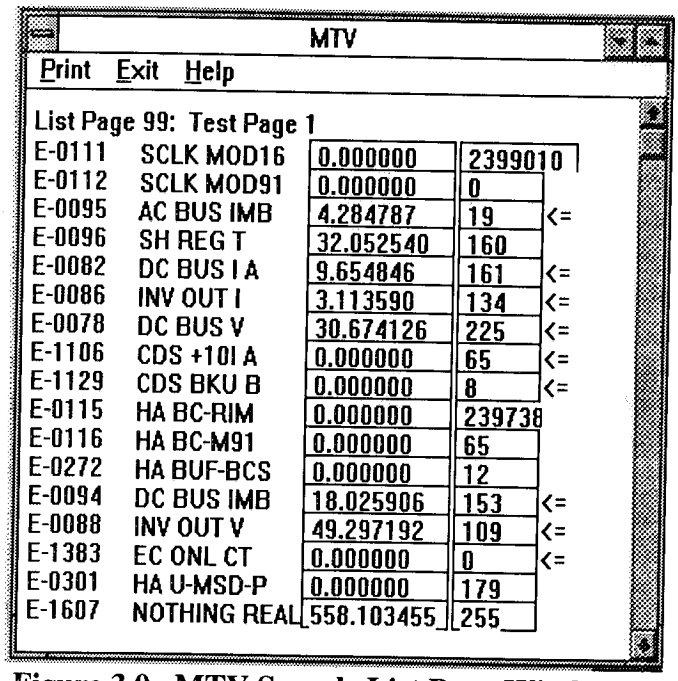

Figure 3.0 MTV Sample List Page Window

These windows can be scaled and sized by the user and seamlessly cut and pasted into other popular Windows™ applications like Excel™, or Word™. The MTV user can also configure the system to analyze the selected data streams for anomalous science or engineering data outside the range of setpoints. When such conditions are encountered, the MTV system sends a message and alarm to the user at their location of choice, i.e. home, office, or on travel. This feature reduces the time of notification over using the DTV-operator-in-the-loop method. The system interface was also designed to use color in discriminating conditional cues for data states.

Network Interface

MTV currently operates with Novell's LAN Workplace for DOS™ (future adaptations for Microsoft's LAN Manager™ and PC-NFS™ are planned) as the principal network transport interface.

After an initial connection has been made with the Unix server, data is transported across Ethernet (and soon, telecom lines) on a point-to-point basis. If the requesting PC has the proper security registration, it will begin to receive the requested data as a background process that will be ongoing on the PC. On 33 Mhz or faster PCs, the degradation of CPU power by this process is virtually imperceptible. When a user wishes to view a particular page of spacecraft data (a page being a select group of engineering channels-see Figure 3.0), all he or she is required to do is open the MTV window that shows the available pages, mouse-click the desired icon button, and immediately the list page with the latest available data is displayed.

Data Synchronization

One of the significant features in the design of MTV is the functional requirement that *all* users of MTV have access to and view exactly the same data. This aspect was inherent in the earlier analog DTV system. Users who tuned into channel 23 viewed consistent channel 23 data. But with the advent of client-server, distributed computing architectures and custom GUIs, synchronized data views are no longer guaranteed.

With spacecraft alarms capable of being changed at will and independently on all platforms, no one user has the same data viewpoint. This becomes very apparent with data plots. For instance, at time t_1, a mission controller, monitoring a temperature value, notices the value oscillating in and out of an alarm setpoint over a period of time. When the controller notifies a spacecraft engineer of the condition and requests that they investigate it, the engineer displays his plot at time t_2 and views the data which appears nominal. With MTV, all users would be seeing the same data/plots, independent of when or where they started the request.

Remote Monitoring and Alarming

Recent tests with portable PCs and Personal Digital Assistants (PDA) with Beeper Notification Systems have demonstrated that MTV can be transmitted over telecom lines via modems.This feature will allow a mission controller almost anywhere in the world to be promptly alerted to data anomalies in science experiments, or failure of a spacecraft component. The MTV server will automatically contact the mission manager's MTV laptop, notebook, or PDA for alarming and immediate access to the required data channel, thus providing continuous 24-hr., 7-days-a-week monitoring of critical data setpoints.

V. FUTURE PLANS FOR MTV

As MTV evolves from the prototype, proof-of-concept stage into a fully-supported system product, several enhancements are planned. The Prototyping Phase has been very useful in developing a solid set of user requirements and continuous product improvement strategy. Currently, there are twenty registered prototype users. Requests for connectivity are increasing daily. The potential exists for over 600 users at JPL, and probably 300 more at remote locations. To further aid in the widespread distribution of information about MTV, a JPL Mosaic Home Page is planned for Internet. Diffusion to other platforms include Macintosh™ versions in Fall '94. When this task is completed, all major desktop platform types at JPL can be supported by MTV.

Specific enhancements and modifications planned for FY '95 include the following:

- Help System support with spacecraft telemetry data dictionary.
- Automatic software configuration control and download of current versions and data.

- DSN tracking, sequence of events, and readiness status reports on demand.
- Whiteboard shareware, video teleconferencing, and E-mail between cooperating MTV users.
- System-defined global alarms.
- Communications port for MS LAN Manager™ for NASA Headquarters.
- Communications port for PC-NFS networking protocols.
- Customize GUI for each supported mission.
- Expand system to include status monitoring of other critical JPL infrastructure-related systems, such as the IBM™ mainframes, Cray™ supercomputers, and TV display of the NASA Select and CNN broadcast channels.

These improvements will provide MTV with the capabilities to support an expanding user population and provide data and information when and where they need it at the lowest possible cost. Figure 4.0 shows the MTV prototype suite as it is installed in the Mission Control Center of JPL.

Dual-Use Commercial Applications

The MTV system has commercial applications in manufacturing process control, medical monitoring, and other critical real-time systems requiring automatic feedback loops and adaptive control. Potential commercial projects may be found in the medical, chemical, energy, and process industries.

Physicians, plant managers, researchers, and other decision makers could be instantly notified of critical conditions and monitor key industrial process parameters on their MTV systems. The MTV team is currently in technology transfer discussions with several outside sponsors. Most process control systems are site-localized. MTV ,in contrast, is based on the concept of remote monitoring and control.

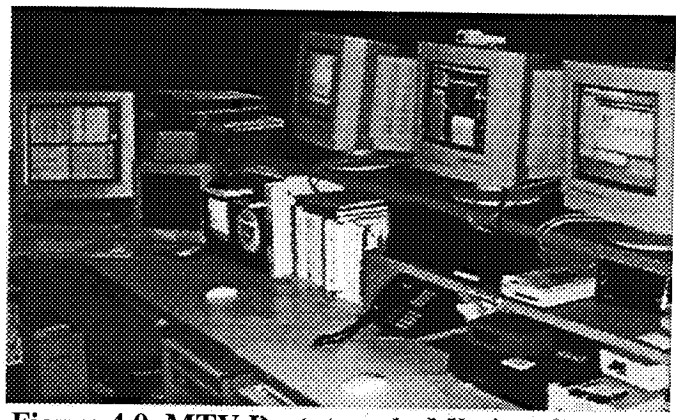

Figure 4.0 MTV Prototype in Mission Control

MTV Development Strategy

As MTV becomes a fully-supported, mature system at JPL and moves from development to an operational status, the strategy for its continued improvement and success will be contingent upon the following five ongoing activities:

1. Listening and understanding the user's needs.
2. Sponsoring Lab-wide technical demonstrations and communications for potential users.
3. Developing efficient processes-small technical teams, minimum bureaucracy, recognize and foster innovation and new technologies which promote generic multimission designs.
4. Promoting the effective use of outside technology, i.e. integrate COTS technologies and external scientific and engineering innovations.
5. Gaining sponsorship from senior managers and key mission operations teams.

As new missions are planned and costs become key factors in funding decisions, mission planners will be searching for new ways to deliver scientific objectives for less. MTV was designed to provide JPL with a low-cost, flexible alternative by focusing on the ubiquitous PC with its declining cost and increasing power. MTV is proving to be a cost-effective solution to s/c data distribution.

VI. MULTIMEDIA COMMUNICATIONS LABORATORY (MCL) DESCRIPTION

This section describes the technical core competencies and product incubating features of JPL's MCL. The MCL is becoming a focal point in transitioning emerging institutional requirements into high-quality multimedia products such as MTV at the lowest possible cost to users. To realize this goal, the MCL has developed an advanced prototyping center to facilitate the test, evaluation, and insertion of off-the-shelf, interactive, multimedia technology into multimission applications for use by JPL science and engineering teams.

The MCL includes a platform triad of (1) Apple Macintosh Quadra™ 950, (2) Sun Microsystems SPARCstation™ 2, and (3) IBM 486 Ultimedia™ PC. Each of these platforms is equipped with state-of-the-art multimedia subsystems and software libraries for managing full-motion video playback, capture, and editing; graphics; animation and 3-D rendering; and interactive authoring applications.

These systems are connected to Ethernet, ISDN, and FDDI networks to aid in the investigation of local and global multimedia compression and transmission requirements. Each system is also linked to a central, multichannel, high-resolution, large screen RGB projector for technical evaluation demos and briefings involving MCL developments. Figure 5.0 shows an overview of the MCL architecture.

In addition to serving multimission requirements at JPL, other institutional applications include TCP/IP multimedia electronic mail, scientific visualization, technical and executive-level presentation, interactive CD-ROM/videodisk training and educational authoring, photographic image and video storage and retrieval, video teleconferencing/groupware, and management of engineering data libraries. The JPL MCL was also designed to investigate bandwidth requirements, packet video transmission, compression effects on visual quality, user ergonomics, storage requirements, productivity, and feasibility of network distribution of video, images, and HDTV broadcasts to NASA science centers worldwide.

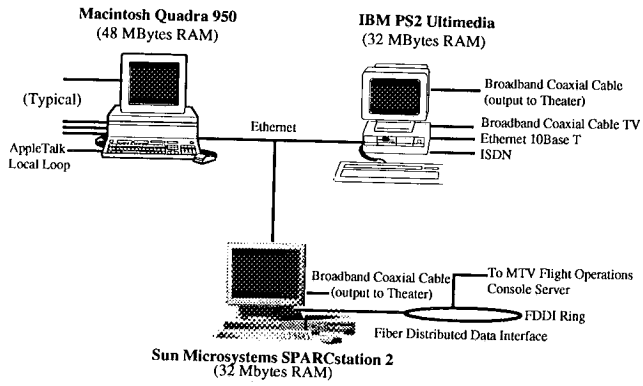

Figure 5.0 MCL Desktop Architecture

VII. MCL PLATFORM DESCRIPTIONS

Macintosh Quadra 950-This system is a high-end PC workstation which has a variety of multimedia devices integrated for playback, capturing, editing, and producing full-motion video from any National Television Standards Committee (NTSC) Source. This system has the primary task of multimedia content production and visual data base management. Once the content material is developed, it is converted to target file formats and transmitted to other multimedia workstations. It is capable of producing video tapes, 35mm slides, CD-ROMs, high-resolution photographs, and technical presentations in a Science Conference Center. The system has 48 Mbytes of RAM and 6.5 Gbytes of magnetic and optical disk storage. It is equipped with a Radius VideoVision/Studio™ high performance A-D converter and compression/decompression subsystem. The system has a professional flatbed scanner and film recorder capable of 4000 lines resolution output. Audio is sampled at16-bits and the system has a built-in speaker and microphone. Video teleconferencing is accomplished through a special interface card which is connected to an ISDN switch. Ethernet and AppleTalk™ are used for local communication, and connection to the FDDI ring is planned.

Desktop display is accomplished by dual-16 and 13-inch Apple monitors. Full-screen, full-motion 640x480 digital video is displayed on the smaller monitor while desktop applications are displayed on the larger unit.

Sun Microsystem SPARCstation 2- This RISC-based workstation is used for video teleconferencing and groupware test and evaluation. The system has a X-Video™ A-D video converter (S-bus subsystem) which allows the simultaneous display of two video sources using the Joint Photographic Experts Group (JPEG) compressor. The system is equipped with a dedicated CD-ROM drive and video camera for video teleconferencing. Broadcast TV and other NTSC sources can also be displayed, captured, and stored. A built-in microphone, speaker, and headset jack allows audio input and output. The system runs BSD Unix version 4.1.2 with Open Windows™ 3.0 GUI. A high resolution 21" monitor allows very detailed pixel manipulation of graphical imagery in 16 million colors. The system has 32 Mbyte of RAM and 1.5 Gbyte of magnetic storage. The system has a frame buffer which allows 3-D modelling and rendering at 310 vectors/sec. The communications interface includes an FDDI dual attach connection which is on a subnet fiber ring.

IBM Ultimedia M77 486 DX2-This system is the most powerful desktop multimedia system in IBM's product line. The system comes equipped with a 66/33 Mhz cached microprocessor and includes a math coprocessor. Its features include 32-bit bus architecture, XGA non-interlaced graphics adapter, and 32 Mbyte of RAM. The system has a built-in CD-ROM Drive, and a 212 Mbyte capacity hard drive. Multimedia content is displayed at 640x480 pixels with a pallet of 65K colors, or 1024x768 at 256 colors. Audio is processed through the M-Audio Capture and Playback Adapter with analog conversion to and from a digital PCM data format at 8- and16- bit stereo with sampling rates up to 44KHz. Digital audio processing is 16-bit ADPCM compression, CD-extended architecture audio decompression, mix line in with PCM audio. The system is equipped with an Action Media II™ display adapter which uses Intel's proprietary i750 Digital Video Interactive (DVI/Indio)™ chip. This subsystem allows 72 minutes of full-motion, compressed video to be recorded and played back on a standard CD-ROM, in addition to a variety of other input devices.This platform is connected to JPL's ILAN and shares many of the Quadra's video and desktop multimedia systems.

VIII. MCL PROJECT PORTFOLIO

The MCL has been under development since1992 and recently achieved operational status. It now supports several JPL projects including MTV. Other projects are described below:

Science Conference Center- The MCL controls a complete digital theater projection environment from any of its platforms. Support includes real-time visualization episodes, executive and technical presentations and technology demonstrations, or group video teleconferencing.

DSN Archiving Project-As the construction of the next generation of advanced tracking antennas progresses, video footage is collected for each stage of construction. This video as been stored on laser disk. MCL software for rapidly retrieving analog video clips by DSN personnel was provided. Currently a series of digital, interactive CD-ROMs is under development for rapidly navigating and displaying digital source material, i.e. video clips, narration, still photographs, CAD drawings, etc.

Video Conference Center Design, T&E-To effect better communications among suppliers and subcontractors and to lower travel costs, a low-cost video teleconferencing center is being designed for a major JPL instrument project. The MCL is designing and integrating the subsystems for this project. International and domestic connectivity is being provided through ISDN switched technology.

Robotic Vehicle Communications, T&E- The MCL recently tested the remote control of a lunar rover using an Asynchronous Transfer Mode (ATM) switch and FDDI ring for transmission of JPEG compressed video telepresense signals.