AUTOMATING PLANETARY MISSION OPERATIONS

Dr. Eric M. De Jong

Space Science Data Systems Section
Jet Propulsion Laboratory/Caltech
Pasadena, CA 91109
Mail Stop 168-414
Eric.M.DeJong@jpl.nasa.gov

Barbara A. McGuffie

Space Science Data Systems Section
Jet Propulsion Laboratory/Caltech
Pasadena, CA 91109
Mail Stop 168-414
Barbara.A.McGuffie@jpl.nasa.g0v

Steven R. Levoe

Space Science Data Systems Section
Jet Propulsion Laboratory/Caltech
Mail Stop 168-414
Pasadena, CA 91109
Steven.R.Levoe@jpl.nasa.gov

Paul M. Andres

Space Science Data Systems Section
Jet Propulsion Laboratory/Caltech
Mail Stop 168-414
Pasadena, CA 91109
Paul.M.Andres@jpl.nasa.gov

J. Michael McAuley

Space Science Data Systems Section
Jet Propulsion Laboratory/Caltech
Mail Stop 168-414
Pasadena, CA 91109
Myche.McAuley@jpl.nasa.gov

ABSTRACT

Planetary mission are characterized by the need to receive, process, archive, and transmit remotely sensed data to geographically extended science and engineering teams. Operations for a single mission may last only a few days or may extend for several decades. In recent years, developments in sensor technology have provided instruments with increased resolution, wavelength sensitivity, and decreased sampling intervals. Spacecraft operations are constrained by the limitations of on-board: power, processors, storage, and communications bandwidth.

Planetary missions must operate in a hostile environment with radiation hardened technology. Transmission distances vary from less than one million to over ten billion kilometers. It is expected that power constraints for future missions will be mitigated by the increased size of solar arrays and Radioisotope Thermoelectric Generators (rtg's). The next generation of Earth orbiting satellites will provide Planetary Missions with faster radiation hardened processors, and storage devices. These new technologies will have no effect on bandwidth issues. Bandwidth is controlled by three factors: transmitter power, wavelength, and communication distance. Signal strength falls off as 1/r**2. JPL operates the Deep Space Network (DSN), a global set of large antennas to provide continuous monitoring of the signals from space.

The data collected from all planetary missions is sent from the DSN to Central Telecom Services (CTS) and then to JPL's Image Processing Laboratory (IPL). It is the responsibility of IPL to receive, label, process, store, transmit, and archive spacecraft instrument files for Planetary Missions. Science and Engineering Team members are located in industry, academic, and government centers all over the world. Current solar powered spacecraft designs often provide only a few hours of power reserves, and limited autonomy. Constant updates of instrument health, pointing, and data quality are required to maximize science return, and assure the success of these missions.

In this paper, we describe the elements of a semi-autonomous system designed to provide instrument health, pointing, and data in a cost effective fashion. The design uses automation, parallel processing, and data subscription services. The elements of the system include: 1. Telemetry Data System (TDS), 2. Raw Science Data Server (RSDS), 3. Visualization and Analysis Test-bed (VAT), 4. File

Exchange Interface (FEI), and 5. Planetary Data System (PDS).

1. NASA PLANETARY MISSION COMMUNICATION REQUIREMENTS

National Aeronautic and Space Administration (NASA) planetary missions can be divided into three categories based on mission operations: 1. Flyby; 2. Orbiter; 3. Surface. In this taxonomy; rovers, landers, penetrators, submarines, balloons, and airplanes are included in the surface operations category. A sample return activity may be included with any of these three categories. While there are large differences in each of these categories, and even in individual missions in the same category; they all share several common needs. These include the need to receive, process, and archive remotely sensed spacecraft and instrument data. They also share the requirement to transmit this data from:

1. Spacecraft to a conveniently located Earth receiving station.
2. Earth receiving stations to mission operations and control centers (MOCC).
3. MOCC to science and engineering teams.

These three "down link" requirements drive the design of NASA's deep space communications system. Two "uplink" drivers for this system are the requirement to transmit commands and software updates from:

4. MOCC to Earth transmission stations.
5. Earth transmission stations to Spacecraft.

A single mission may include dozens of instruments, and engineering sensors; that must share the communications path. The same Earth transmission and receiving stations must support dozens of missions, operating at the same time. Operations for a single mission may last only a few days or may extend for several decades.

2. DEEP SPACE MISSION SYSTEM (DSMS)

The Jet Propulsion Laboratory (JPL) has the responsibility to develop, operate and maintain a communications and ground data system that meets NASA's deep space mission down link and up link requirements. JPL's Deep Space Mission System (DSMS) was developed to fufill this responsibility. The DSMS is divided into two primary components:

1. Deep Space Network (DSN).
2. Advanced Mission Operations System (AMOS).

Deep Space Network (DSN) provides telemetry information from the spacecraft to the Telemetry Distribution System (TDS). The Deep Space Network (DSN), includes a global set of large antennas to provide continuous monitoring of the signals from space. Telemetry Distribution System (TDS) provides telemetry data to the end science user. Advanced Multi-Mission Operations System (AMMOS) provides tools used by customers to operate their missions and to develop their mission operations systems.

3. PLANETARY MISSION BANDWIDTH LIMITATIONS

Planetary missions must operate in a hostile environment with radiation hardened technology. Developments in sensor technology will provide planetary mission instruments with increased resolution, wavelength sensitivity, and decreased sampling intervals. Spacecraft operations are constrained by the limitations of on-board: power, processors, storage, and communications bandwidth. Bandwidth is controlled by three factors: transmitter power, wavelength, and communication distance, r. It is expected that power constraints for future missions will be mitigated by the increased size of solar arrays and Radioisotope Thermoelectric Generators (rtg's). The next generation of Earth orbiting satellites will provide Planetary Missions with radiation hardened on-board fast processors, storage devices, transmitters and receivers; and the components required to develop a laser communications system. Fast on-board processors and sophisticated compression algorithms will help; but distance remains the primary factor limiting deep space communication bandwidth.

Communications signal strength falls off as the square of the communications distance, 1/r**2. Communication distances for deep space missions are extremely large; and vary from less than one million to over ten billion kilometers. The distance from the Earth to the moon is approximately 384,000 kilometers. Several near earth objects (NEO) have approached within a few million kilometers of the Earth. On September 29th 2004 the 5 kilometer asteroid Toutatis is expected to be at a distance of less than 1.5 million kilometers from the Earth. This is the closest approach of a Potentially Hazardous Asteroid (PHA) in the next thirty years. The closest approach of a planet to the Earth, in the last 60,000 years, will occur on August 27th, 2003. On that day, the distance from the Earth to Mars will be approximately 67 million kilometers. By the end of this year Voyager I will be over 13 billion kilometers from Earth. You may find more information about Earth's close encounters at the following web sites:
http://neo.jpl.nasa.gov/index.html
http://mars.jpl.nasa.gov/
http://nssdc.gsfc.nasa.gov/space/helios/heli.html
http://www.space.com/spacewatch/where_is_mars.html
http://www.space.com/scienceastronomy/solarsystem/asteroid_toutatis_001101.html

4. ADVANCED MULTI-MISSION OPERATIONS SYSTEM (AMMOS)

Current solar powered spacecraft designs often provide only a few hours of power reserves, and limited autonomy. Constant updates of instrument health, pointing, and data quality are required to maximize science return and assure the success of these missions.

JPL is developing a semi-autonomous system to provide instrument health, pointing, and data in a cost effective fashion. The design uses automation, parallel processing, and data subscription services. The elements of this system include: 1. Telemetry Data System (TDS), 2. Raw Science Data Server (RSDS), 3. Visualization and Analysis Test-bed (VAT), 4. File Exchange Interface (FEI), and 5.Planetary Data System (PDS).

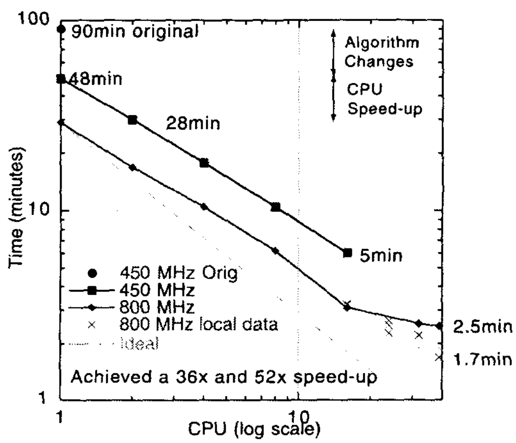
The data collected from all planetary missions is sent from the DSN to Central Telecom Services (CTS). CTS receives the data stream from the DSN and uses the Telemetry Data System (TDS) and CCSDS File Delivery Protocol (CFDP) processor to create science instrument, engineering data and transaction files. These files are temporarily stored on the Distributed Object Manager (DOM). The Image Processing Laboratory (IPL), {aka Multi-mission IPL (MIPL)} receives these files and other metadata, including NAIF navigation and pointing information. IPL uses the RSDS and Visualization Analysis Testbed (VAT) to store these files for the length of the mission. In collaboration with the Planetary Data System (PDS), IPL uses the metadata to create detached PDS label files. It is the responsibility of IPL to receive, label, store, transmit, and archive spacecraft instrument data files. IPL uses File Exchange Interface (FEI) to transfer these files to science and engineering teams. FEI transfers use ftp/TCPIP protocols. The subscriber specifies the machine, the directory, and type of data. The data is then automatically pushed or pulled to the science team as soon as it is available on the RSDS. Members of the science team later send final versions of the instrument data to the permanent PDS archive.

The Raw Science Data Server (RSDS) provides one stop shopping for science instrument and engineering data during all phases of the mission from ATLO to Archive in a standard format. Earlier versions of key RSDS technologies have been developed and approved by DSMS and used to support previous missions including Mars Pathfinder, RSDS automated delivery technology, web-based monitoring, inexpensive terabyte disk arrays, and Beowulf clusters are being developed to support the Mars Exploration Rover (MER),Mars Reconnaissance Orbiter (MRO) and Mars Science Laboratory (MSL). A prototype version of the RSDS technology was tested during the recent MER field tests.

5. AUTONOMOUS RSDS AND VAT ELEMENTS

1. Transcoders - Autonomous transformation of image formats:
A new package, entitled ImageIO, has recently been added to the Java. This package provides a framework for the creation of image "codecs" that enable Java programs to read and write image files. Included in this specification is a "transcoder" label metadata Application Programming Interface(API). The transcoder is used to preserve label information when converting from one image format to another. The ImageIO system breaks image IO into 3 parts, reading, transcoding, and writing. Collectively a reader, writer and transcoder are referred to as a Codec. A transcoder must understand the metadata of the input format and convert it to the proper format for the output format writer. In general, image metadata is ASCII text with a value, or set of values being associated with a keyword. This metadata is often grouped into subsets with a particular structure. Map projection information is a common example of metadata. If the map projection information metadata is correctly saved into a VICAR or PDS image file, then VICAR or PDS programs can use this data to perform autonomous map projection operations on the image.

2. Beowulf Clusters and Parallel Processing Algorithms:
We are developing autonomous and semi-autonomous parallel processing algorithms to provide rapid image registration, transformation, mosaic generation and visualization. The figures below illustrate some of our progress in these areas.

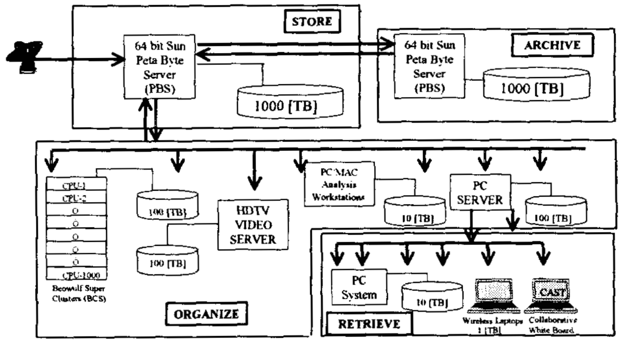


6. FUTURE AUTONOMOUS GROUND AND ONBOARD PROCESSING RESEARCH

The long term goal is to design, develop and deliver autonomous technology that provides: real time access to remote large high resolution images and image sequences; and eventually to develop the processing and display components required to establish a "virtual presence in space." In the future a strong system engineering approach will provide a design that enables missions to autonomously dynamically allocate the mix of on-board and ground resources necessary to meet operational requirements. Three areas of future research in this area include:

1. Store Organize Archive and real-time Retrieve (SOAR):
Scientists and analysts experience large delays in the search, retrieval , and display of remote data. High resolution images, image sequences, maps, and ancillary data are stored on central databases and data repositories. Data transfer rates have not experienced the dramatic increases seen in CPU speeds, random access memory, disk storage, and graphics cards. The compute power available in today's data servers is under utilized. Data transfer is the major bottleneck to rapid search, retrieval, and display of large data files. We need to create a real time client – server scalable vector graphics (SVG) system. In this system, the user identifies the region of interest (ROI) by selecting a latitude –longitude center or a set of search criteria. The server uses content-based image retrieval , wavelet compression, trans coder, and SVG technology to create custom hierarchical compressed data structures from existing data sets. The client uses SVG, VRML, JAVA and advanced graphic processor (AGP) technology. The server first transfers low resolution versions of the ROI, to make the best use of the available bandwidth. Higher resolution versions, are transferred next. The client caches the hierarchical compressed data structure for the ROI. The client performs real-time local transformations using this data structure. This provides the ability to rapidly create a wide variety of higher level analysis products. The figures below display the preliminary design for SOAR.

Store Organize Archive and real-time Retrieve (SOAR)



Store Organize Archive and real-time Retrieve (SOAR)

Visualization and Analysis Testbed VAT

FY	%	Nodes	HDTV [TB]	DISK [TB]
03	1	10	1	10
04	2	20	2	20
05	4	40	4	40
06	8	80	8	80
07	10	100	10	100
08	20	200	20	200
09	40	400	40	400
10	60	600	60	600
11	80	800	80	800
12	100	1000	100	1000

2. **Memory-Resident Cooperative Portable (MCP) Revisions to the VICAR Library:**
JPL's Video Image Communication Archive and Retrieval (VICAR) is NASA'S primary planetary science image processing environment. VICAR libraries preserve a legacy of code from forty years of successful NASA missions; while the VICAR environment continues to evolve to efficiently use the elements of modern distributed computer networks. However, some aspects of the VICAR design will need to be modified to fully utilize: 1. Beowulf Super Clusters (BSC); 2. Peta Byte Servers (PBS): 3. heterogeneous networks of inexpensive computers. We need to modify the VICAR Run time library (RTL) to enable VICAR programs and subroutines to be: 1. memory resident; 2. sharable; 3. dynamically linkable; 4. re-entrant.; and 5. thread safe. This modification will enable a single copy of a VICAR module to remain resident in memory and be called by many other programs. Memory resident changes will increase the processing speed of VICAR software by a factor of 10. Use of Beowulf Super Clusters will increase the speed of many applications by a factor of 100; assuming sufficient random access memory is provided with each node of the cluster. Local Peta Byte Servers will provide quick access to all planetary data. Additional information on the VICAR RTL can be found

at: http://rushmore.jpl.nasa.gov/RTL/RTL_Manual-3_2.html

3. Content-based Sequence, select, and Image search (CSI)

Develop general purpose content-based sequence generation, resource selection, prioritization, and feature search algorithms to maximize downlink capability of any future mission investigating dynamic features (clouds, dust devils, sand dunes, ice, CMEs etc.).

7. CONCLUSION

JPL has the responsibility to develop, operate and maintain a communications and ground data system that meets NASA's deep space mission down link and up link requirements.

JPL's Deep Space Mission System (DSMS) was developed to fufill this responsibility. In recent years, developments in sensor technology have provided instruments with increased resolution, wavelength sensitivity, and decreased sampling intervals; placing increased demand on the resources of the DSMS. Advances in space communication technology, including: wavelet compression, optical communications, and delay tolerant networks, will be used to meet this demand on the Deep Space Network (DSN) communications system. Advances in ground and onboard parallel processing, Beowulf clusters, memory resident code, wavelet compression, scalable vector graphics, transcoder and advanced visualization technology will be used to meet demand on the Advanced Mission Operations System (AMOS). While this paper has focused on the requirements for planetary robotic missions; the concepts presented here can be adapted to support the requirements of other Space and Earth observation systems

8. ACKNOWLEDGMENT

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9. REFERENCES

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are needed to see this picture.