The Mission Operations Center (MOC) at APL is the first processing link in the MSX data system. Two key components of the MOC that play a role in the telemetry acquisition and processing functions are the Mission Control Center (MCC) and the Mission Processing Center (MPC). This paper will present a summary of the telemetry acquisition and data processing structure built to handle the high volume of MSX data and the unique hardware and software systems to perform these functions.

The primary responsibility of the MCC is to maintain the health and safety of the MSX spacecraft. This is accomplished by communicating with the spacecraft through the APL stations and the AFSCN. The MCC receives the spacecraft housekeeping 16 Kb telemetry stream and commands the spacecraft via the 2K command link. Due to the complexity of the spacecraft various analysis tools exist to evaluate the spacecraft health and to generate commands for controlling the spacecraft.

The primary responsibility of the MPC is the initial processing of the 1Mb and 25Mb spacecraft science telemetry streams. The science data is recorded in a raw format, both analog and digital, and a digital 8 mm tape format, Level 1A tape, which serves the MSX program as the transport media and format for science data dissemination. The MPC also collects downlink data from the MCC and planning products from the Operations Planning Center for inclusion on the Level 1A tape to enable the MSX data community to analysis the data. This data is sent electronically to the MPC via a LAN. One of the key products provided on the Level 1A tape from the MCC is a measure of the spacecraft clock against time standards.

The MPC consists of a hardware front end for the capture and formatting of the science data and a computer system for the processing of the formatted science data to produce Level 1A tapes. The hardware front end includes wideband analog recorders, decryption devices, data selectors, bit sync, and frame syncs. One of the unique features of the 25 Mb telemetry stream is that is transmitted to the ground in the reverse direction. The MPC must then reverse the data again which is accomplished via analog recorders in order to perform further processing. The computer system consists of three model VAX 4000 computers with 107 Gb of disk space and 12 8 mm tape drives. One VAX is task with
reading the 25 Mb telemetry onto the disk. The second VAX reads to the 1Mb telemetry onto the disk and produces a digital 8 mm tape of the raw data. The third VAX is tasks with processing the data and writing the Level 1A tapes. The systems architecture is such that while today's data is being downlinked yesterday's data is being processed and written to Level 1A tapes. Custom software was developed to perform the processing and data management within the MPC.

INTRODUCTION

The task of operating the MSX spacecraft in fulfillment of its mission to collect various kinds of observation data was different into two different areas; one being spacecraft command and control and the other being spacecraft science data processing. The Mission Control Center is charted with command the spacecraft and monitoring the housekeeping telemetry to ensure the health and safety of the spacecraft. The Mission Processing Center is chartered with processing the science data from the spacecraft and disseminating the data to the MSX data community.

MCC

The MCC consists of the hardware and software necessary to command, control, and monitor the MSX spacecraft. While providing the capability to format a command, it also provides the ability to receive, decommutate, distribute, and process the MSX housekeeping telemetry. This section will focus on the processing, interpretation, and display of the raw telemetry processed in the MCC.

MCC TELEMETRY PROCESSING

The 16 kbps telemetry contains the “housekeeping” information of the various subsystems and instruments on-board. This 16 kbps telemetry may also contain particular “dump” formats which contain special information from the various on-board processor’s memory. The MCC software distributes this information to various workstations throughout the MCC where the processing of the telemetry is performed. This method of distributed processing allows for more efficient TM processing in that only those parameters displayed, are processed at each individual workstation as opposed to all parameters being processed and then distributed for display. Because of the various different formats the 16 kbps may contain, many specialized software tools have been developed to process and display this information to the controllers.
TELEMETRY DISPLAY

The displaying of telemetry in the MCC consists of some high level graphical interfaces as well as that of raw numbers and their conversion to enumerations or engineering unit values. The graphical interfaces include the use of a COTS product called DataViews. This interface displays the information in a system level block diagram format where actual numbers are included along with colors to indicate alarms as well as configurations. This type of display allows for many parameters to be grouped together to provide a “big picture” view. Other views are more at a subsystem level, providing more details when necessary.

A custom-made graphical display tool is called SEEMSX. This tool displays the attitude of the spacecraft based on an interpretation of the housekeeping data and indicates its offset from the normal PARKED mode orientation. This housekeeping data would normally include a series of engineering units. SEEMSX actually displays a physical model of the spacecraft and its orientation relative to the sun and earth in addition to information concerning the status of other spacecraft functions, including the orientation of the X-band antenna for prime science downlink.

Also in the MCC is a real-time plotting capability which allows for strip-chart type of visualization on any telemetry parameter. This is useful in trending a parameter over several station contacts. Multiple parameters may be displayed simultaneously.

TELEMETRY CONVERSION

The Telemetry Dictionary provides the method by which the standard “housekeeping” data is decommutated and converted into engineering units. The Telemetry Dictionary is maintained in an Oracle Database which contains the byte offsets from the Major Frame for decommutation, and scale factors, offsets, lookup tables, and polynomials required to convert each housekeeping parameter for display in engineering units. Additional parameters added to the Telemetry Dictionary include “special conversions”, which are based on other parameters tied together through a mathematical algorithm. These types of “derived” parameters lead to higher level indications of the overall status of a component or subsystem. Such parameters may include adding all of the spacecraft individual current monitors to indicate the total load on the power system.

ALARM PROCESSING

The Telemetry Dictionary also contains alarm information for the different telemetry parameters. These alarms consist of both yellow and red conditions, where yellow indicates a warning and red, that of a problem. The Alarm Status Window reports red,
yellow, and green alarms of all parameters for which alarm information is contained in the Telemetry Dictionary. These alarms are time-tagged with the first alarm occurrence and re-occur once a minute until acknowledged by the controller. An audible alarm occurs upon the change of status in the window. A Green condition only appears when a yellow or red alarm returns its state back to nominal. This alarm notification ability provides a method of informing the controller of any parameter’s status without actually viewing those parameters on a display.

SPECIAL UTILITIES

Although the conversion and display of normal housekeeping data are the majority of the processing done on telemetry in the MCC, various other tools are used for analyzing the information contained in the various formats other than the housekeeping telemetry. Some are used for real-time performance assessment, while others are used in anomaly investigation. Several of the more essential tools are discussed below.

COMMAND HISTORY DISPLAY

The MSX Command Processors each contain a buffer, called Command History, which holds the last 500 commands executed along with their time of execution, command source and status of execution. As part of the normal housekeeping data, two commands from the Command History buffer and the last command executed are downlinked per second. In addition, there is the capability to “dump” the Command History buffer to obtain the entire contents at once. Software was developed to interpret the information and display it as it is received in real-time and then sorted chronologically after the contact. This utility is essential in anomaly investigations to determine the actual “as-flown” command sequence.

MEMORY VERIFY

The On-board Processors are routinely commanded to “dump” their raw memory such that an “actual” image of their stored command sequences may be compared to that of an expected version based on what was uplinked. The Memory Verify Utility performs the maintenance of these “actual” and “expected” images along with the comparison and reporting of differences. This utility is necessary to determine if memory was loaded correctly.

DECODE COMMAND MEMORY

To determine what is actually stored on-board in certain regions of Command Processor memory, a utility is used to decode its “actual” on-board image in a method similar to that of command history. During
certain anomalous conditions, it is imperative to determine the actual state of the command memory resident in the Command Processor. This utility provides the method to determine the status.

AUTONOMY DISPLAY

The MSX Command Processors possess an autonomy feature which allows for logic to be specified between telemetry parameters to determine anomalous conditions in the form of rules. If such anomalous conditions are detected, the Command Processor will issue a series of pre-defined commands in an attempt to correct the situation. If such an event should occur, the only method to determine which set of the logic or rules were implemented is to “dump” a portion of that Command Processor’s memory. The Autonomy Display Utility was developed to recognize and decommutate this information based on the format of the downlink, and display it in a tabular format such that an evaluation may be made by a controller as to the status of the on-board autonomy.

HEX DUMP

There are particular “dump” formats for which there is no conversion to engineering units. In these cases, there is no other method to decipher the data than to look at it raw. The Hex Dump Utility provides a method of displaying the raw data in hex format per major frame. Each major frame being divided into minor frames. This is the brute force method of determining what was downlinked in telemetry when no other method has been developed. This is essential when analyzing particular “dumps” from processor memory which are not downlinked routinely and therefore not routinely decommutated.

ARCHIVED TELEMETRY

Following a station contact, the 16 kbps received in the MCC is saved in an archive file. There are several tools which allow for this archive file to be used in the investigation of anomalies which may have occurred during the station contact.

TELEMETRY ARCHIVE PLAYBACK

The Telemetry Archive Playback allows the controller to “re-play” the archive file or a portion thereof, back through the system as though it were being received in real-time. In addition to being an essential tool when investigating anomalous conditions, it is also useful when several important events occurring during a contact, prevent the controller from verifying their successes all at once.
ENGINEERING DUMP UTILITY

The Engineering Dump Utility allows the controller to strip out of an archive file, up to seven items from the Telemetry Dictionary, convert and display them on the screen or save them to a file for printing. The constraint of seven was driven by the maximum number which could be displayed on the screen. The format of the output is a tabular listing. This is essential in the investigation of anomalies to determine when exactly a particular configuration was achieved.

ENGINEERING SPREADSHEET UTILITY

Similar to the Engineering Dump Utility, the Engineering Spreadsheet Utility provides the method for extracting as many telemetry parameters from the archive file as desired. The input is an ASCII text file which lists the names of the parameters as specified in the Telemetry Dictionary Report. The output is a tab delimited ASCII formatted text file which imports directly into many spreadsheet software packages such as Excel.

MPC

Before any data flowed from the spacecraft to the MPC the data needed to be documented in detail. The MSX Mission Operations Center Data Products Document was disseminated to the MSX data community to enable them to design the various systems which would receive and process the science data. This document was first released in 1992 with a major rerelease in 1994. The final version was released in 1996. This document provided the detail which governed the design of the data products as supplied by the MPC. The format of the Level 1A tapes is described in painstaking detail. Each day the MPC produces one set of Level 1A tapes which consists of one or more tapes for each of the Data Processing Centers, UVISI, SPIRIT III, SBV, OSDP, and Contamination, as well as a copy of these tapes for the Background Data Center which is the archive facility for the program. Each tape contains data unique to each instrument as well as ancillary files, i.e., files from other portions of the MOC.

The challenge of the MPC is to record and process 12Gb of science data each day from the MSX spacecraft in addition to 3 Gb of operations data. This challenge was meet by designing a system which performs simultaneous data collection and processing functions. The MPC design supports 12 Gb or 50 minutes of 25Mb downlink per day and 14 1Mb downlinks per day. This data collection function is accomplished by utilizing a hardware front end and VAX computer system for storing the data on disk in both realtime and nonrealtime operations. While in the collection mode the MPC receives operations data from other parts of the MOC for inclusion on the Level 1A tapes. When the data for a day is "collected", the MPC passes the data to another member of the VAX computer cluster.
and enters a processing mode which first sorts the data and then writes the Level 1A tapes. At the conclusion of the processing mode any data which is incomplete is copied to the data collection system for further processing on the next day. This ping-ponging of collection and processing continues for the mission.

MPC FRONT END

The MPC hardware end front captures data on the 25Mb and 1Mb telemetry streams on analog tape and formats the data on a major frame basis as transmitted from the spacecraft. The hardware front end incorporates one of basic principles of telemetry capture: record the data in an unprocessed format should any of the processing equipment fail. This concept permits the MPC to post pass reprocess the data should it be necessary due to equipment problems during the pass. During a contact the prime 25 Mb data is stored in decrypted form on analog recorder. After the pass the 25 Mb data is playback at half speed for storing on the MPC disk array. During a spacecraft contact the 1Mb data is also stored on the computer disk while being stored on the analog tape.

The 25Mb science data, prime science, as transmitted from the spacecraft is playback from the spacecraft tape recorders in the reverse direction. This is done to extend the life of the spacecraft tape recorders. The MPC turns the prime science around by also playing the decrypted analog data in the reverse direction into the MPC VAX computer.

MPC COMPUTER SYSTEM

The MPC computer system is a tri-hosted cluster of VAX 4000 computers which all have access to 107 Gb of disk space for the storage of spacecraft science data. The spacecraft science is only written to the disk and read one time for writing on Level 1A tapes. During the process of writing the science data to the disk a subset of data is extracted for subsequent processing. This subset, pointer files, completely describes the data and where it is stored on disk. The pointer files are used by DBase IV for time ordering the data. In addition to time ordering the DBase IV application also handles any overlap due to the stop and start of two contacts and fills in any gaps in the data with fill bytes. The DBase IV application organizes the pointer file for generation of Level 1A tapes. At the conclusion of the data processing, a tape writer program begins the process of writing the Level 1A tapes. Eight Level 1A tapes are written simultaneously. The UVISI, SBV, SPIRIT III, and OSDP data sets are written with the Contamination data being written to disk files. At the completion of the writing of these four data sets the Contamination Level 1A tapes are written. The tape writer program can handle up to four of each type of Level 1A tape per day.
MOC NETWORK

The MOC network connects all parts of the MOC and includes a mail server for the transmission of electronic products on an automated basis. The design of the MOC included the realization that certain data products as documented in Reference 1 were needed to perform operations. The MOC server handles the routine dissemination of these products to the various portions of the MOC on an automated basis using software specifically developed for this purpose. Since this network deals with both classified and unclassified data, the MOC server also records all transactions to satisfy security requirements of electronic file transfer.

The MOC network and server forward the operations products to the MPC which the MSX data community will need to analysis the data and understand the spacecraft operation.

CONCLUSION

The MCC and MPC provide tools, facilities, and systems for the handling of both spacecraft housekeeping telemetry and science data which enable the MSX spacecraft to fulfill its mission.

REFERENCE

1. MIDCOURSE SPACE EXPERIMENT (MSX) PROGRAM Mission Operations Center Data Products, SDO 9861.1 The Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland, February 1996