SPACE-BASED VISIBLE (SBV) SURVEILLANCE DATA VERIFICATION AND TELEMETRY PROCESSING

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ABSTRACT

This paper discusses the telemetry processing and data verification performed by the SBV Processing, Operations and Control Center (SPOCC) located at MIT Lincoln Laboratory (MIT LL). The SPOCC is unique among the Midcourse Space Experiment (MSX) Data Processing Centers because it supports operational demonstrations of the SBV sensor for Space-Based Space Surveillance applications. The surveillance experiment objectives focus on tracking of resident space objects (RSOs), including acquisition of newly launched satellites. Since Space Surveillance operations have fundamentally short timelines, the SPOCC must be deeply involved in the mission planning for the series of observations and must receive and process the resulting data quickly. In order to achieve these objectives, the MSX Concept of Operations (CONOPS) has been developed to include the SPOCC in the operations planning process. The SPOCC is responsible for generating all MSX spacecraft command information required to execute space surveillance events using the MSX. This operating agreement and a highly automated planning system at the SPOCC allow the planning timeline objectives to be met. In addition, the Space Surveillance experiment scenarios call for active use of the 1 Mbps real-time link to transmit processed targets tracks from the SBV to the SPOCC for processing and for short time-line response of the SPOCC to process the track of the new object and produce new commands for the MSX spacecraft, or other space surveillance sensors, to re-acquire the object. To accomplish this, surveillance data processed and stored onboard the SBV is transmitted to the APL Mission Processing Center via 1 Mbps contacts with the dedicated Applied Physics Laboratory (APL) station, or via one of the AFSCN RTS locations, which forwards the telemetry in real-time to APL. The Mission Processing facility at APL automatically processes the MSX telemetry to extract the SBV allocation and forwards the data via file transfer over a dedicated fractional T1 link to the SPOCC. The data arriving at the SPOCC is automatically identified and processed to yield calibrated metric observations of RSOs. These results are then fed forward into the mission planning process for follow-up observations.

In addition to the experiment support discussed above, the SPOCC monitors and stores SBV housekeeping data, monitors payload health and status, and supports diagnosis and correction. There are also software tools which support the assessment of the results of surveillance experiments and to produce a number of products used by the SBV instrument team to assess the overall performance characteristics of the SBV instrument.

KEY WORDS

Automated Telemetry Processing, Decommutation, Space Surveillance

OVERVIEW

The Midcourse Space Experiment (MSX) is a satellite-based experiment sponsored by the Ballistic Missile Defense Organization (BMDO) to be flown in a low-earth orbit. MSX was initially conceived as the first extended duration, long wave infrared (LWIR) phenomenology measurement program sponsored by BMDO; however, these early objectives have evolved into a more comprehensive experiment. MSX is now a multi-year experiment designed to collect broad-band phenomenology data on missiles, plumes, naturally occurring earthlimb backgrounds and deep space backgrounds. In addition, MSX will be used to collect spacecraft contamination data, to integrate, validate, and transfer advanced technologies to current and future BMDO systems, and to conduct functional demonstrations of space-based space surveillance.

MSX will be launched from Vandenberg Air Force Base into a near-polar, low-earth, near sun-synchronous orbit. The MSX, discussed further in Ref. 1, consists of the satellite superstructure, three primary optical sensors, contamination instrumentation and the spacecraft support subsystems. The optical axes of the three primary sensors (Space Infrared Imaging Telescope (SPIRIT III), Space-Based Visible (SBV) sensor, and Ultraviolet/Visible Imagers and Spectrographic Imagers (UVISI)) are parallel to one another and point in the +X direction.

The SBV sensor, discussed in Refs. 2 and 3, is the primary visible wavelength sensor aboard MSX. It will be used to collect data on target signatures and background phenomenologies, but the primary mission of SBV will be to conduct functional demonstrations of space-based space surveillance. SBV incorporates a 15 cm, off-axis, all-reflective, reimaging telescope with a thermoelectrically-cooled CCD focal plane array. SBV also includes an image processing system, experiment control system, telemetry formatter, and a RAM data buffer for temporary data storage.

MSX SPACE SURVEILLANCE OPERATIONS

Currently the United States maintains a world wide network of ground based sensors tasked with the acquisition of tracking data on all manmade objects in orbit around the earth. These sensors include a network of passive optical systems which are limited to a short duty cycle by poor weather and by daylight. Since foreign based sites are progressively more expensive and inconvenient to support, it is natural to ask whether ground based sensors could be supplemented or replaced by satellite based sensing systems. Satellite based sensors are not limited by daylight operation or poor weather and a single satellite borne sensor can sample the entire geosynchronous belt satellite population several times per day.

One of the missions of the MSX satellite is to demonstrate the feasibility of these space-based space surveillance operations. The mission planning for the Space Surveillance experiments on the MSX satellite requires the ability to leave considerable flexibility in the experiment timing and attitude profile to be followed by the MSX in the experiment execution until late in the experiment planning process. Under "normal" circumstances the details of the operation, consisting of the list of satellites to be observed, the attitude profile for the MSX and the data acquisition times can be defined one to two days before the execution on the MSX. Special "quick reaction events", such as acquiring track data on a newly launched satellite in its transfer orbit to the geosynchronous belt, require reaction times on the order of hours. More details on the concept of operations which allows space surveillance operation to be planned and executed on the MSX satellite is provided in Ref 4. These experiments also require that the observational data be quickly down-linked, processed and the results be available to feed forward into the next series of space surveillance observations to be executed by the satellite.

The MSX control network used to execute MSX space surveillance operations is shown in Figure 1. The SPOCC, located at Lincoln Laboratory, is connected to the MSX Mission Operations Center, located at Applied Physics Laboratory (APL), via a dedicated fractional T1 link. The SPOCC develops the commands needed to execute the space surveillance operations, including all instrument and bus commands, and forwards them to APL for inclusion in the command uploads. Command uploads may be sent to the MSX via a dedicated station at APL or via the AFSCN. One Mbps telemetry is returned to APL via the AFSCN stations or is received at the dedicated APL station. Generally the CONOPS of the SBV calls for surveillance data to be processed onboard to yield detections of moving objects in the field and the results stored in an RAM buffer for later down link. The data are down-linked via the 1 Mbps link, processed at APL to extract the SBV allocation of the telemetry stream and the results automatically forwarded to the SPOCC.

SPOCC ARCHITECTURE OVERVIEW

The top level architecture chosen for the SPOCC is shown in Figure 2. The flow of operations starts in the upper left with the receipt of the experiment requirements. The Mission planning process is an iterative process between the SPOCC and the Mission Operations Center (MOC), as described in Ref. 4, and results in the generation of the commands needed to execute the space surveillance event on the MSX. The commands are provided to the MOC, over the dedicated link between the facilities, for incorporation into the MSX command uploads. The resulting telemetry is provided to the SPOCC via file transfers across the same dedicated link shortly after the completion of any contact between the MSX and a ground station. The files received at the SPOCC may contain 1 Mbps or 16 Kbps telemetry or a broad range of other planning and operations data. The files are automatically identified, decommutated and processed as described in the following section. The resulting data are forwarded to the SBV health and status monitoring function or the science data processing pipeline. The science data processing pipeline automatically applies the appropriate calibrations and processes and the observational data to yield calibrated metric and radiometric observations of resident space objects. The processing includes the determination of spacecraft attitude from the astrometric information contained in the observations.

TELEMETRY DECOMMUTATION AND PROCESSING

As discussed above, the telemetry files downloaded from the MSX spacecraft are sent from APL to the SPOCC via a dedicated fractional T1 link. The traffic on the link also includes many other types of files, including ancillary mission planning products, such as the predicted MSX orbital geometry data and MSX operations schedules. Thus, the SPOCC ingest processing must receive and appropriately process a number of products in an automated fashion. As each file is received, a data ingest script checks the received data file's extension and launches the appropriate processing. The downloaded telemetry files are routed to the decommutation software and the ancillary files are sent to various processes or copied to destination directories. This process is shown pictorially in Figure 3.

During a surveillance experiment, the SBV collects data sets, composed of a series of between 2 to 16 frames of CCD data, while pointing in an inertially invariant direction. Each “frame set” is processed by the SBV's onboard Signal Processor. The Signal Processor extracts star data, seen as fixed point source objects, and target data, each seen as a streaking point source. The positions and signatures of the desired number of stars are stored in the SBV's internal RAM buffer. During ground processing, these stars will be automatically matched against a star catalog and a fit accomplished to precisely determine the pointing of the SBV. Information on each streaking Resident Space Objects (RSOs) detected is stored in a report containing the locations of the endpoints of the streak, and the radiometric values associated with a swath of pixels along the path of the streak. Several other reports are also stored in the buffer. Observation header (OBSHDR) reports store information regarding the SBV's configuration and time of frame set collection. Snapshots of SBV health and status data are stored as housekeeping (HSKP) reports. Reports from a Single Event Upset (SEU) experiment and a Total Dosimetry (TD) experiment are also recorded periodically. After the data collection event has been completed, the contents of the SBV RAM buffer are downloaded via the 1 Mbps link during a contact, generating a prime science file.

During ground contacts, health and status telemetry are also downloaded via the 16 Kbps link, generating a health and status file of all the MSX systems and instruments. The SBV has enough allocation to provide only a snapshot of the SBV health and status once per second. The full health and status report is contained in a subcommutated portion of the telemetry frame which takes 22 seconds to complete a single cycle.

Both prime science and health and status files are sent to the same decommutator software but they are processed differently, as shown in Figure 3. For health and status files, the decommutator strips out the SBV health and status data. These data are stored in a health and status database where they can be viewed and processed for long term trending. The data are also processed by real-time software which monitors the SBV health and status, looking for anomalies and malfunctions. This software is relatively complex due to the subcommutated nature of the health and status telemetry stream. The monitoring software generates different levels of alarms for different anomalies, the most urgent of which result in automatic paging of key personnel for anomaly resolution. The automated notification of alarm conditions is of great importance because due to funding limitations, the SPOCC is staffed only 8 hours/day, five days per week.

Prime science files are processed by the decommutator to extract the star, streak, and other reports. The star and streak data will be processed by the data reduction software to generate metric observations. The data reduction software requires a command file describing the data to be processed. This command file is automatically generated by the decommutator, based on the contents of the telemetry file, to process each set of star and streak data from a particular frame set. The star and streak data themselves are extracted from their reports and loaded into a prime science database. SEU and TD reports are processed and stored in data files associated with radiation experiments and the snapshots of health and status in the HSKP reports are added to the health and status database.

Figure 4 shows the data reduction pipeline process which is applied to each frame set of data. The data reduction software takes as input the command file generated by the decommutator, and accesses the prime science data base to extract the stars and streak data along with an estimate the SBV attitude based on the MSX's attitude system output, which is stored in the OBSHDR data. The data reduction process begins by refining the knowledge of the attitude of the SBV using a known star catalog as a reference. Candidate reference stars are extracted form the catalog and transformed into focal plane coordinates by applying a distortion map. The distortion of the SBV optical system is large due to the off-axis design which is optimized for stray light rejection. The star detections are matched with the cataloged candidates on the list, and a fit run to establish the precise (better than an arcsec in most cases) attitude of the SBV during the frame set. This information is output to the attitude history file.

The precise attitude is used to calculate the Right Ascension and Declination of the endpoints of each streak in the frame set, whose signature is used to refine the endpoint locations. The endpoint positions are then checked against the catalog of known resident space objects in an attempt to identify known and unknown objects. These endpoint positions and their times are then written out as metric observations. Data quality indices are calculated for each frame set based on factors such as the residuals from the star match.

SUMMARY

This paper has described the mission planning and telemetry processing system developed to support the execution of space surveillance operations on the MSX satellite. The system is highly automated to support the short timelines inherent in the mission and is closely integrated with the MSX Mission Operations Center which operates the MSX satellite. The SPOCC telemetry processing system is also constructed as an integral part of the SPOCC data management system so that incoming telemetry files are immediately processed, distributed to the appropriate data base and the user notified. In addition, the receipt of specific types of data automatically initiate additional levels of processing to generate derived products. This level of automation allows the operations of the SPOCC on a timeline suitable to the mission and with a minimum of operations personnel.

ACKNOWLEDGMENT

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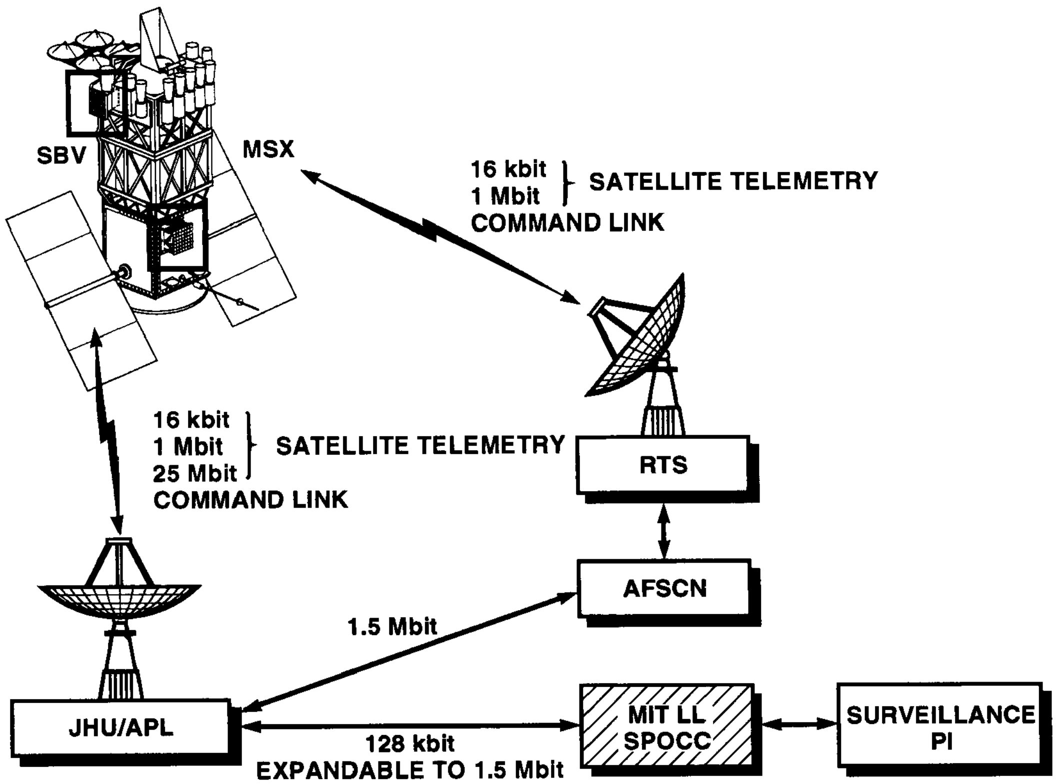

Figure 1. MSX Control Network

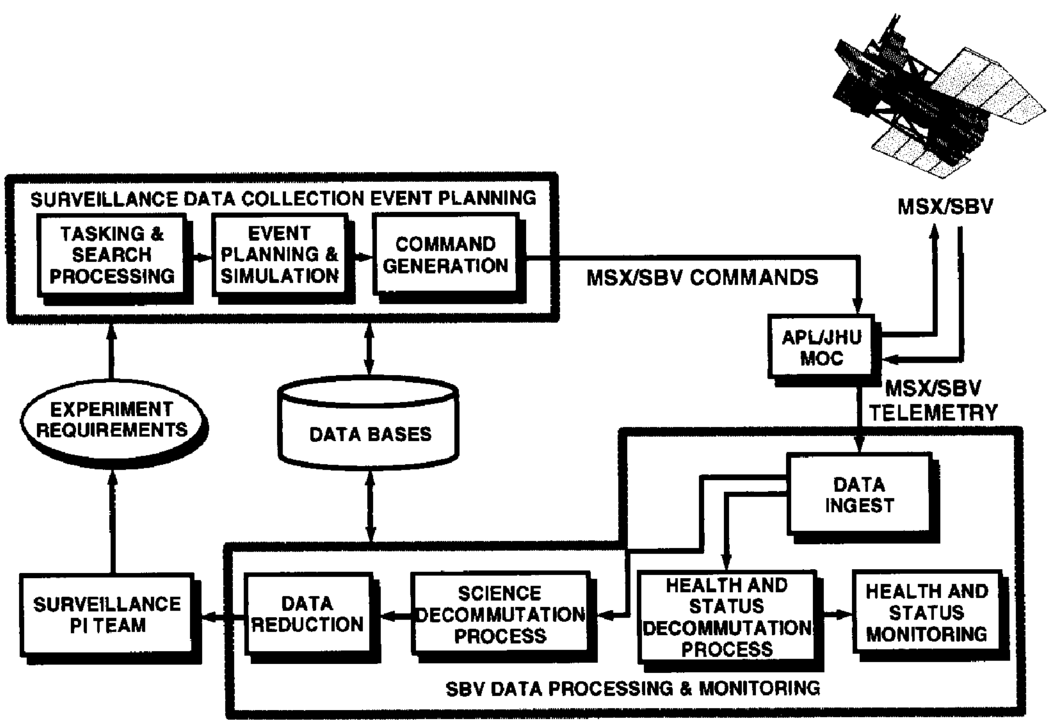

Figure 2. SPOCC Architecture

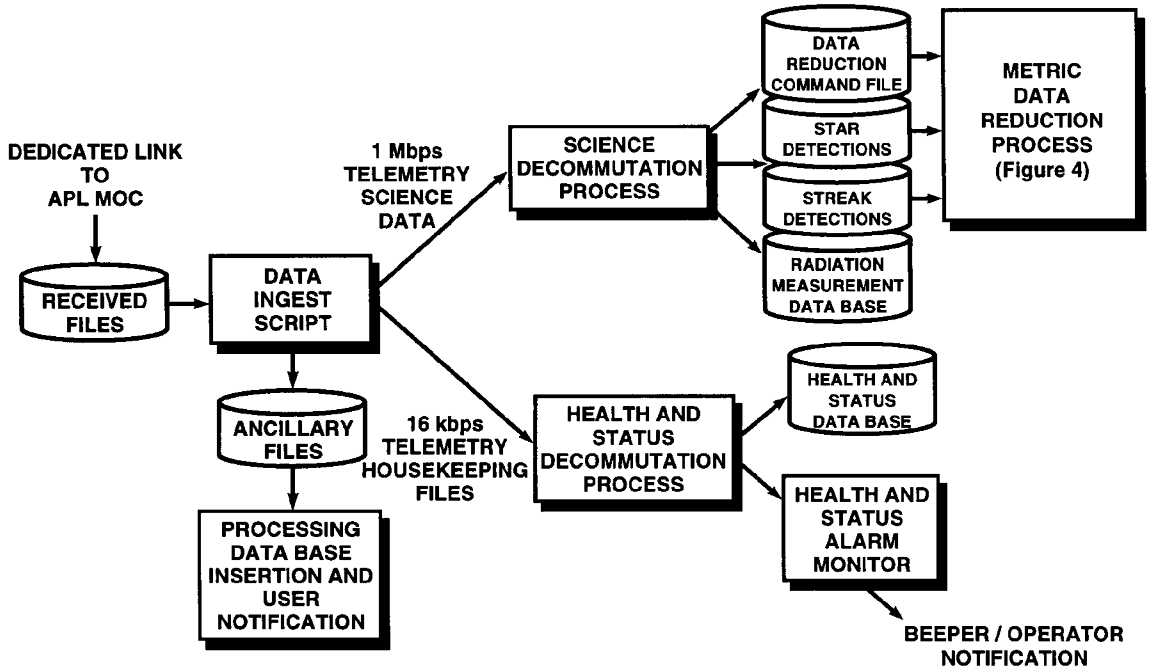

Figure 3. Processing applied to incoming telemetry files

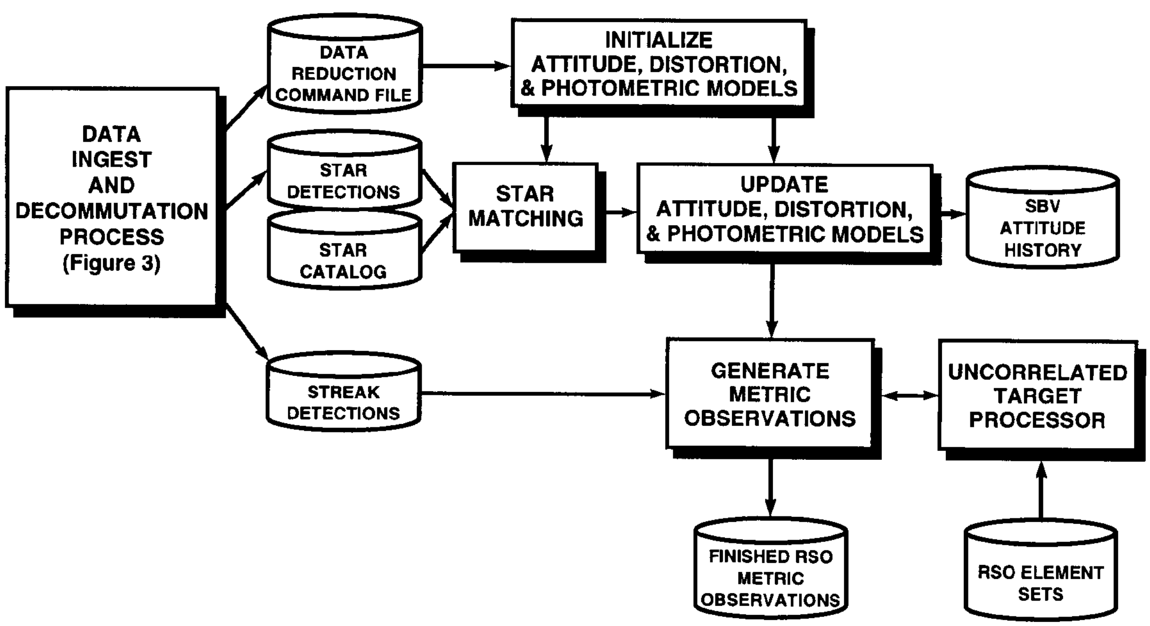

Figure 4. Processing applied to SBV metric data