An Automated Ground Data Acquisition and Processing System for the Advanced Land Imager

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The calibration and performance assessment of the Advanced Land Imager (ALI) on the Earth Observing 1 (EO-1) satellite required a ground data system for acquiring and processing ALI data. In order to meet tight schedule and budget requirements, we developed an automated system that could be run by a single operator. This article describes the overall ground data system and the individual electrical ground support equipment (EGSE) and computer components used. The ALI calibration control node (ACCN) serves as a test executive with a single graphical user interface to the system, controlling calibration equipment and issuing data acquisition and processing requests to the EGSE and other computers. EGSE1, a custom data acquisition system, collects ALI science data and passes ALI commanding and housekeeping telemetry collection requests to EGSE2 and EGSE3, which are implemented on a custom integration and test workstation. A performance assessment machine stores and processes collected ALI data, and automatically displays quick-look processing results. We also describe the custom communications protocol developed to interface these machines and to automate their interactions, including the various modes of operation needed to support spatial, radiometric, spectral, and functional calibration and performance assessment of the ALI.

Integration and test and ground calibration of the Advanced Land Imager (ALI) was performed at Lincoln Laboratory prior to delivering the ALI to the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) for integration with the Earth Observing 1 (EO-1) spacecraft. In support of the integration and test and ground calibration, a data acquisition and processing system was developed for commanding the ALI, recording science and housekeeping telemetry, and processing these data. Portions of this data system are used during mission operations to process and analyze data recorded on-orbit to assess the performance of the ALI.

Overview of the Ground Data System

Figure 1 depicts the EO-1 ALI ground data acquisition and processing system. The ALI is depicted in the center of the figure and has two types of data connections. The first is a 1773 bus over which commands are issued to the ALI and housekeeping telemetry is output. The second is a science data output port from

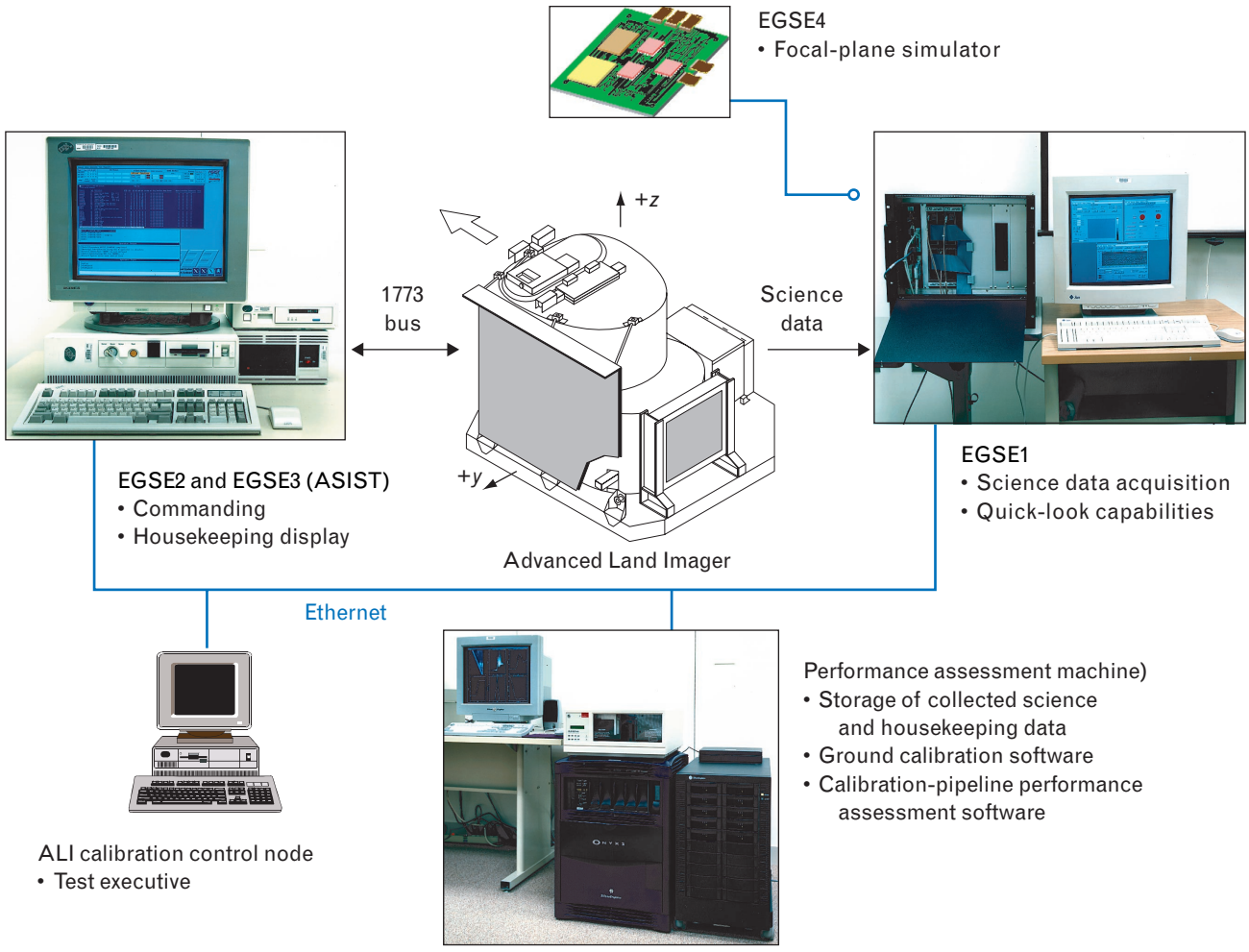

FIGURE 1. The Advanced Land Imager (ALI) ground data acquisition and processing system, with the four electrical ground support equipment (EGSE) components, the ALI calibration control node (ACCN), and the performance assessment machine (PAM). The focal-plane simulator (EGSE4) was used to test the ground acquisition and processing system by providing test data in the same format and timing characteristics as the ALI.

which multispectral/panchromatic data and the performance assessment data are recorded.

The data system consists of four electrical ground support equipment (EGSE) components, a test executive computer, and a data storage and analysis workstation. EGSE1 is the science and data acquisition system that records the multispectral/panchromatic data with high-speed data acquisition cards. The data are then read out from the cards and saved to disk. EGSE1 also has some limited quick-look capabilities for displaying a preliminary view of the collected data. EGSE2 performs the commanding of the ALI while EGSE3 receives and interprets housekeeping telemetry. Both EGSE2 and EGSE3 are implemented on a single Advanced System for Integration and Spacecraft Test (ASIST) custom workstation provided by NASA. EGSE4 is a focal-plane simulator, a digital system that outputs test pattern data in the same format and with the same electrical and timing characteristics as the ALI. EGSE1 can record data from either EGSE4 or the ALI.

The data storage and analysis workstation is called the performance assessment machine (PAM). All housekeeping and science data are archived on the PAM. The PAM also hosts the software for reducing and analyzing ground calibration data, a radiometric calibration pipeline, and software for performance assessment. The test executive function is performed by

the ALI calibration control node (ACCN), which was developed to coordinate the operation of all the system components and to automate the many repetitive steps involved in the ground calibration. The ACCN coordinates the actions of the EGSE and the PAM, and also controls calibration equipment such as illumination sources and reticle translation stages used to project test scenes into the ALI. EGSE1–3, the PAM, and the ACCN communicate and transfer data via an Ethernet connection.

EGSE1: Science Data Acquisition System

EGSE1 is a custom-built (by Celerity Systems, Inc.) VME-based science data acquisition system that reads science data from the ALI. EGSE1's VME enclosure contains two ACC256 high-speed memory cards, a Sun Microsystems Sparc 20 Unix workstation card, a 2 GB system disk drive, and two 9 GB data disk drives. A monitor, keyboard, and mouse are connected to the Sparc 20 workstation card. The workstation has two Ethernet ports, fast (100 Mb/sec) and slow (10 Mb/sec). The fast Ethernet port is used to transfer the large science data files to the PAM. The ACC cards each contain 512 MB of RAM. Both cards have an input daughter card, while only one has an output daughter card. Two ACC cards were included for redundancy. The ACC256 card with the output daughter card was used during development in a loop-back test mode, in which one ACC256 card wrote data to the other ACC256 card to simulate a data collection.

EGSE1 operates as a Unix workstation with integrated data acquisition hardware. The system was originally designed so that the data acquisition cards are controlled through a LabView interface. This interface allows an operator to manually configure the cards for data collection and transfer to disk, and also supports some quick-look displays of the data. The LabView interface was modified and extended to support automated control by the ACCN test executive over Ethernet. In this mode, EGSE1 receives requests from the ACCN for EGSE1, EGSE2, EGSE3, and PAM support, and EGSE1 coordinates the actions of itself, the ASIST, and the PAM.

Data recorded in the ACC256 cards can be saved to either the local EGSE1 data disks or across the network to the PAM disk drives. During integration and test and ground calibration at Lincoln Laboratory, data were typically saved to the PAM disks. EGSE1 followed the ALI when it was integrated with the EO-1 spacecraft at GSFC while the PAM remained at the Laboratory. During that time, ALI data were saved to the EGSE1 local disks, and were processed by using a subset of PAM performance assessment software ported to EGSE1.

EGSE2 and EGSE3: Commanding and Housekeeping Telemetry Processing

The ASIST workstation was provided to Lincoln Laboratory by GSFC for use during ALI integration and test and ground calibration since similar ASIST workstations were going to be used by GSFC during mission operations. The ASIST's hardware is comprised of an IBM RS/6000 workstation in a floor-mounted system unit, with monitor, keyboard, mouse, and external disk and tape units. The standard workstation configuration contains 64 MB of memory and 1 GB or more of disk storage. Each workstation also includes a DOS-compatible 3.5 inch floppy disk drive and a 4 mm tape cartridge unit for backups. The IBM RS/6000 runs AIX Unix and an ASIST software system developed by NASA.

The ASIST sends commands to, and receives telemetry from, the ALI. The ASIST uses the Consultive Committee for Space Data Systems (CCSDS) protocols for transfer over TCP/IP Ethernet, which at some point must be converted to CCSDS for transfer over a 1773 bus. During ALI ground calibration, this conversion was accomplished by using a bus interface box (BIB), developed by Jackson and Tull, which consists of an IBM PC with an Ethernet card and a 1773 optical transceiver card, plus software for making the conversion.

The ASIST software contains three primary components: the systems test and operations language (STOL) interpreter, a display system, and a database system. The STOL interpreter is used to send commands to the ALI. EGSE1 access to the STOL interpreter was achieved via a built-in remote log-in STOL (RSTOL) ASIST feature, which allows EGSE1 to start and stop housekeeping recording and to send ALI commands as requested by the ACCN. Since this RSTOL feature is accessible only from another

Unix machine, the ACCN could not use it directly, so EGSE1 had to be used as an intermediary. EGSE1 was used for this purpose instead of the PAM because the ACCN, EGSE1, and the ASIST followed the ALI for use in a post-delivery test while the PAM remained at Lincoln Laboratory.

The display system for the ASIST software is used to define various telemetry displays for viewing and analyzing housekeeping telemetry. The database system contains a command database that describes the format and function of each ALI command, and a telemetry database that describes how to interpret the ALI housekeeping telemetry. After delivery of ALI for spacecraft integration, the ALI ASIST command database, telemetry database, and display descriptions were transferred to NASA for incorporation into the EO-1 ground control system. The ASIST returned to Lincoln Laboratory for analyzing housekeeping during mission operations.

The Performance Assessment Machine

The PAM is a Silicon Graphics Origin 2000 Deskside Unix workstation with two R10000 processors. The PAM is used to archive, reduce, and analyze data from the ALI during integration and test and ground calibration. The PAM is also used to reduce and analyze on-orbit data for sensor performance assessment. It is outfitted with 120 GB of disk storage in RAID array disks, and a multi-slot robotic DLT 4000 drive for permanent data storage.

In addition to issuing commanding and data collection requests to the EGSE, the ACCN also requests the PAM to enter one of several modes for performing quick-look processing and display. These modes are designed to provide quick-look displays that are helpful for the various types of calibration and integration and test data collections. These modes include various test modes and other modes of operation needed to support spatial, radiometric, spectral, and functional calibration and performance assessment of the ALI. A detailed description of the performance assessment software resident on the PAM is found elsewhere [1].

The software running on the PAM during ground calibration performs three distinct tasks. First, the PAM communicates with the ACCN and EGSE1 to enter the proper mode and coordinate the data collection, signaling the ACCN to begin the next round of data collection once all of the expected data are collected and copied to the PAM's disks. Second, upon receiving a set of data, the PAM software performs an initial real-time, quick-look data analysis to ensure that the data are valid, and displays the results of this analysis to the operators to allow them to monitor the integrity of the data collection. Third, the PAM serves as a general post-processing tool for analysts once a set of calibration data are complete and the data are stored on the PAM disks.

PAM's task of communicating with the other EGSE systems is managed by a Perl script manipulating files on a disk drive shared by the ACCN and EGSE1. The real-time data reduction and display are accomplished with IDL and C programs automatically launched by the Perl script. The final data analysis is performed with a variety of IDL, Perl, and C programs.

As data are collected from the ALI, several steps are needed to produce analytical displays to reassure the operators that the data collection is proceeding smoothly. These steps vary depending upon the type of calibration being conducted, but all of the modes share the same initial processing step. After the data are saved to a file on the PAM's disks by EGSE1, the first step in the PAM's data reduction is to unscramble the data. The data format produced by the ALI is complicated because of the details of the read-out electronics. Therefore, the PAM first reformats the data into simpler image array structures with the multispectral and panchromatic data separated into different files. The unscrambled data are then processed according to the type of calibration being performed.

The ALI Calibration Control Node

The ACCN is the test executive and data collection coordinator for ground calibration and integration and test of the ALI prior to integration of the instrument with the EO-1 spacecraft. The ACCN is a Dell Computer Corporation 266 MHz personal computer running the Microsoft Windows 95 operating system. A suite of general-purpose interface bus LabView programs was used to control all external calibration equipment throughout laboratory testing of the instrument. ALI commanding and data collection control is accomplished by sending a request file to the EGSE1

and the PAM. This request file contains not only science data-collection requests to be carried out by EGSE1, but also requests for commanding and housekeeping collection for the ASIST, as well as processing modes for the PAM. While the PAM and EGSE1 read this file directly for their instructions, the ASIST commanding and housekeeping requests are read by EGSE1 and forwarded to the ASIST. IDL software also resides on the ACCN for a quick-look analysis of calibration data and data trending. Finally, a history of ACCN commands is recorded in command logs that reside on the ACCN for later review.

During ground calibration, a single operator can control the entire ALI ground data acquisition and processing system through a graphical user interface on the ACCN. Figure 2 shows the main screen for this interface, which was written in LabView.

Communications and Automation

Because of the number of individual computers in the data system whose actions must be coordinated for a successful data collection, EGSE1, the ASIST, and the PAM were put under the control of the ACCN. This decision eliminated the need for an operator at each computer and eliminated mistakes due to uncoordinated setup and use of the various computers. Also, because of the repetitive nature of many of the ground calibration data collections, the use of the data system needed to be automated to avoid human error and further minimize operator staffing.

This section describes the automation and communications in the system. Briefly, the ACCN first sets up the calibration equipment needed for the data collection. Next, the ACCN generates one or more request files that are sent to EGSE1 by copying them to a directory called /data1/eo1/ on a shared PAM disk. EGSE1 sets up its memory cards and forwards command and housekeeping requests to the ASIST. Once the science data files are collected and transferred to the PAM, EGSE1 forwards the request file to the PAM to trigger processing and display of the data in the proper mode. Note that the system is very flexible. In some modes the ACCN uses the several request files to sequentially configure the ALI, EGSE1, the ASIST, and the PAM, and then initiates the data flow, while in other modes the ACCN does all of the above with a single request file.

ACCN Request File Generation

Each time a set of science data is to be collected, a data collection event (DCE) is carried out by the data system. Each DCE typically consisted of collecting a single set of ALI multispectral/panchromatic science data, along with related ancillary files, such as housekeeping data. If only a single DCE is to be completed, the operator manually commands a single DCE from the ACCN interface. For operations such as spectral or radiometric calibrations, a single DCE must be completed for each step in a series of steps (for example, several radiometric levels), so the ACCN would repetitively set the calibration equipment for the next step and then request another DCE.

Each DCE is accomplished by the generation of a request file by the ACCN. The request file is a simple text file describing what support is needed from the EGSE and PAM. It also documents the configuration

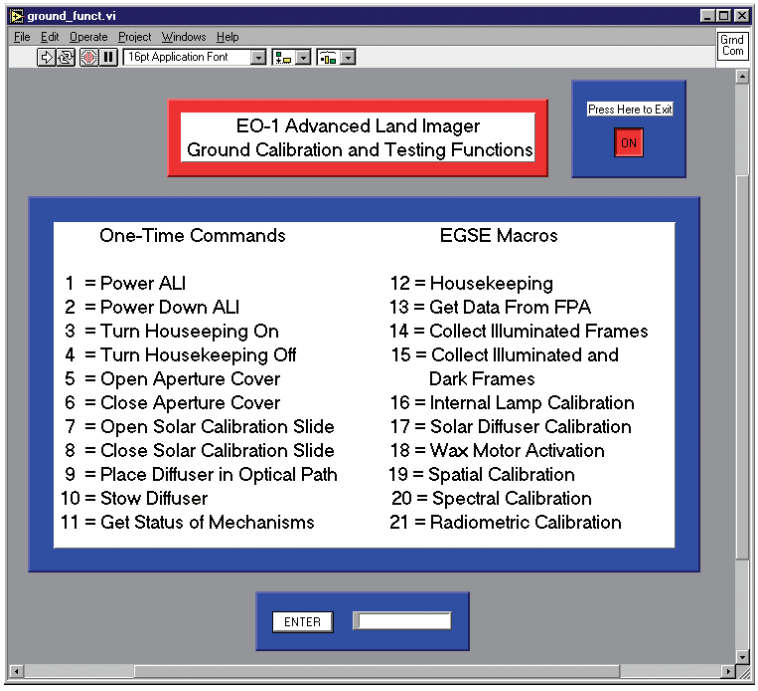

FIGURE 2. ACCN main control interface, which allows a single operator to control the entire ALI ground data acquisition and processing system.

Table 1. Format of Request Files

```
BEGIN
!
! Comments describing file and type of support requested
!
! Filename
ALI_NNNNNNNNNN_MMDDYYYY_TTTTTTTT
! ASIST command script request 0
command_script_name
! EGSE1 data processing mode (0-4)
1
! ASIST command script request 1
command_script_name
! PAM data processing mode
mode_name
! Detector on input board 0
MS/PAN
! Detector type board 0 (0=RAW, 1=MS/PAN, or 4=TEST)
1
! Number of data units to collect board 0
5
! Data units board 0 (0=frames, 1=seconds, 2=bytes)
0
! Percent column sampling level board 0 (pixel frequency?)
100
! Integer N (0-15), where board 0 integration time = (0.81 + 0.27*N) msec
10
! Integer N (0-4095), where frame rate = 9.6*10^6/(3*(N+13440)) Hz
1
! Detector on input board 1
MS/PAN
! Detector type board 1 (0=RAW, 1=MS/PAN, or 4=TEST)
1
! Number of data units to collect board 1
5
! Data units board 1 (0=frames, 1=seconds, 2=bytes)
0
! Percent column sampling level board 1 (pixel frequency?)
100
! Integer N (0-15), where board 1 integration time = (0.81 + 0.27*N) msec
10
! Ignore the next line
XX
! Illumination source (dark, monochrometer wavelength (nm), or Hg lamp)
400
! Filter 1 position (1-5)
1
! Filter 2 position (1, 2)
1
! Cal equipment X (1-n)
N/A
! Cal equipment Y (1-m)
N/A
! EGSE1 mode 3 command
0
! Integer N (0-15), board 0 PAN Integration time = (0.27 + 0.09*N) msec
10
! Integer N (0-15), board 1 PAN Integration time = (0.27 + 0.09*N) msec
10
END
```

of the other calibration equipment controlled by the ACCN. Each request file is assigned a unique look number that is included in the file name of the request file and also in every file name generated during that DCE. In this way, the request file itself serves as documentation of what was done during the DCE and allows the files of collected data to be associated via the unique look number.

The request file format is designed to be a flexible format that the ACCN can use to request different types of support from the EGSE and PAM. The basic format of the file is a fixed number of comment lines and data lines. The file begins with a line containing the word BEGIN and ends with a line containing END. These two lines bracket the comment and data lines.

Four leading comment lines are used to describe the contents of the request file, and they always follow the BEGIN line. After this, comment and data lines alternate, with each comment line describing the data line that follows. The number of leading comment lines and the order of the data lines are fixed and do not vary. All comment lines begin with an exclamation point (!). Data lines can contain numerical or string data; the letters N/A are used if the field is not applicable to this request. Table 1 shows the format of the request files.

In the format of the file name on the sixth line, the letters NNNNNNNNNN represent the ten-digit look number and are padded with leading zeroes. The letters MMDDYYYY represent the date of creation, using a four-digit year. The letters TTTTTTTT represent a title field that describes what type of activity is being done; it is included to make the file names more readable by an operator. The TTTTTTTT field is always eight characters long, and is padded with trailing underscores as needed. The total file name is always 32 characters long. An example file name would be

ALI_0000001234_08151997_SPECTRAL

Files generated as a result of this request file use the same name as the request file but different extensions to denote what type of file it is. When EGSE1 and ASIST complete their tasks, EGSE1 creates a file called Filename.egse1done. The contents of this file are the same as the original request file. When the PAM finishes its processing, it also creates a file called Filename.pam1done. The presence of these files in the directory on the shared disk signals the ACCN that the EGSE and PAM have completed the tasks specified in the latest request file, and that a new request file can now be sent.

Request File Processing on EGSE1

The request file can contain requests for ASIST ALI commanding, ASIST housekeeping file opening and closing, PAM processing mode selection, and EGSE1 science data collection. The request file can contain only one of these requests, or it can contain a combination. Typically, the ACCN is first used to configure the ALI, open a housekeeping file, and put the PAM into the desired mode. After that, a series of EGSE1 DCE requests are sent as part of a repetitive calibration sequence.

ACCN ASIST-Only Requests

The ACCN can request the ASIST to command the ALI without doing any EGSE1 data collection or doing any PAM processing. For example, the ACCN can ask the ASIST to power up the ALI or reset it prior to a calibration run. In this case, the ACCN generates a request file that specifies the *ASIST command script request* line and puts N/A in all other data fields in the request file.

ACCN PAM-Only Requests

The ACCN can request the PAM to switch to a certain data processing mode without doing any ALI commanding or doing any data collection. For example, the ACCN can ask the PAM to switch from spectral wavelength calibration processing to spectral focal-plane calibration processing, as defined. In this case, the ACCN generates a request file that specifies the PAM data processing mode line and puts N/A in all other data fields in the request file.

ACCN EGSE1-Only Requests

The ACCN can request EGSE1 to collect a specified amount of data without changing the PAM data processing mode or commanding the ALI. For example, the ALI can be put in a free-run mode in which data are continuously being output and a housekeeping file is open. Then the ALI can step calibration equipment through different settings and request EGSE1 to capture data at each setting. In this case, the ACCN generates a request file that specifies the lines related to EGSE1 data collection and puts N/A in all other data fields in the request file.

ASIST Commanding

The ASIST is commanded by EGSE1 twice per request file (see lines eight and twelve of the request file in Table 1), once before EGSE1 data acquisition and once after. Each line can contain multiple ASIST commands, separated with the letters XX as delimiters (thus an ASIST command cannot contain the character string "XX"). Line eight of the request file could look like this:

ASISTCOMMAND1 XX ASISTCOMMAND2 XX ASISTCOMMAND3

EGSE1 parses each command as necessary (e.g., for the Data_on command, some numerical parameters from the request file would have to be appended to

Table 2. Commands Not Sent Verbatim to ASIST

ACCN sends	*EGSE1 sends to ASIST*
OHSKP	archive on FILENAME I
CHSKP	archive off
p_fpe_config	p_fpe_config (37583, 16396, 16908)
data_start	data_start (37583, 16396, 16908)
WAIT X	[no command sent to ASIST, LabView on EGSE1 does a wait for X seconds]
IDLE	[no command sent to ASIST]
EARTH_OBS	EARTH_OBS

Table 3. Sequence of Request File Processing

1.	ACCN generates a request file and moves it to the shared disk on the PAM.
2.	EGSE1 monitors the /data1/eo1 directory and processes the request file when it arrives.
3.	EGSE1 updates a simple text display of the calibration setup state and what data and/or processing support has been requested.
4.	EGSE1 configures the data acquisition cards to ingest the requested data.
5.	EGSE1 sends a remote log-in stytems test and operations language (RSTOL) command to the ASIST (via a Unix *rsh* command) and commands ASIST to run a command sequence specified by two lines in the request file to output the requested data from the ALI and collect Standard Formatted Data Unit housekeeping data under the file name of the *.req file but with the .arc extension.
6.	The ALI outputs the data and the EGSE1 data acquisition cards ingest the data.
7.	EGSE1 moves the collected focal-plane array data file(s) to /data1/eo1/*.dat1 on the PAM.
8.	EGSE1 issues an RSTOL command to the ASIST to close the housekeeping file (ASIST may not need this command to know when to close the housekeeping file, so this step may be unnecessary).
9.	EGSE1 writes an *.egse1_done file to the /data1/eo1/ directory to let the PAM software know that the data files are complete.
10.	The ASIST closes the SFDU housekeeping file, names it appropriately (on the basis of the file name passed from EGSE1 via RSTOL), and copies it to the /data1/eo1 directory on the PAM.
11.	Once the PAM has found all the necessary files for this calibration step in the /data1/eo1 on the PAM, it writes a *.pam_done to the /data1/eo1 directory monitored by the ACCN. If the PAM is still processing the data from the previous calibration interval, it will finish that processing as well before issuing the *.pam_done file. This allows pipeline processing.
12.	The ACCN can now move to step 1 again.
13.	The PAM performs the appropriate processing on the collected data.

the command) and passes the command to the ASIST via the Unix *rsh* command and the ASIST *rstol* command. In fact, all ASIST commands that EGSE1 receives from the ACCN are passed on to the ASIST verbatim, except the commands listed in Table 2.

The housekeeping commands (OHSKP and CHSKP) are changed to ASIST format as seen above. The next two commands set up the focal-plane electronics for the multispectral sensor and the panchromatic sensor for default integration times (both 12 internal timing units) and frame rate (719 internal timing units). The three numbers after these commands encode these setting; other frame rates and integration times would require these three numbers to be changed. The WAIT and IDLE commands cause no ASIST commands. EARTH_OBS is passed verbatim to the ASIST, and it initiates a macro sequence stored onboard the ALI for conducting a complete earth observation data collection as would be done on orbit.

PAM Processing of Request File

Once EGSE1 finishes reading data from the ALI, it transfers these data to a shared disk on the PAM, then transfers the request file to the PAM. When the PAM receives the request file, it checks to see that the data file was properly transferred to its disk, then signals the ACCN to continue with the next DCE by creating another file on the shared disk. As the ACCN begins the next DCE, the PAM automatically reformats the raw data from the ALI, performs a preliminary data analysis, and displays one or more quick-look plots appropriate for the commanded mode. In this manner, the

PAM quick-look processing is done while the next set of science data is collected and transferred to disk.

Table 3 shows the generic sequence of request file processing, summarizing the previous sections. In all these cases, all files are deleted at the appropriate times in preparation for the next calibration interval.

On-Orbit Performance Assessment

During mission operations, portions of the ground data system were used to process data collected on-orbit to assess the performance of the ALI and verify or improve on the ground calibration. EGSE1 and EGSE4 were no longer needed. Data were received on digital linear tapes, which were read with the PAM. Housekeeping data were sent via ftp to the ASIST for playback and trending analysis. The science data were processed and analyzed for performance assessment purposes, as described elsewhere [1].

Summary

A ground data acquisition and processing system was developed to support integration and test, ground calibration, and performance assessment of the ALI sensor for the EO-1 mission. In order to meet a tight schedule and satisfy budget constraints, we developed an automated system that could be run by a single operator using the ACCN. The system was used successfully to complete the integration and test and ground calibration of the ALI, and portions of the system were used during mission operations to assess the performance of the ALI sensor.

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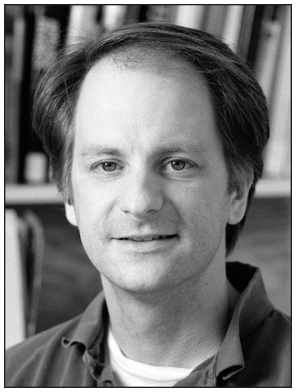

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