Evolution of the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Flight and Ground Data Processing System

Wallace M. Porter, Thomas G. Chrien, Earl G. Hansen, and Charles M. Sarture

Jet Propulsion Laboratory, California Institute of Technology
Pasadena, California 91109

ABSTRACT

The AVIRIS instrument underwent its first flight season in the summer of 1987. Since then, both the instrument and its data processing facility have evolved through a number of changes designed to correct performance and operating deficiencies observed during the first flight season. This paper describes the modifications made to both the instrument and the data processing facility, the reasons for these modifications, and the resulting improvements.

1. INTRODUCTION

During the last three years (1987–89) several problems were noted in the performance of the AVIRIS instrument and corrected. The observed performance deficiencies fell into two major categories. The first concerned instrument stability. The radiometric performance of the instrument showed variations of 0% to 40% between laboratory calibration and ground truth.

The other concern was the instrument noise performance. The Gaussian noise measured in the signal chains was between three and five times higher than predicted in the system model. Other noise problems included fixed-pattern noise in the images, offset drift that would cause occasional signal clipping, and random level shifts in the signal that were manifest as banding along the flight line.

The AVIRIS has produced large volumes of data in each of the last three years, requiring a dedicated ground data processing facility to process and archive this data. Over this time period the data facility has evolved, especially in regard to the software used. The increase in the amount of data to be processed and a need to improve the response time for data requests have necessitated changes in processing techniques and products. Additional changes were made to increase the capability for error detection and to allow for data product quality control procedures.

2. INSTRUMENT STABILITY

Analysis performed at the time that the instrument was built called for each of the spectrometers to be maintained within 5°C of a constant temperature to maintain their optical alignment.[1] This was initially accomplished by means of two strip heaters around each of the spectrometers. These heater pairs were each controlled by a thermostatic switch having a hysteresis of 3°C.

During the initial instrument calibration, it was noted that the thermal transients caused by the cycling of the thermostatic switches produced fluctuations of several percent in the outputs of the spectrometers, Furthermore, data taken during the first flight season, showed temperature-related variations in spectrometer output approaching 40%. To overcome these problems it was decided to fit each spectrometer with a proportional temperature controller and to distribute the heaters more uniformly over the spectrometer structure. Two separate controllers were used on each spectrometer: one on the structure supporting the optics, and the other on the outer shell of the dewar holding the detector. The structure is maintained at 27°C.

The two belt heaters have been replaced by 24 spot heaters positioned empirically over the spectrometer structure, including the grating and collimator mirror housings. Spectrometer thermal gradients under simulated flight conditions were measured to be on the order of a few tenths of a degree C.

An additional radiometric stability problem, discovered prior to the first flight season, had to do with the way the spectrometers were mounted to the instrument frame. The spectrometers, which have a flat base, were simply bolted to two parallel frame rails. Initially, this caused no trouble. But after several flights, differences in spectrometer performance of up to 50% were observed between operation in the instrument and operation on the test bench. This problem was demonstrated to be caused by warpage of the spectrometer structure by the frame rails, which were no longer parallel.

This problem was corrected by fitting the spectrometers with kinematic mounts. Spectrometers A, B, and C are each mounted on a three-point vibration isolation mount, while spectrometer D is mounted on a four-point mount, made necessary by packaging constraints.

A final stability problem had to do with a plastic isolation bushing which supported the dewar/detector assembly in each spectrometer. This bushing would slip under temperature cycling and vibration, allowing the dewar to move. This problem was solved by replacing the plastic bushing with an aluminum bushing.

The modifications described above have resulted in an overall radiometric stability of better than 10%, with stability of only a few percent during a single flight.

3. INSTRUMENT NOISE PERFORMANCE

During the 1987 flight season, signal-to-noise ratio was three to four times lower than it should have been. Laboratory measurements of the detectors and signal chains predicted a noise figure of 1 to 2 DN. Under flight conditions, however, noise was as high as 8 to 9 DN. In addition, random offset changes and noise stripes occurred in the images.

The offset and striping problems were solved by rebuilding the preamplifiers to remove potentiometer adjustments which were vibration sensitive.

Overall noise performance was improved by repackaging the timing circuitry driving the detectors (Fig. 1). Originally, this circuitry was packaged with the data buffers and instrument control circuitry sharing common power supplies. Phase jitter on the detector drive waveforms translated to noise at the output of the signal chains.

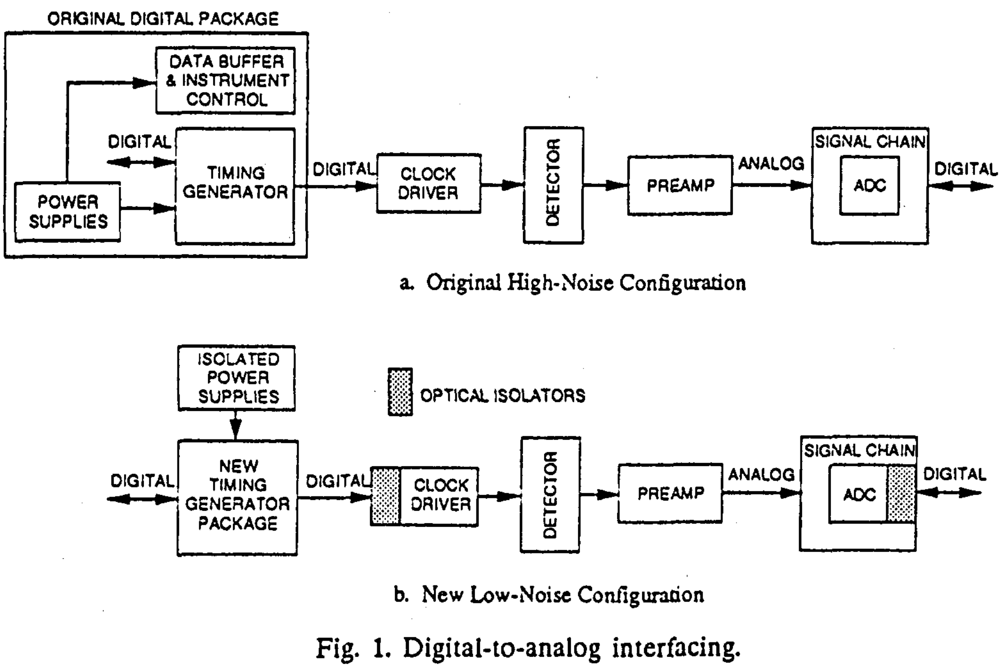

Fig. 1. Digital-to-analog interfacing.

Retirement of NASA's last U2 aircraft allowed AVIRIS (which was at its upper weight limit) to be modified to incorporate a separate package containing detector timing and isolated power supplies. The noise improvement resulting from this repackaging is shown in Fig. 2.

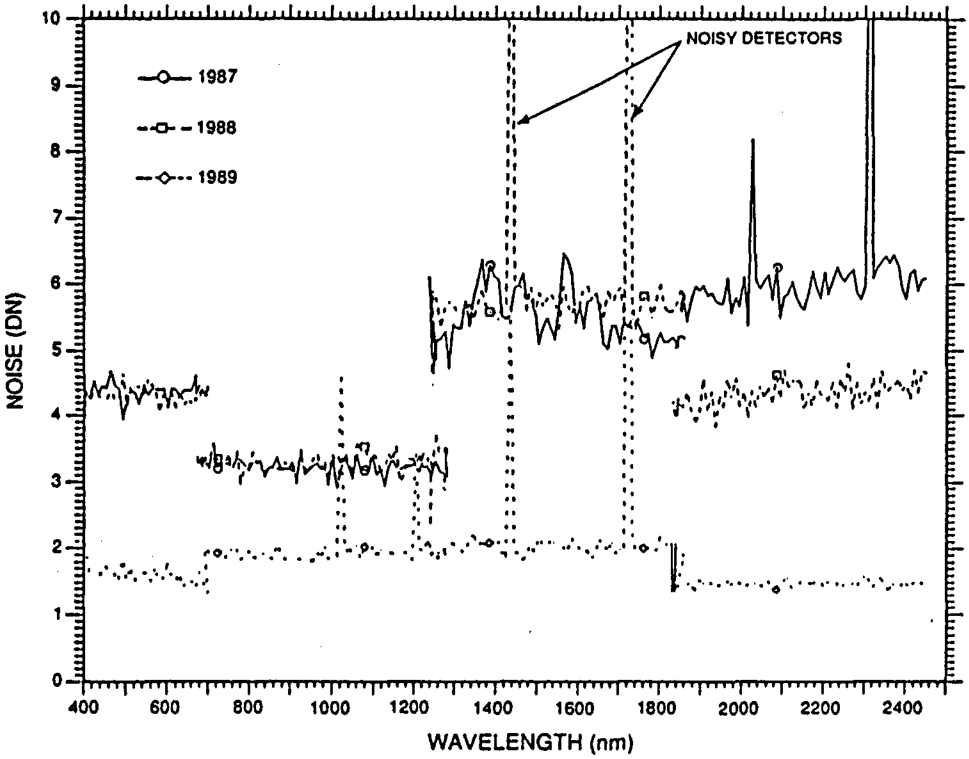

Fig. 2. Noise comparison between 1987, 1988, and 1989.

4. CURRENT INSTRUMENT PERFORMANCE IMPROVEMENTS

In preparation for the 1990 flight season, two performance improvements are under way. The first deals with water damage incurred during the last two flight seasons. Condensation occurring in a high-humidity environment has been damaging the instrument's mirror coatings and has destroyed the IR fibers.

To prevent further damage, the scanner will be sealed behind a window. Air entering the scanner will pass through a desiccant bed. The LN_2 fill system has been modified to vent outboard of the instrument, and fill sensors have been added to prevent overfilling. A dry-air purge system is being purchased to dry and warm the instrument in the aircraft upon return from a flight.

The second improvement is a modification to the onboard calibrator to provide calibration through the data fibers connecting the scanner and foreoptics to the spectrometers.

5. DATA FACILITY OBJECTIVES

The general objectives of the AVIRIS data facility are:

(1) To provide rapid and automated decommutation and archiving of data.

(2) To provide the ability to assess the quality of the data and the health of the instrument.

(3) To provide an automated procedure for applying radiometric corrections to the data.

(4) To provide responsive processing of data requests from investigators.

These objectives have applied throughout the 3-year lifetime of data production. The alterations to programs and procedures have been instituted to expand the ability of the data facility to accomplish these goals. Previously published details of these objectives[1] have been followed, and goals have been met. The experience gained over this time period, however, indicated that specific changes were needed to meet these objectives in the context of current conditions.

6. HISTORICAL DEVELOPMENT OF DATA SYSTEM

Although the general objectives of the data facility have not changed, many specifics have. The data processing flow is depicted in Fig. 3. Neither the systematic processing flow nor the data processing system has changed over the 3-year period (1987 to 1989), but several requirements have. The quantity of data to be processed has increased, the need for shorter turnaround times for processed data has been expressed, data quality control procedures have become necessary, and an increased role in instrument performance monitoring has developed. All of these factors precipitated changes in the data processing system currently operational and point to additional enhancements needed in the future.

Each of these changes to requirements was addressed by a change to the processing system. The increase in data to be processed was the result of more data being acquired. More and longer flights for more investigators increased the data load by more than 20% from 1987 to 1989, with expectations of further increases in subsequent years. A comparison between the 1987 and 1989 quantities is shown in Table 1. The problem that has occurred as a result of this expanded data load can be seen by noting that the processing times have increased for both archival and retrieval processing. Since the hardware system being used has not changed from the original VAX 11/780,[1] further delays in processing were expected. This became unacceptable, and several software changes were implemented in attempts to handle the processing load.

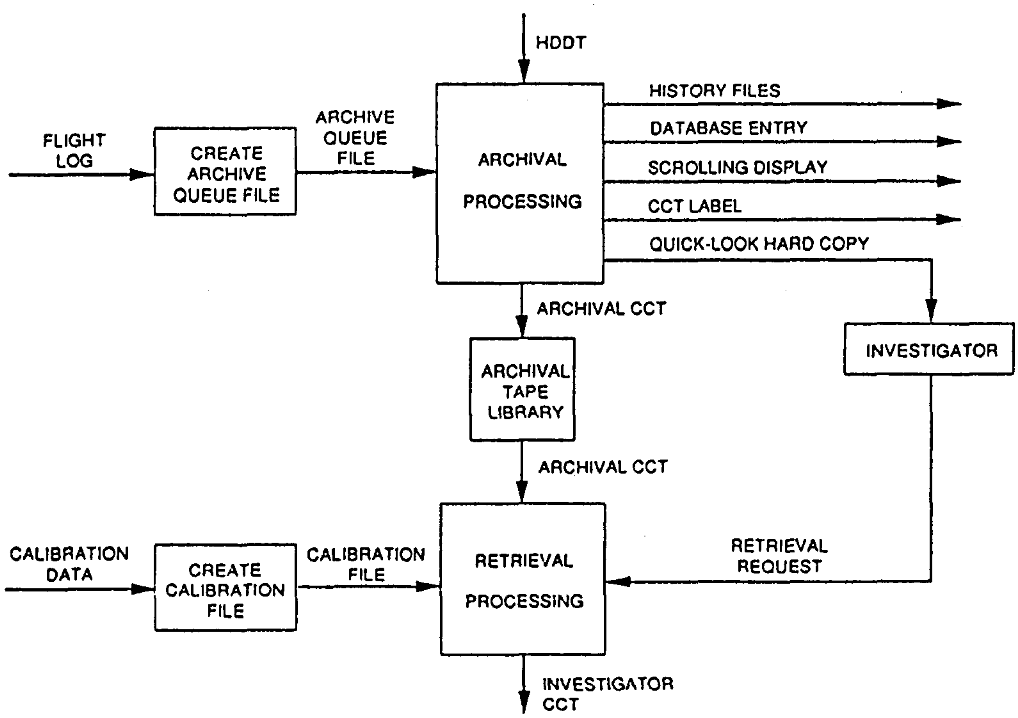

Fig. 3. Systematic processing flow diagram.

Table 1. AVIRIS data processing statistics

	1987	1989
Data quantity collected (high-density data tapes)	33	43
Data quantity archived (computer-created tapes)	795	958
Data quantity archived (gigabytes)	111	134
Data quantity retrieved (computer-created tapes)	339	400
Data quantity retrieved (gigabytes)	47	55
Number of investigators receiving data	58	70
Data processing times (average in weeks):		
From acquisition through archival	6	8
From receipt of request to distribution	3	8

Initially, the retrieval processing system was changed. Retrieval processing consists of several steps that transform archived raw data to the needed form to be sent to the investigator who has requested the data.[2] This function is process intensive in two ways: it handles large amounts of data in the form of the 140-megabyte image, and it does many floating-point operations on each of the more than 70 million pixels of the image. In the original design, both radiometric and geometric rectification were to be done on the image.[2] The geometric rectification process was never implemented. The intensive processing needed for this step was prohibitive, and the spatial image from the AVIRIS instrument was found to be acceptable in its raw form.

The radiometric rectification process consisted of two major parts. First the instrument data values were converted into radiance values, and then the spectrum was reconstructed by resampling the data in the spectral direction into bands of uniform spacing. The resampling step was very process intensive and irreversibly altered the data. It was felt that such a data-altering procedure was not within the proper scope of systematic processing, and so this step was discontinued. This decreased the overall processing time, but it needed to be decreased further.

The computing-intensive step of radiometric correction was changed next. Each retrieval of a single 512-line scene was taking 7 hours of processing time. The radiometric correction step was executing 1.4 billion floating-point operations per scene. Since the VAX hardware used has a small floating-point operation capability, changing this step would make a significant impact on the time required to process each scene. Through algorithm changes and intensive code optimization, the number of floating-point operations needed was decreased to 350 million per scene, and the overall run time was decreased to 3 hours per scene. This processing enhancement allowed for a 50% increase in retrieval request throughput for the upcoming 1990 flight season.

Once changes to the retrieval system were completed, the archival system problems were addressed. Decommutating and archiving the raw data is the first step in the data processing flow. All the data acquired by the instrument must go through this process to become usable by the investigator. Thus, although archiving each scene takes only 60 minutes, the aggregate time needed for all the flight data is large. Also, the requirement for this amount of time per scene resulted in backlogs of acquired data waiting to be archived and extended the turnaround time to the investigator. To alleviate this problem, changes were made to the archiving software. Each scene processed is 140 megabytes in size and was read several times in order to decommutate and reformat the data. This process was altered to reduce by half the number of times the data is read and to discontinue some of the reformatting steps. This decreased the run time by one-third, resulting in a projected 30% increase in archival processing throughput.

Both of the software changes described above were implemented to increase throughput and alleviate serious delays in data request response times. Additional steps will need to be taken for further improvements, including hardware upgrades, as the quantity of data handled continues to increase.

Throughput problems were not the only issues to be addressed in the evolution of the data facility system. Another major area was data product quality control. A procedure was implemented to monitor the quality and correctness of the data being sent out in response to investigator requests. Previously, a randomly conducted manual process was used to determine the quality of the output product of the retrieval system. At randomly selected times the image from the retrieval program was viewed on an image display to see if it appeared reasonable. This was an inadequate quality control method.

A new procedure was implemented which checks every output image in two ways. The retrieval software was expanded to record a one-band 100-line test image and to store a selected spectrum across all bands of the image. The test image is photographically recorded as an audit of the retrieved data and to assure a reasonable spatial image. A hard-copy plot of the spectrum is produced and checked for conformity to expected results. This procedure gives both a means of checking system performance and an audit trail of all products produced for future reference and problem resolution.

An increased role in data quality monitoring at the input stage has also developed. After the instrument records the image and ancillary data on the high-density output tape, the data facility provides the only means of viewing this information. Monitoring both the health of the instrument and the quality of the data recorded must be done at this phase of the process. As the acquisition flights became more frequent and critical, a means to determine the health of the instrument was needed. It was determined that a minimal review of the acquired data was necessary within 24 hours of a flight. Because processing times were so extended, as described above, a limited reviewing system was put in place to respond in the required time. This system processes a small amount of data from selected portions of the high-density data tape to assure that the instrument is imaging from all spectrometers and that specified threshold limits for signal strength and noise are met. By use of this system, instrument failures can be detected and long-term instrument performance trends can be monitored.

In addition to this review process, further error detection means were added to the archival system software. Prior to these changes, data recording errors were minimally processed. Each type of error was detected and flagged as a group, and no detailed information was provided. This was an inadequate means of error tracking and feedback to the engineering team. To rectify this problem, software enhancements were implemented to record each error separately and to present a detailed view of what the erroneous data contains. With this information the possible points of error production can be ascertained, and the engineering team has adequate feedback for use in instrument diagnostic procedures. This additional information has already provided the means to recognize an instrument failure and assist the engineering team in its resolution.

All the changes described have been put in place in preparation for the 1990 flight season. Their implementation should increase the throughput and error detection capabilities of the AVIRIS data processing system. Further changes are envisioned to respond to the continuing increases in data acquired and investigators supported. The retrieval system will be changed to improve the input/output methods. With the large amounts of data handled for each scene processed (more than 140 megabytes), enhancements to this part of the retrieval process should gain another substantial reduction in processing time. In addition to this change, the entire retrieval system is being prototyped for movement onto new hardware, a SUN server system. With this type of system, it is expected that run times for retrieval processing can be reduced to less than one hour per scene. The archival system is also being prototyped onto a SUN system, with the high-density tape processing hardware interfaced to the SUN input/output bus structure. An increase in high-density tape reading speed is expected, which would both decrease processing time for the archival process and improve the data quality through reduction of errors. The movement of the archival processing to this type of hardware system is hoped for in the near future.

The system changes described above have improved the means by which the AVIRIS data is processed and delivered to the science community. Both the responsiveness to data requests and the quality of data provided have been enhanced. The projected future changes should extend these improvements, allowing them to be maintained for larger processing requirements.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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