New Calibration Techniques for the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)

Thomas G. Chrien, Robert O. Green, Chris Chovit, Mike Eastwood, Jessica Faust, Pavel Hajek, Howell Johnson, H. Ian Novack, and Charles Sarture

Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive, Pasadena, California USA 91109

Recent laboratory calibrations of the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) include new methods for the characterization of the geometric, spectral, temporal and radiometric properties of the sensor. New techniques are desired in order to: (1) increase measurement accuracy and precision, (2) minimize measurement time and expense (3) prototype new field and inflight calibration systems, (4) resolve measurement ambiguities and (5) add new measurement dimensions. One of the common features of these new methods is the use of the full data collection and processing power of the AVIRIS instrument and data facility. This allows the collection of large amounts of calibration data in a short period of time and is well suited to modular data analysis routines.

INTRODUCTION

AVIRIS is an airborne sensor which measures high spatial resolution image data of the earth in 224 spectral channels in four spectrometers (A, B, C, and D) covering the range from 380 to 2500 nm. These data are spatially, spectrally and radiometrically calibrated (Vane, 1987, Chrien 1990, Chrien 1993b). Modifications to AVIRIS have resulted in substantial improvements in signal-to-noise ratio, calibration accuracy and operability of the sensor (Chrien, 1991, Chrien 1993a). Validation experiments are conducted to verify instrument performance and calibration in flight (Green, 1993a).

Recent improvements in both the signal-to-noise ratio of the AVIRIS instrument and the unmixing algorithms applied to AVIRIS data have prompted a re-evaluation of its calibration requirements. Of primary interest are improvements to the current instrument radiometric accuracy of 5% absolute and spectral accuracy of 1 to 2 nanometers. This paper describes new calibration techniques tried during a recent laboratory calibration. Preliminary results from these measurements will be shown.

CALIBRATION DIMENSIONS

The process by which instrument response is converted to units of spectral radiance is generally called calibration. The precision and accuracy of this calibration must be sufficient to avoid calibration errors that show up as systematic noise in subsequent data analysis. The frequency of the calibration is determined by the instrument stability such that residual response drift is also sufficiently small.

Each spectral-spatial channel responds to the input spectral radiance with some digitized number (DN) output. The DN responds to both signal and non-signal sources such as thermal background and dark current. A shuttered detector sample is used to subtract this non-signal component. The remaining relationship between DN and signal photons is the radiometric response function. If the response is linear, and dark subtraction is done properly, the radiometric calibration is reduced to a single gain coefficient for each detector channel. If linearity does not apply, then more coefficients are required.

The number of received signal photons, Φ, is also determined by the temporal, spectral and spatial characteristics of the sensor as shown by the following equation:

$$\Phi := \int L \cdot A \cdot \Omega \cdot \Delta\lambda \cdot t \cdot \frac{\lambda}{hc} \quad dL\, dA\, d\Omega\, d\lambda\, dt$$

where L is the spectral radiance field presented to the sensor, A is the aperture response function, Ω is the geometric response function, $\Delta\lambda$ is the spectral response function, t is the temporal response function, and λ/hc converts energy into the number of photons of wavelength λ.

A complete calibration must measure each of the above response functions for each spectral-spatial channel and show the relative relationship between adjacent response functions. In the extreme case, each image cube element has a unique set of response functions to describe its calibration. Fortunately, parameters can be used to approximate the response functions and their interrelations. The goal is to measure the pertinent calibration coefficients, to an adequate accuracy, in a time and cost effective manner.

Radiometric Calibration

The standard method of AVIRIS radiometric calibration is based upon the radiance standard constructed out of a calibrated reflectance panel and an irradiance standard lamp (Chrien, 1990). A Spectroradiometer is used to transfer this radiance to a large integrating sphere which has uniform output over the 30 degree field-of-view of the AVIRIS scan mirror. The error associated with the intermediate calibration and radiometric stability of the integrating sphere is estimated to be 1.1%.

Direct observation of the radiance target has been proposed as a method for eliminating this error source. An early attempt at this revealed a significant increase in stray light from the irradiance lamp. An investigation of scattered light sources has led to a radiance target design which uses baffles and an off-axis look angle.

An additional requirement for the direct radiance standard was that it be field portable. The desire was to have the capability to place a ground based radiometric calibration on the AVIRIS instrument while it is on deployment away from JPL.

As an additional experiment, data was collected at a number of lamp current levels. Past experience shows that the lamp irradiance spectrum closely matches that of a blackbody. The assumption is that other current levels will also correspond to blackbody temperatures. The spectral ratio between any two of these level will be a good test of band-to-band radiometry, spectral calibration accuracy, and linearity of the radiometric system response.

The irradiance accuracy of the calibrated lamp source is the dominant uncertainty term in the short-wave infrared. In order to improve the absolute accuracy in this spectral range, a cavity blackbody source was used. Data was collected at cavity temperatures between 100°C and 1000°C in roughly 100°C intervals. Ratios of these cavity temperatures will also be investigated.

Spectral Calibration

The standard method for spectral calibration consists of using a scanning Monochromator which is calibrated using spectral emission lamps. A new method bypasses the Monochromator and uses the emission lamps directly. The lamps were placed at the collimator focus and data was collected with the scanning mirror disabled. The following lamps were used: krypton, argon, helium, neon, deuterium, xenon, hydrogen, carbonic acid, carbon dioxide, mercury vapor, iodine, bromine, water vapor and nitrogen. A related method uses rare earth oxides (Holmium Oxide, Erbium Oxide, and Dysprosium Oxide) embedded in a sintered halon base in a reflectance configuration.

Several different approaches to using a scanning Monochromator with an embedded spectral sync pulse have been investigated. The general approach is to mix in a known spectral source such as an emission lamp or laser line. As the Monochromator scans, the current wavelength position is also encoded into the sensor data by way of the spectral sync pulse.

A Michaelson interferometer was also used as a wavelength input source. The interferometer is scanned through the zero path length to a path length that is unresolved in the spectral domain. The resultant inteferogram is collected during the scan. The Fourier transform of the inteferogram is used to determine the spectral response function of the individual spectral channels.

Geometric Calibration

The standard method for geometric calibration is to scan a narrow slit at a fixed rate across the focal plane of a collimator. This measures the relative shape of the geometric response function as well as the sampling interval between spatial pixels. A new variant of this technique use a double slit. Careful measurement of the slit spacing, collimator focal length, and instrument timing information is used to place an accurate angle calibration on the geometric response function data. A similar set of experiments was performed with an extra wide slit, which presented two edge response functions at a known spacing.

The field of view of a scanner is simply the number of cross track pixels times the sampling interval between adjacent pixels. The scanning slit technique works well for measuring the sampling interval, but only for a few nadir pixels. In order to test that the sampling interval was constant over the full scan field-of-view, a new technique was developed. The technique uses a HeNe laser passed through a Ronchi ruling transmittance grating. Carefully aligned, this configuration produces a large number of pulses spaced across the full scanned field-of-view. Standard diffraction theory is used to compute the angular spacing of each of the diffracted orders.

In a related test, a full-aperture Ronchi ruling was placed between the instrument aperture and a collimator projected a white light illuminated slit. We expect to find an interesting combination of spatial and spectral calibration data from the resultant data set.

Temporal Calibration

In order to investigate the temporal spacing between spectral channels, data were collected of a strobe light source at a range of strobe frequencies. The phase delay between adjacent channels within a spectrometer and across spectrometers boundaries provides insight to these relationships.

CONCLUSIONS

The new techniques discussed here are all relatively easy to implement. Data collection is done in the natural imaging mode of the instrument under test. Results from the new techniques presented here are still pending data analysis. The accuracy that results from the new techniques as well as the ease of processing this data will be used to decide the value of the new approaches.

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