An Improved Data Structure for AVIRIS-Type Imaging Spectrometer Measurements

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1. Introduction

Imaging spectrometers, such as the Airborne Visible/Infrared Imaging spectrometer (AVIRIS), measure spectra in the region from 400 to 2500 nm at nominally 10-nm sampling. This gives approximately 200 continuous spectral channels of data for every spatial element measured. These spectroscopic measurements are used to determine the composition and infer processes of the Earth system through spectroscopy analysis. Spectroscopic analysis is based on the physics, chemistry, and biology revealed through the interaction of energy with matter recorded in each measured spectrum.

AVIRIS measures spectra sequentially of the radiance incident at the aperture of the instrument. These measurements are stored as a 224-dimensional spectral vector ***Ll***. This vector holds the radiance (***L)*** for each of the 224 wavelengths (***l***) measured. Traditionally these spectra are arranged as a bidimensional array of spectra Lx,y, ***l***. Figure 1 shows a portrayal of this traditional storage architecture for the AVIRIS image of Moffett Field, California.

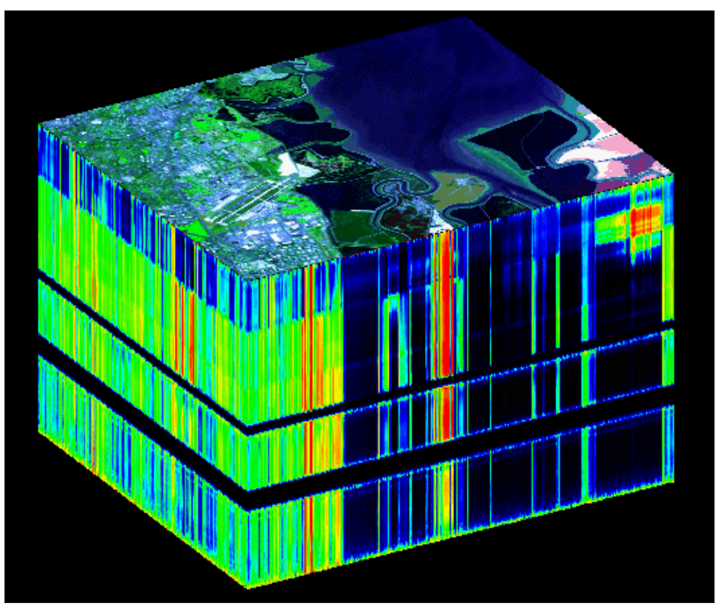

Figure 1: Traditional image cube where every spatial element x,y of the scene has a vector, Lx,yl, that is the radiance for the l spectral channel and the x,y spatial element.

However, this traditional format of data structure has not been designed optimally for AVIRIS-type imaging spectrometer images where each spectrum is measured sequentially with some variation in pointing from aircraft motion. Rather the data structure heritage is from image framing cameras where all the image pixels are obtained simultaneously. For example, from a metric camera carefully modeled and with thousands of spatial points and few spectral bands. This traditional data structure format imposes an unnecessary burden on point sequential data instruments such as AVIRIS.

2. AVIRIS-Type Imaging Spectrometer Measurement

AVIRIS uses a cross-track scanners to measured spectra across the field-of-view and aircraft motion to build up the along track image. Each spectrum is measured sequentially across the scan. This imposes a cylindrical coordinate system to the spatial location of each measured spectrum. To acquire data with nominally uniform cross-track to cross-track scan, the AVIRIS scan mirror rotates backwards quickly before beginning the next forward scan of image collection. No ground image data is collected during the back scan. Based solely on the scanner, AVIRIS collects data in a cylindrical coordinate system across a 33 degree field-of-view. Figure 2 gives a depiction of the cross-track scan approach used by whiskbroom instruments such as AVIRIS.

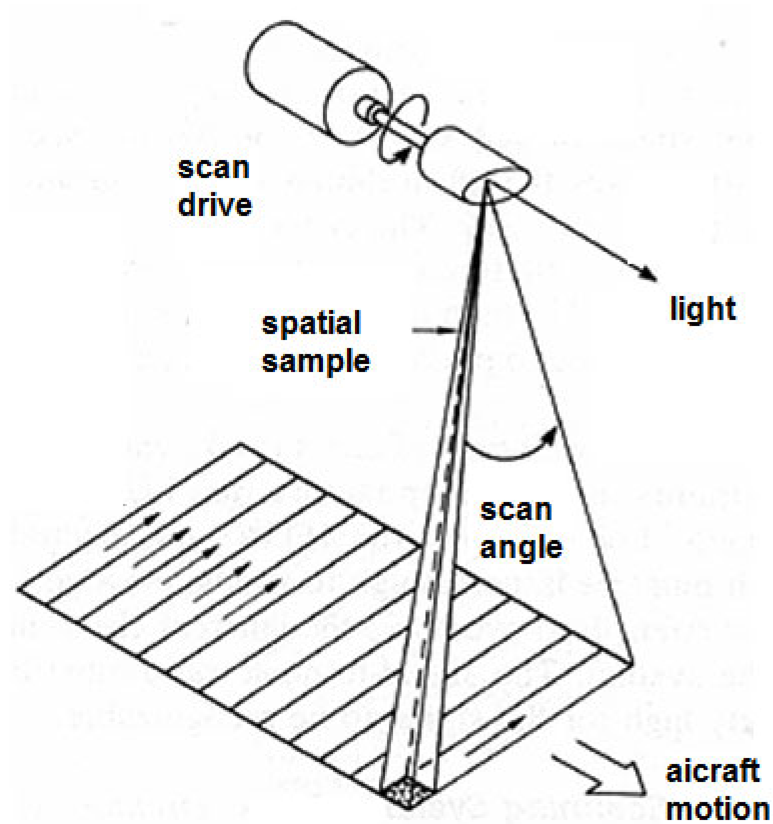

Figure 2. Nominal spatial sample acquisition for a whiskbroom scanner instrument. For AVIRIS each spatial sample records a 224-channel spectrum.

The simple cylindrical coordinate system provide by the scan mirror and scan drive is complicated when combined with the effects of aircraft motion a turbulent atmosphere. The aircraft platform for AVIRIS and any airborne instrument impart translations in the x,y,z directions and angular motions in the roll, pitch and yaw sense. Figure 3 shows the translation and rotational effects imposed upon AVIRIS from the aircraft motion.

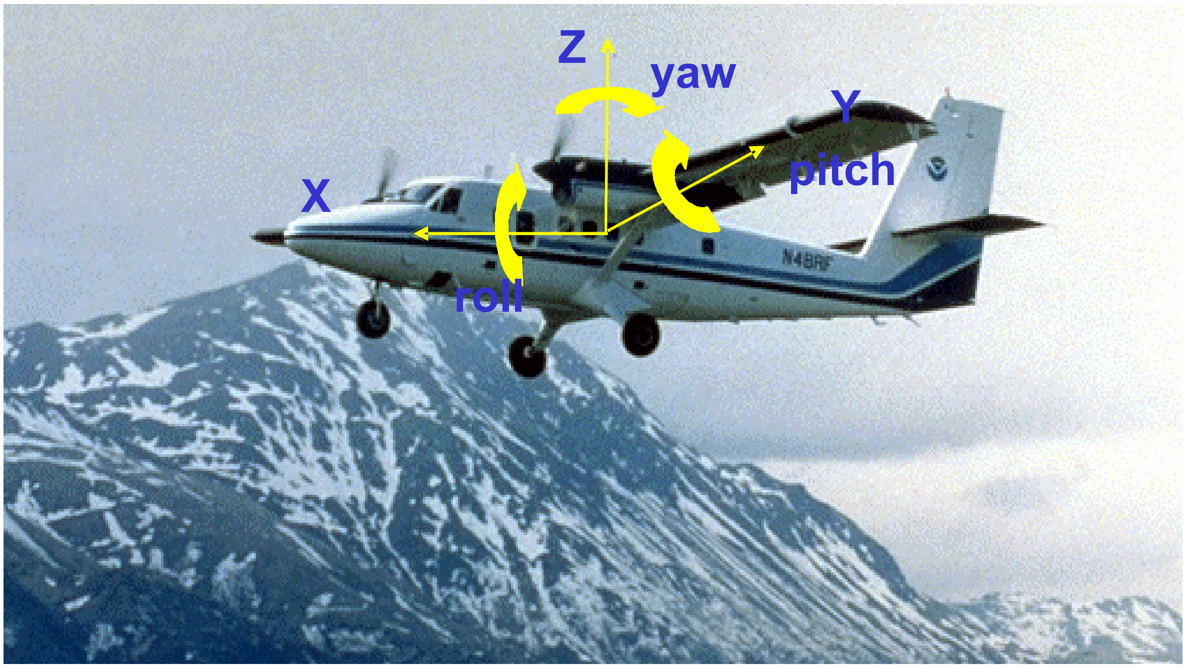

Figure 3. Image of AVIRIS in the Twin Otter aircraft platform with representation of translation and angular motion imparted to the AVIRIS measured spectral data.

The combination of the whiskbroom scan mirror approach in conjunction with an aircraft acquisition platform assures that the AVIRIS measurements are not acquired as a simple three dimensional array of x,y,l arrays. For this reason the AVIRIS instrument includes a GPS/INS (Global Positioning System/Inertial Navigation System) to record both the instrument position and pointing throughout the period of data acquisition. These position and pointing measurement allow the AVIRIS measurements to be forced into an approximation of the traditional simple three-dimensional array data storage and display structure. The measurements also allow contemplation of a new more efficient data storage structure for AVIRIS-type imaging spectrometer measurements.

3. Traditional AVIRIS Georectification and Data Distribution Format Approach

Using the knowledge of the cylindrical motion of the AVIRIS scan mirror and the knowledge of AVIRIS position and pointing from the GPS/INS, the measured location of each AVIRIS spectrum may be predicted. The projected spatial size of each area sampled (Ground-Instantaneous-Field-of-View, GIFOV) may also be calculated based on the distance between AVIRIS and the surface for each spatial sample. The GIFOV varies as a function of panoramic scan angle, terrain elevation, and aircraft motion. Figure 4 show the panoramic scan angle type growth of the GIFOV as larger scan angles. This effect is not large for AVIRIS with a scan angle of ±16.5 degrees. For AVIRIS a 4-m sample dimension at nadir is 4.17 m at the maximum scan angle.

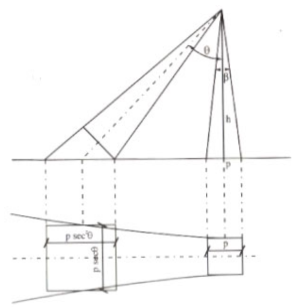

Figure 4. Panoramic growth for spatial GIFOV as a function of increasing scan angle.

Because of these motion and angular effects AVIRIS data must be geo-rectified to place them in a regular coordinate system that allows knowledge of the location of each spectrum measured. Figure 5 shows and AVIRIS image for a small town near Rogers Dry Lake, California before and after geo-rectification.

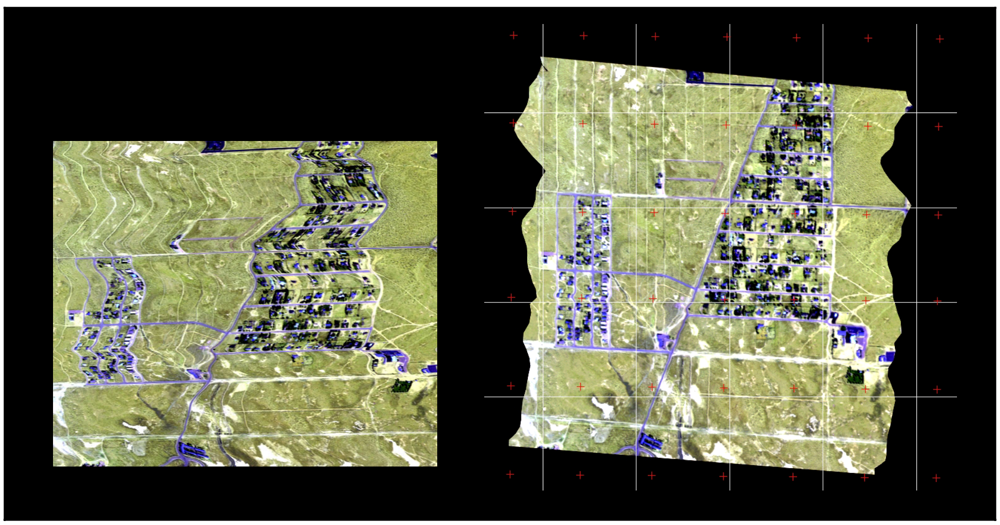

Figure 5. AVIRIS data before and after geo-rectification.

AVIRIS geo-rectification is accomplished by using the AVIRIS scan mirror knowledge in conjunction with the GPS/INS knowledge to predict the location and size or each GIFOV on the surface. In this process the UTM location of each measured spectrum is calculated and stored in the Input Geometry (IGM) file.

To generate a geo-rectified AVIRIS image a nearest neighbor sampling algorithm is used to place the nearest measured AVIRIS spectrum into the UTM coordinate system of geo-rectified product. In this process a Geometric Lookup Table (GLT) file is created. This file shows the source spectrum for each location in the geo-rectified image in terms of the line and sample location from the original measured data. If the spectrum in the geo-rectified product is directly measured the sign of the data in the GLT file is positive. If the spectrum is a nearest neighbor, then the sign is negative.

Currently AVIRIS geo-rectified data are delivered with each spectrum placed in the geo-rectified image based upon the GLT file. This has the important advantage of providing a data set that is easily compatible with the wide range of current imaging analysis systems. This choice was made to keep the barriers to analysis or imaging spectroscopy as low as possible for the widest number of people.

There are several notable disadvantages to this choice for distribution of AVIRIS data. In the process of nearest neighbor infilling of the geo-rectified product some spectra are replicated and some spectra are not reported. Replicated spectra occur when AVIRIS has undersampled the surface due to rapid aircraft motion. Failure to report some spectra occurs when AVIRIS has measured the same location on the surface two or more times due to turbulent motion of the aircraft. In addition, in the process of creation the georectified produce in the traditional Lx,y,l preservation of the edges of the measurements in the geo-rectified product requires insertion of many zero value spectra. The net result of the current geo-rectification process is inflation of the size of the data set. This can be a severe effect in cases where the AVIRIS aircraft motion was excessively fast and turbulent.

In addition, accurate comparison of unmixing results obtained from different spectral images is a difficult task by the inaccuracies in the position of the centers and foot-print sizes of each pair of pixels. .

In order to assure the geocorrected data are real you must test the GLT file for each pixel and in some turbulent flights several points can be selected for the same geographical position. (Fig Boardman JPLWS 2004).

These consequence of the choice to deliver AVIRIS geo-rectified data in the traditional Lx,y,l format cause us to consider alternate approaches to the representation of AVIRIS data in distribution and analysis.

4. A New Approach to AVIRIS Data Representation

In considering a new approach, we asked these questions:

1. Can the spectral measurements format and the image format impose the structure of the AVIRIS hyperspectral data?

2. Can the visualization task impose the hyperspectral data structure?

3. Can a hyperspectral image be considered like a regular sampled scene?

4. Why not use a data structure related to the sensor acquisition task?

5. Why use spatial discrete coordinates when the real scene coordinates are continuous?

6. Why use images in the preliminary computing phases if you need to lose spatial information?

5. Our Proposed Solution: Sparse Matrix

In order to preserve this acquisition scheme we propose a “data measurement register (DMR)” as the data structure. For each sensor measurement we use a register with the following fields:

1. Latitude

2. Longitude

3. Altitude

4. Roll

5. Pitch

6. Yaw or Heading

7. Time

8. Spectrum Lx,y compressed in an appropriate lossless manner.

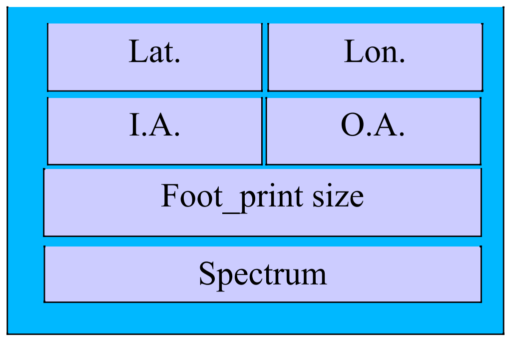

Figure 6. Data measurement register.

Using this data measurement register you may store an image as a file of DMR. The main disadvantage of this kind of structure is the loss of the location principle for the spatial image information (neighbor pixels on the image can be stored separately in the file and memory).

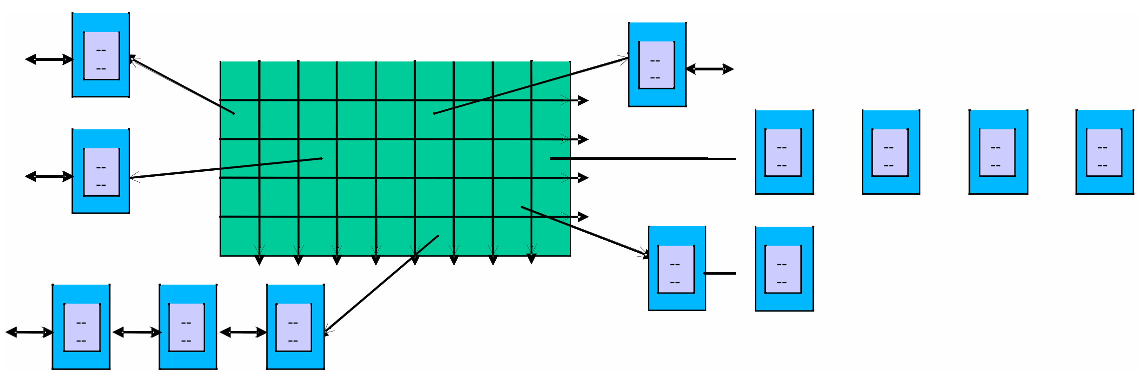

Figure 7. Sparse matrix illustration.

In order to avoid these problems we propose a new data structure for AVIRIS spectral images that we term a Sparse Matrix. In a Sparse Matrix DMR data are linked to a regular spatial grid. The size of this grid can be obtained from the spatial information itself (using the real spatial sampling information) or from the size of the map you need as the final result of your remote sensing task. In each cell of the matrix there is a pointer to a dynamic set of vector of the structure. Some of then could be null.

6. Sparse Matrix Advantages

1. A Sparse Matrix does not miss any sensor acquired information (no re-sampling is applied).
2. The data processing subject is the sensor measurement.
3. The continuous ground coordinates (Latitude – Longitude) are preserved.
4. Data (for unmixing, classification, etc.) are independent from the visualization task.
5. Only in the last steps of the data management interpolation or resampling is applied.

7. Conclusions

A new more rigorous treatment of the spatial sampling of AVIRIS image data is an important next step in imaging spectroscopy analysis as the GIFOV and sub-GIFOV scale.

Future multi-angular and unmixing research and applications will likely require comparison of two or more imaging spectrometer data sets on a spatial element by spatial element basis.

New, more appropriate data structures will enable this new advanced research.

Sparse Matrix facilitates comparison between image pixels in a quantitative way, by using accurate comparison techniques as producer and consumer accuracy (Congalton).

Sparse Matrix facilitates comparison between different sensor data, including ground truth data obtained by field spectrometers.

Sparse Matrix can help the breakup of the AVIRIS processing program into a series of simple object-oriented program modules.

Sparse Matrix will improve the parallel computation of hyperspectral datasets.

New algorithms will be designed for this kind of data.

8. Bibliography

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