Ortho-rectification of pre-1998 AVIRIS spectroscopy data

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Abstract:

Airborne imaging spectroscopy data is progressing from concentrating on investigations of spectral properties to the transfer of the technology for operational applications. In order to effectively validate classification results, geocoding techniques need to be refined to handle localized geometric artifacts and provide for terrain correction of the data. If the data are to be merged with other types of geodata to perform geospatial analysis, the locational problems need to be minimized. However, the geometric distortions inherent in airborne sensors cannot be easily corrected using traditional ground control point-based polynomial transformations. This paper discusses a method that georectifies and terrain corrects pre-1998 AVIRIS airborne spectroscopy data. Terrain correction of the data was necessary to obtain precise areal extents and placement of suspected polluting minerals in the extreme relief of the San Juan Mountains in southwest Colorado (Dalton et al., 1998). Results from the corrected data will help characterize the relative extent of natural and anthropogenic sources of acid water runoff and their effect on water quality in the Animas River watershed for the United States Geological Survey's Abandoned Mine Lands Project.

Introduction

In the past, research concentrated on the spectral characteristics of the AVIRIS (Advanced Visible/Infrared Imaging Spectrometer) hyperspectral airborne sensor. Over the past decade, sensor calibrations and signal-to-noise ratio have progressively improved enabling the investigation of a wider range of applications, including geologic investigations, environmental modeling, vegetation analysis, wetlands assessment, wildlife studies, hazard evaluation, hydrology, and agriculture (Root and Wickland, 2000). These applications require accurate geospatial referencing especially in areas of extreme relief. While developments starting with the 1998 flight season are beginning to deal with the need for spatial accuracy (Boardman, 1998, Clark et al., 1998), large amounts of AVIRIS data are in uses that were collected before 1998.

The United States Geological Survey's (USGS) Abandoned Mine Lands (AML) Project used AVIRIS data obtained on June 18, 1996, to help characterize the relative extent of natural and man-induced sources of acid water runoff and their effect on water quality in the Animas River watershed in southwestern Colorado. Elevations in this area range from mountain valleys at 8,800

feet to mountain peaks over 14,000 feet. To effectively use AVIRIS data, the imagery must be ortho-rectified: it must be georeferenced and the distortion caused by the topography must be corrected. A method to ortho-rectify pre-1998 AVIRIS data using commercially available software will be discussed in this paper.

Background

The Animas River headwaters in south-western Colorado are within the San Juan and Silverton volcanic calderas, which are the sources for much of the mineralization that attracted a proliferation of gold and silver mines in the late 1800s. Mining continued until 1991 when the Sunnyside Mine just upstream from Silverton finally closed. The AML project is concerned with evaluating the remediation needs of the area, including thousands of abandoned prospects and mines on both federal and private properties. Results from these analyses will help the managers of the lands affected by abandoned mines and mine-related sites, to make more informed decisions on the remediation of these lands.

Ortho-rectification of AVIRIS data to remove the relief displacement is needed for accurate mapping of areal extent and location of minerals found in these rugged mountains (Dalton et al., 2000). Project scientists used the mineral and vegetation information to help determine the relative extent of natural and man-induced sources of acid water runoff and their effect on water quality (Figure 1).

The position of airborne scanning systems like the AVIRIS instrument is not as stable as that of similar sensors on satellites. While the scanner has a relatively geo-metrically correct scan line, the attitude of the instrument constantly changes with the pitch, yaw, roll, and velocity. The engineering and navigational data recorded on the aircraft are distributed with the AVIRIS data to correct most of the aircraft-

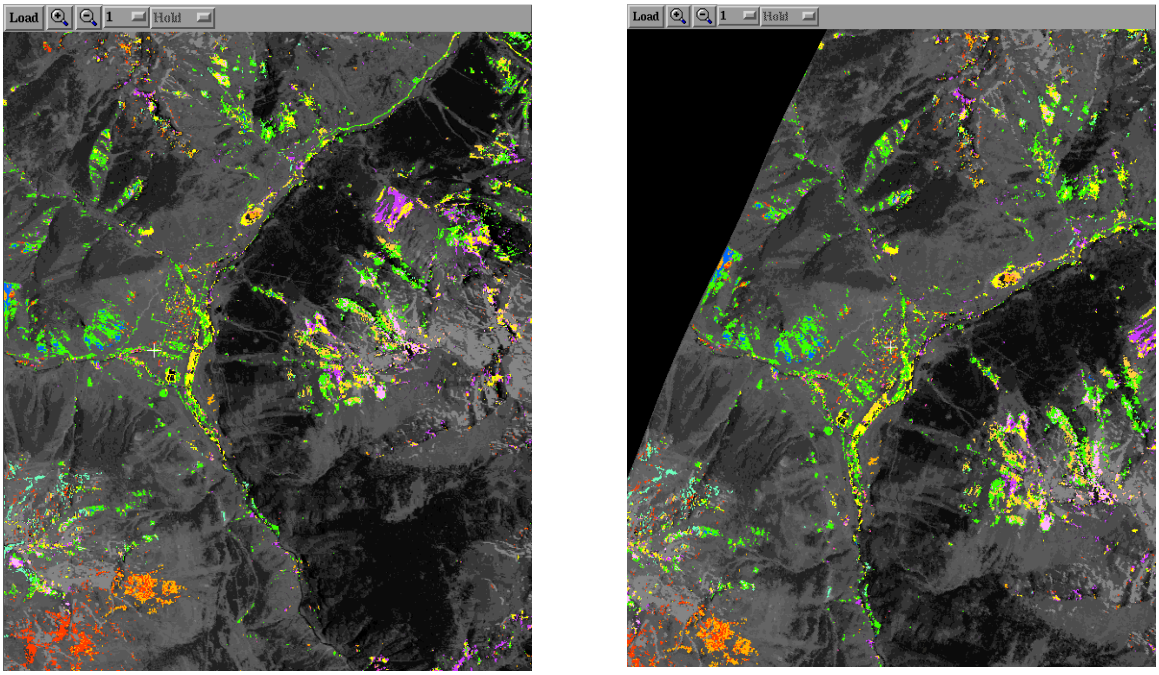

Figure 1. AVIRIS flight line AnRun3 Group 1 Minerals, centered on Silverton, CO before (left) and after (right) correction.

induced distortions. Generally, the data are corrected for the x and y axes and assumes a flat plane using a mean elevation value for the entire flight line. This correction has been adequate for researchers whose main concerns were in the evaluation of the spectral information. As more and more of this type of imagery is used to map different phenomena for natural resource management, high spatial accuracy becomes as important as the spectral information.

Great strides were made to solve the spatial accuracy problem with the start of the 1998 flight season. The addition of a low-altitude platform with GPS/INS (Global Positioning Satellite/Inertia Navigation System) information provided not only higher spatial resolution but also the real-time delivery of position and attitude data. Starting in 1999, both the high- and low-altitude platforms have GPS/INS data, which makes it possible to use photogrammetric camera models for accurate georectification. However, the problem has not been completely solved; geometric anomalies from the 1999 flight season were still found in both the low- and high-altitude data that could not be eliminated via traditional photogrammetric registration techniques, raising concerns with land managers about the usefulness of the AVIRIS data for applied mapping purposes (Tuell, et al., 2000; Schlapfer et al., 1998). As in the past, continued use and feedback from scientists will produce data with not only high spectral resolution but with high spatial accuracy as well. However, the abundant AVIRIS data collected prior to 1999 still have non-systematic characteristics that cannot be eliminated with traditional ground control point-based polynomial transformations (Wiemker et al.).

Procedure/methodology

Traditional orthorectification processes cannot be used for airborne scanner data because the image information is not instantaneous as it is in aerial photography. Each pixel of each scanline has a unique geometric model. The traditional photogrammetric processes rely on information about camera lens distortions and accurate ground control points (GCP) in x, y, and z locations to orthorectify aerial photography. Radial basis functions, such as multiquadric and thin plate spline, have produced the best results for ortho-rectification of airborne scanner data (Wiemker et al.; Ehlers, 1994; Ehlers and Fogel, 1994). Two principal characteristics distinguish the multiquadric and thin plate spline from the polynomial approach: 1) the functions interpolate (the control points match exactly between images) and 2) their behavior is mathematically constrained between control points (Ehlers and Fogel, 1994; Bookstein, 1989).

Thin plate spline functions interpolate the values at all GCPs and a new GCP can be added (or deleted) where the transformation is not satisfactory. Unlike polynomial transformations that require a small amount of points depending on the order of the polynomial, the thin-plate spline may require hundreds of points in rough terrain. There should be a point at every extreme of the terrain, peak or valley and along break lines. For this project, there were two flight lines to be corrected. Flight line AnRun2 was 636 pixels by 3034 lines and used 234 GCPs. Flight line AnRun3 was 636 pixels by 3928 lines and used 371 GCPs (Figure 2). While this process requires a large number of control points, there is a fine line between having too many points and not enough. Too many points in a location can actually distort the correction in that area.

The AVIRIS data to be orthorectified were not raw scanner data; scientists at the USGS Spectroscopy Lab in Lakewood, CO (Clark et al., 1999) first applied a systematic geometric preprocessing to the data. These corrections minimize distortions caused by sensor optics so that an image pixel anywhere within the image represents the same size patch of ground as any other pixel in the image. The data were then interpreted for the various acid-generating and acid-buffering minerals. Orthocorrection was applied to the final interpretation of data layers.

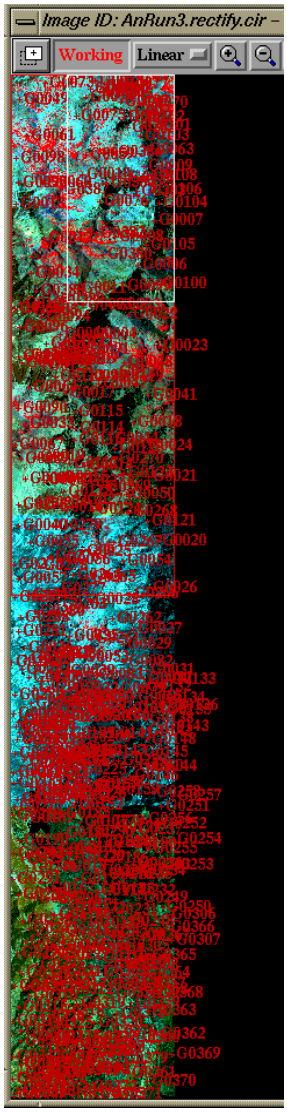

Figure 2. AVIRIS flight line AnRun3 with GCP's overlaid on the image.

A two-step process was used to correct the 12-meter resolution AVIRIS data using the PCI OrthoEngine, v. 7.0, software package (PCI Geomatics, 2000). The project area covers nine 1:24,000-scale quadrangle maps. USGS 1-meter digital orthophoto quadrangles (DOQs) were used for reference points. These DOQs form the foundation for the revision of the hydrography and transportation vector layers and subsequent USGS Abandoned Mine Lands project fieldwork. Terrain elevations were obtained from USGS 10-meter digital elevation models (DEMs). The first step defined the GCPs using a second-order polynomial transformation. This was done to evaluate the selection of the points. Root mean square (RMS) errors were normally kept in the three- to four-meter range with no RMS errors accepted over ten meters. During the second step, each GCP was tagged with an elevation from the DEM. Once the points were tagged with elevations, the image correction using the thin-plate spline transformation was performed. This two-step process was similar to the methods used by Ehlers (1994), in which he used a global second-degree polynomial followed by a registration based on multiquadric interpolation using a radial basis function.

The registration was checked by selecting points throughout the AVIRIS image and comparing them to points in the DOQ image. Comparisons of the AVIRIS image

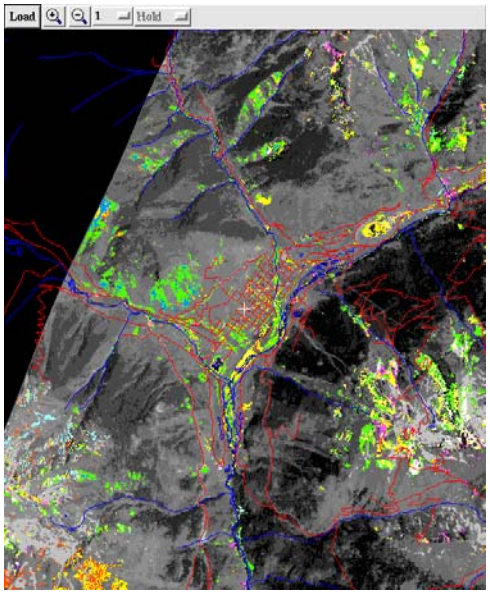

Figure 3. Corrected AVIRIS flight line AnRun3 Group 1 Minerals with transportation (red) and hydrography (blue) vector lines overlain.

were also checked against revised hydrography and transportation vectors (Figure 3). These comparisons were within an accuracy level of one or two pixels.

Results

Hyperspectral characteristics of AVIRIS have contributed to the understanding and mapping of a variety of problems facing land and resource managers. In order to effectively validate classification results, geocoding techniques applied to AVIRIS data need to be refined to handle localized geometric artifacts and provide for terrain correction. This underscores the importance of developing consistent and accurate geo-positioning in AVIRIS missions if the data are to be effectively used for mapping applications and merged with other types of geodata in a land manager's GIS databases. Since the1998 flight season, great strides have been made to solve the spatial accuracy problem with the inclusion of INS/GPS information, which makes it possible more accurately georectify the scanner data. Starting in 1999, both the high- and low-altitude platform collections include the INS/GPS data. Nevertheless, archives of almost fifteen years of AVIRIS data do not have the accompanying GPS data for accurate georectification. Using commercially available software, 1m DOQs for referencing GCPs and 10m DEMs, an AVIRIS data set was orthorectified over an area of rough terrain. This paper demonstrates one solution to achieving accurate spatial mapping of airborne scanner data.

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