THE ADVANTAGES OF BORESIGHT EFFECTS IN THE HYPERSPECTRAL DATA ANALYSIS

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ABSTRACT:

The Dual push-broom line-based hyperspectral sensors combine two different instruments that are usually mount on the same optical bench. This configuration leads to problems such as co-registration of pixels and squint of the field of view known as boresight effect. Image orientation parameters and sensor boresight of any sensor during data acquisition became possible by a combination of an inertial measurement system (IMU) and GPS. The different position of the IMU, the GPS antenna and the imaging sensors, causes an orientation and boresight effect. Any small change in the correction of internal orientation affects the co-registration between VNIR and SWIR region of hyperspectral images. Correcting the boresight effect is an almost automatically key mission taken by all Dual system users. This is because the boresight effect is considered as a noise in the system and a problem that needs to be corrected prior to any data analysis. We propose to use the boresight effect as a vehicle to monitor and detect some spectral phenomena in the image that can't be obtained in corrected images. The advantage of the sensors orientation and boresight effect was investigated based on the AISA-Dual sensor that combines EAGLE for the VIS-NIR (400-970nm) and HAWK for the SWIR (980-2450nm). An experience of more than six years with this sensor, we have found that the boresight effect have some positive outcomes on the analysis results of the hyperspectral remote sensing (HRS) data. This led us to generate an HRS processing protocol where this effect is examined for gaining the most from the data. Three applications were investigated as follow: 1) enhancing shadowing effect, 2) generating a 3-D view, and 3) performing a better detection of boarder anomaly. We will demonstrate these three options and suggest a possible use of this idea from orbit.

1. INTRODUCTION

Hyperspectral imaging spectrometers produce data with high spectral resolution (in the range of 5 to 15 nm) and continues band configuration, giving processors the ability to detect subtle spectra features and defined chemical and physical properties of the sensed objects. This powerful capability is important for remote sensing applications e.g. geologic typing and surveying, agricultural monitoring and optimization, environmental damage assessment, forestry surveys, detection of man-made materials, etc.

The determination of image orientation parameters of any sensor during data acquisition became possible by combined use of an inertial measurement unit (IMU) and GPS. In this integrated system, GPS antenna, IMU and imaging sensor are located different position in airborne carrier. Because of this reason, the displacement vectors between sensors have to be determined. Similarly, axes of the IMU and imaging sensor are not same and a miss-orientation matrix exists between them. System calibration is including both calibration of individual sensor and calibration between sensors. The IMU calibration for drifts and biases and the calibration of imaging sensor for interior orientation parameter are components of sensor calibration. Calibration between sensors contains the determination of a constant displacement vector between sensors and a constant miss-orientation matrix between IMU body frame and imaging sensor frame. The boresight misalignment, the relation between the IMU and the imaging sensor is determined by bundle block adjustment using a calibration flight. The small change of correction of interior orientation affects co-registration between sensors and thus hyperspectral images of VNIR and SWIR region. The processing step that can be applied to the data is georectification that collects generated (VNIR and SWIR) imagery and navigation data and automatically geo-locate and rectify pixel-by-pixel the image data.

AISA-Dual is an airborne imaging spectrometer designed by Specim LTD, as a research sensor that capable of producing medial to high fidelity hyperspectral remote sensing (HRS) data in the 400 to 2400 nm wavelength range. The system consists of a sensor head, containing a pair of co-boresighted grating spectrometers (VIS-NIR sensor EAGLE and SWIR sensor HAWK), two electronics racks, and a digital data recorder. It simultaneously acquires images in 198 contiguous spectral bands with spectral resolution in the range of 12nm in VNIR region, and 6nm in SWIR region. Each spectrometer consists of a set of refractive foreoptics that image the scene onto a slit. Light passing through the slit is dispersed perpendicular to the slit by a flat rating and then imaged onto a 2-D focal plane array. One dimension of the array along the slit provides spatial scene information. The second dimension of the array, along which the light from any given point in the slit has been dispersed, provides spectral information. An image is generated by moving the instrument across a scene in a push-broom fashion, perpendicularly to the instrument’s slits, and recording frames of spectral and spatial information detected by the VNIR and SWIR. The system is usually operated on aircraft at altitude of 10,000 ft that together with instant field of view (IFOV) of 1 mrad provides a spatial resolution of 1.5 m. A standard AISA-Dual data set is a 3-D data cube in non-earth coordinate system. It has 286 pixels in the cross-track and hundreds of pixels in the along-track direction. The top-level performance requirements were for an instrument with fair signal to noise ratio (SNR), co-registered spectral bands taken simultaneously by different detectors, accurate location for each pixel, and accurate radiometric calibration.

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Since AISA-Dual instrument operated in Israel, has no GPS/INS system available, it is incapable to perform the pixel-by-pixel geo-location and rectification of the images, generated in an extensive HRS dataset. In this study, the advantage of the sensors orientation and boresight effects were investigated based on AISA-Dual HRS data. Our study shows that those "negative" effects are suitable to spectral/spatial analysis and processing of HRS images. Thus, we are suggesting three efficient and practical applications: 1) enhancing shadowing effect, 2) generating a 3-D view, and 3) performing a better detection of boarder anomaly.

2. METHODOLOGY

Apart from the image sensors, an airborne mobile-mapping system has to equip for direct geo-referencing involves one or several GPS receivers and antennas as well as an IMU. In the most ideal case, all sensors are attached to a common rigid mounting structure, preventing variations of their relative positions and orientations. In practice, AISA-Dual system is operated with no GPS/INS data available. Consequently, it is impossible to geo-locate or rectify the VNIR and SWIR images. The spatial/spectral boresight effect of AISA-Dual sensor is illustrated in Figure 1.

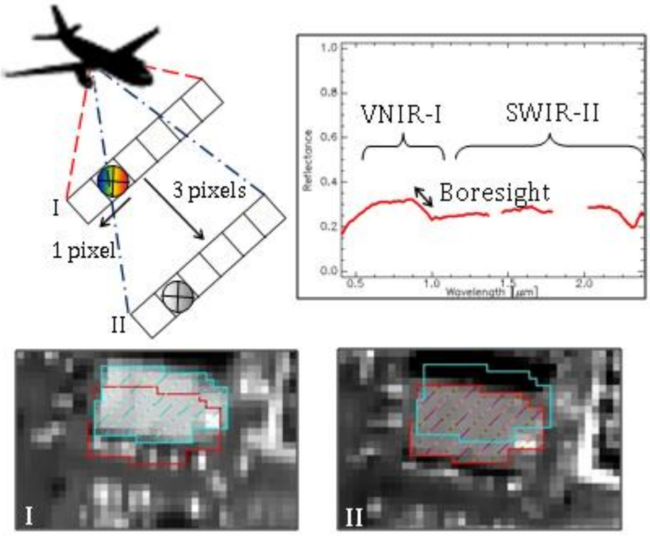


Figure 1. Boresight effect schematic demonstration, image I and II illustrating boresight then I is the target in VNIR wavelengths and II is the target in SWIR region, and the spectrum of the target then region I is concrete (target in VNIR) and II is asphalt (background in SWIR)

We suggest to converting the boresight shift into additional spectral/spatial information by calculating a simple band ratio between VNIR and SWIR images. The boresight "band ratio" presented in Figure 2.

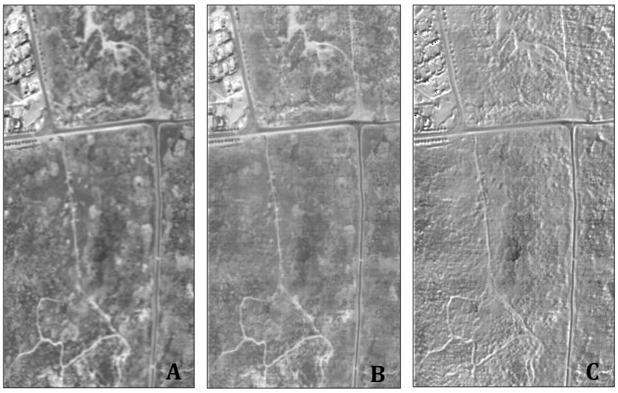


Figure 2. Additional Boresight "band" (October 31, 2009; 10:00 GMT; midlatitude summer model; 28.2 º solar zenith, 137.6 º azimuth angle), A is the 948nm band, B is the 1010nm band, C is the calculated band ratio (948nm/1010nm) interpreted as Boresight band

3. RESULTS

We have found that the boresight effect have applicable outcomes on the spectral/spatial analysis and processing that is based on an extensive dataset of AISA-Dual images, acquired during more than six years of operated campaigns. Three applications were investigated as follow: 1) enhancing shadowing effect, 2) generating a 3-D view, and 3) performing a better detection of boarder anomaly.

3.1 **Enhancing shadowing effect**

Current implementations of the de-shadowing process within the ATCOR-4 model uses image's statistics to gain knowledge about the darken area in order to correct the shadow effect. This routine is not suitable for data sets acquired on clouds shadow as the inter-comparison process is missing in the diffuse light conditions. This de-shadowing algorithm consists of a sequence of eight processing steps: an atmospheric correction, clouds and water bodies masking, five additional statistic manipulations including covariance matrixes and matched filters to define a core shadow mask, and final step is a de-shadowing that exclusively applied to the pixels in the shadow mask (Schläpfer et al., 2009).

The method suggested here is mapping shadow areas in HRS images of AISA-Dual sensor. An interpretation of boresight band is identifying core shadow areas with highly negative values and evaluating 'darkening' for each pixel in the classification shadow map. This technique provides an external shadow map for de-shadowing algorithm of ATCOR-4, allows it to skip six steps of shadow mask identification. The proposed a fully automatic method was successfully tested on six scenes covering different landscapes. The advantage of the presented method is that it does not need a human operator, and it is fast processing algorithm exclusively relying on the boresight ratio calculated band.

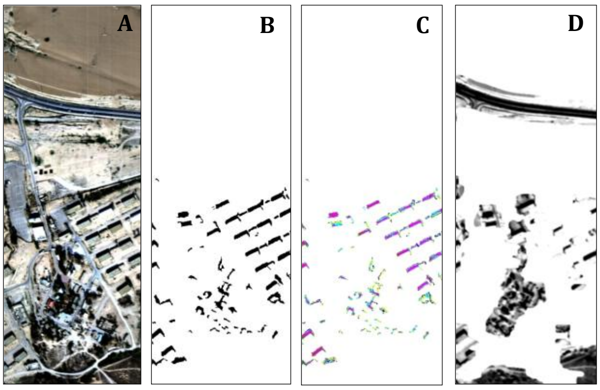
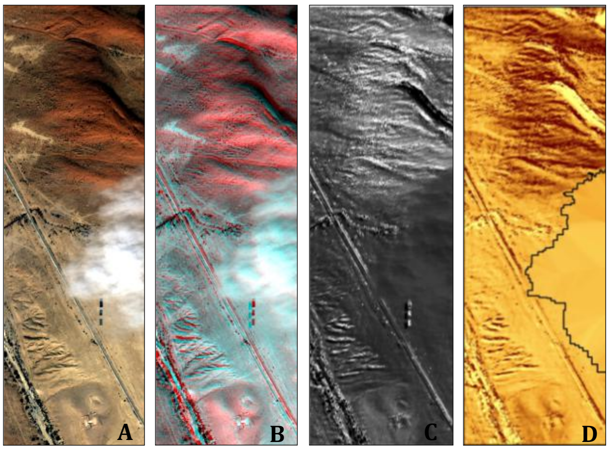


Figure 3. Shadow masks of – A is an AISA-Dual image (December 18, 2009; 11:30 GMT; 15km visibility; midlatitude winter model; 60 º solar zenith; 205.8 º azimuth angle), B is a boresight shadow mask, C is a boresight shadow estimation (yellow 0.1-20%, cyan 20-50%, magenta 50-80% and maroon 80-100%), D is an ATCOR-4 shadow mask

3.2 **Stereo 3-D map**

The simultaneous across-track stereo-data acquisition gives a strong advantage in terms of radiometric variations. Since an error of ±3 pixel along-track and ±1 pixels across-track for the parallax measurements in the automated matching process has been achieved with these different datasets (along-track and across-track), the potential accuracy for the across-track stereo-derived local DEM from AISA-Dual could be on the order of 3 m (1.5x1.5 pixels) . The main objectives of this application are to generate and evaluate pixel based local DEMs from the boresight VNIR and SWIR images. The 3-D stereo intersection is performed using a computed geometric model to convert the pixel coordinates in both images determined in the image matching of the stereo pair to 3-D data. The non earth coordinates are determined for the measured point with a least square intersection process based on the geometric model equations and parameters (Toutin, 1995). The result is an irregular grid in the map projection system, which is transformed to a raw regular DEM.



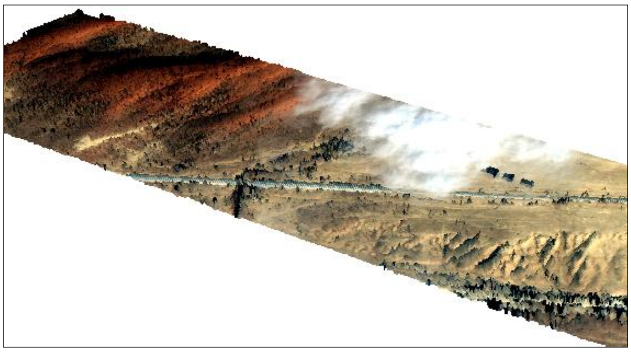


Figure 4. DEM, A is the AISA-Dual image (October 122, 2006; 08:55 GMT; midlalitude summer model; 46.4 º solar zenith; 164.6 º azimuth angle), B is the 3-D stereo model, C is the boresight calculated band, D is the raw DEM (cloud masked-black border) modeled with Inverse Distance Weighting (IDW) algorithm (0m 30m), E is the AISA-Dual in 3-D view (x axis 1500m, y axis 500m, z axis 30m)

3.3 **Unmixing and anomaly detection**

Most of the pixels collected by HRS airborne sensors contain mixed spectra from the reflected surface radiation of various materials in the sub-pixels. As a result, mixed pixels may exist when the spatial resolution of the sensor is not sufficient to separate different pure signature classes. The resulting spectral measurement is a composite of the individual pure spectra weighted by a set of scalar endmember-abundance fractions (Adams et al., 1986). Under such circumstances, target detection must be carried out at sub-pixel level. An anomaly detector enables to detect targets whose signatures are spectrally distinct from their surroundings with no a priori knowledge. In general, such anomalous targets are relatively small compared to the image background and only occur in the image with low probabilities. Two approaches are of particular interest. One was developed by Reed and Yu (Reed and Yu, 1990; Yu et al., 1993; Yu et al., 1997) and is referred to as the RX detector (RXD). The RX detects spatial/spectral anomalies using the sample covariance matrix to detect "interesting target" pixels which occur with low probabilities in the data (i.e., the size of target samples is small) compared to Gaussian distribution of the background. Second is a SVDD, (support vector approach) that is a non-parametric method with several benefits, including non-Gaussian modeling basis that can model arbitrarily shaped and multi-model distributions, scarcity and high generalization ability (Banerjee et al., 2006).
We suggest using boresight calculated band as spectral/spatial anomaly detector. Since an anomaly defined as a small target with distinct spectrum, an accurate pixel-by-pixel classification of boresight values may accentuate the targets in question.

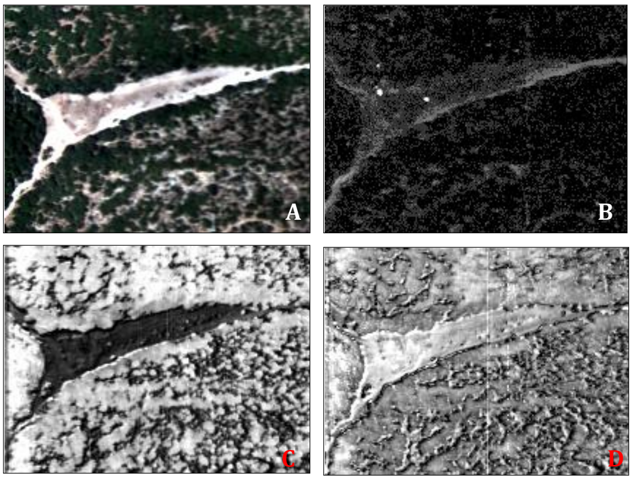


Figure 5. Anomaly detection on a bare soil field, A is the AISA-Dual image (October 31, 2009; 10:10 GMT;; midlatitude summer model; 30.2 º solar zenith, 141.2 º azimuth angle), B is the RXD product, C is the SVDD product, D is the boresight band detection

4. SUMMARY AND CONCLUSIONS

Correcting the boresight effect is an almost automatically key mission taken by all Dual system users. The consideration of boresight effect as a noise in the system leads to the assumption that it needs to be corrected prior to data analysis. This work showed that boresight effect may operate as a vehicle to monitor and detect some spectral phenomena in the image. Three applications were investigated and demonstrated as follow: 1) enhancing shadowing effect, 2) generating a 3-D view, and 3) performing a better detection of boarder anomaly. First application provides an external shadow map for any de-shadowing algorithm, allows it to skips prior steps of shadow areas masking that occasionally misidentifying these areas with highly contrast dark targets. The second application deals with an extraction of 3-D information. The automated matching process has been achieved with different datasets (along-track and across-track) and potential accuracy for the across-track stereo-derived local DEM. The final application detects spectral/spatial anomaly of boresight calculated band. In this study, the advantage of the sensors orientation and boresight effects were used to generate "hidden" information within the data that other techniques could not yield.

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