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The Impact of Position and Attitude Offset Calibration on the Geocoding Accuracy of Hyperspectral Line Scanner ImSpector V9

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Abstract

Hyperspectral images are defined as being recorded simultaneously in many, narrow, contiguous bands to provide information on the major features of the spectral reflectance of a given object. The images can be visualized as a 3-dimensional data set with two spatial and one spectral dimension and the data set is therefore often referred to as an image cube. Originally, raw hyperspectral data are combined together in an image cube with spatial, temporal and spectral dimension, after the imaging characteristic of the hyperspectral sensor (mostly push-broom scanner), and they have to be transformed to geocoded hyperspectral cube for all further spatial analysis of hyperspectral data. There are several methods to transform raw hyperspectral data (raw cube) into geocoded one. Because of imaging geometry of the hyperspectral sensor (the push-broom scanner), only the parametric geocoding methods can be applied directly. The ability of presented algorithm will be shown on test data gathered by airborne multisensor platform. The spatial accuracy of the geocoded cube will be verified on test-field.

1. Introduction

In the scientific project supported by the European Commission “Airborne minefield area reduction (ARC)”, IST–2000-25300, that lasted from year 2001. to 2003., were obtained several digital sensors and the acquisition systems and was developed the acquisition software RECORDER, [1]. Among them was purchased and later used in this project a hyperspectral line scanner V9 (ImSpector), with an insolation collecting unit (Fodis) as shown in figure 2., for the wavelengths from 430 nm to 900 nm.

The scanner was used for the acquisition of the reflectivity samples of the mine suspected areas in several different types of terrain, whereas the quality of data was limited by several factors and also was used for oil spills detection, both times as a part of the system for the Multisensor airborne reconnaissance and surveillance in the crisis and the protection of the environment. This was the reason to advance the characteristics of the airborne hyperspectral remote sensing, by use of V9, in the frame of the technological project TP-06/0007-01, in accordance with the foreseen applications [1].

There are foreseen following kinds of applications: a) measuring the *radiance* at discrete samples (static or in a direction of flight), b) measuring the *reflectance* at the discrete samples (static or in a direction of flight), c) *imaging the radiance* of the area in a form of the strip in the flight direction, d) *imaging the reflectance* of the area in a form of the strip in the flight direction. The basic measuring properties of V9 are determined by its construction. A narrow slit (8mm x 0.050 mm) at the front end of the optical system enables spectral resolution in nearly 45 channels in the wavelengths range from 430 nm to 900 nm. When the scanner is directed at nadir to the ground, the area mapped below the scanner is a narrow strip that has dimensions 0.333H x 0.00208H, where H is relative height of flight, [2]. The digital camera used for this purpose was PCO PixelFly 12bit CCD camera system with 1280x1024 pixels, pixel size 6.7 µm x 6.7 µm and scan area 8.6 x 6.9 mm, [6]. The spatial acuraccy of the imaging depend on the movements of the aerial platform, accuracy of the positioning and orientation system. While during the previous use (2001–2003) were available only GPS data, in a novel solution a positioning and orientation system is applied, combined with the parametric geocoding system program (PARGE). The advanced features of the airborne hyperspectral remote system enable wider kinds of the applications, [1].

2. Parametric geocoding

2.1. Input data for parametric geocoding

Navigation data: Position (longitude, latitude and height) and attitude (roll, pitch and true heading) stored for each line of the scanner image.

Digital elevation model: The DEM has to be given in the same coordinate system as the aircraft data.

Image/sensor general information: FOV (field of view) and IFOV (instantaneous field of view), scanning frequency, starting time, missing lines, and dimensions of the image, [3].

2.2. Geometric algorithm

The parametric processor starts with an estimate of the ‘thepretic view vector’ ($\vec{L}$) which is the imaginary line of sight to the current pixel, oriented from a horizontal aircraft facing direction north, [3]. This vector has to be set up in three dimensions to get the 'effective view vector' ($\vec{L}_t$):

$$\vec{L}_t = R \cdot P \cdot H \cdot \vec{L} \qquad (1)$$

where R, P and H are coordinate transformation matrices for the roll, pitch and true heading. The equation above describes, how the sensor is virtually turned from the north looking flight to the actual position. The vector $\vec{L}_t$ is then intersected with the DEM starting at the aircraft postion $\vec{P}_a$ to obtain the georeferenced pixel position, [3]:

$$\overrightarrow{P_{pix}} = \vec{P}_a + \vec{L}_t \frac{\Delta h}{h(\overrightarrow{L_t})} \qquad (2)$$

where Δh is the height difference between the aircraft position and the DEM intersection point. $h(\vec{L}_t)$ is the height dimension of the effective view vector, [3].

2.3. Processing algorithm

- Calculate the current observation geometry; the vector ($\vec{L}$) has its origin at the entrance pupil of camera lens and at its end reaches the Digital Elevation Model (DEM)
- Find the intersection point on the surface;
- Map the image coordinates; the pixel coordinates of the image (pixel and line number) are written to an array in DEM geometry at the intersection point position.
- Gap fills; triangulation and nearest neighbor techniques are used to create a spatially continuous image

According to Schläpfer, Schaepman and Itten [3] the final processing step performs the production of geocoded images. It is separated from the main processing algorithm. This step is applied band by band which makes the processing of a band sequential raw data cube very fast.

Fig. 1. ImSpector V9 with an insolation collecting unit (FODIS), [5]

3. A ground control point based offset recalibration

A ground control point (GCP) based offsets estimation tool was developed for PARGE application, [3]. The inversion of the geocoding algorithm allows the calculation of the aircraft position for each GCP. The transformed view vector is subtracted from the GCP position and stretched by the relative height:

$$\vec{P}'_a = \overrightarrow{P_{GCP}} - \vec{L}_t \frac{h_a - h_{GCP}}{h(\vec{L}_t)}, \qquad (3)$$

where $\vec{P}'_a$ i $\overrightarrow{P_{GCP}}$ are the position vectors of the aircraft and the GCP, with the absolute heights h_a and h_{GCP}, [3].

The differences between estimated positions $\vec{P}'_a$ and the real navigation data are analyzed statistically to obtain the offsets. The offsets can be calculated for roll, pitch, heading, x-y navigation, height and/or field of view (FOV). The angular and distance offsets for a number of GCPs are evaluated statistically to obtain the corresponding offset estimates as follows, [3]:

- Roll: average of the angular offsets in scan direction,
- Pitch: average of the angular offsets in flight direction,
- X-Offset: average of the distance offsets in longitudinal direction,
- Y-Offset: average of the distance offsets in latitudinal direction,
- Heading: minimum correlation of the angular offsets in flight direction (pitch) to the pixel distances from nadir,
- Height: minimum correlation of the angular offsets in scanning direction (roll) to the pixel
- distances from nadir.

For heading offset estimation, the correlation between pitch offset and nadir distance is minimized by iteratively adjusting the true heading average. An analogous procedure is used for the height with the roll as indicator. Since each offset potentially depends on the others, iterations may be done between them; e.g. the heading offset may be iterated together with the pitch offset over sloped terrain, [3].

3.1. Test Field

The test field on Pula airport was used for GCP calibration procedure. The hyperspectral scanning of the test field was performed in October, 2008. Metal plates and crosses were used as signals for ground control points. The coordinates of the GCPs are determined in Gauss-Krüger metric coordinate system, 5th zone, by precise tacheometric measurements, relied on relative, static GPS-measurements. So, the accuracy of GCPs lies at the cm-level.

The handling of the auxiliary data represents the crucial issue of the whole geocoding procedure. These data consist of aircraft position and attitude. Since the absolute calibration of these data is very uncertain, GCPs are used for the offset calibration of the same data. Calibration procedure based on GCPs was performed in PARGE software.

The first step of the procedure is importing the GCPs. Typical text file with the list of GCP coordinates (image and ground) is shown in table 1, where the first two columns represent the pixel and line number (image coordinates) and the next three columns are X, Y, H (ground coordinates).

Table 1. Text file with the GCP coordinates

px	**ln**	**X**	**Y**	**H**
1092.75	616.00	5414712.40	4972979.70	147.47
719.50	617.75	5414713.13	4972966.96	147.36
720.00	628.00	5414694.49	4972965.70	147.17
877.00	628.00	5414693.90	4972971.09	147.25

Table 2. Coordinate differences, bias and variance test between the measured GCP coordinates and the ones have been read from the geocoded image before calibration

GCP	**Coordinate differences**		**Δy-ny**	**vy*vy**	**Δx-nx**	**vx*vx**
	Δy [m]	**Δx [m]**				
2	–23,70	10,20	0,58	0,34	3,35	11,22
3	–25,43	1,94	–1,14	1,31	–4,91	24,12
7	–23,80	15,81	0,48	0,24	8,96	80,26
8	–24,96	–2,81	–0,67	0,46	–9,66	93,33
11	–22,99	9,45	1,30	1,68	2,60	6,75
12	–23,87	2,67	0,41	0,17	–4,18	17,48
16	–24,44	6,38	–0,16	0,02	–0,47	0,22
17	–25,21	8,67	–0,92	0,86	1,82	3,31
20	–24,70	8,20	–0,42	0,17	1,35	1,82
22	–23,75	8,00	0,54	0,29	1,15	1,32
Σ	–242,85	68,51	0,00	5,53	0,00	239,84
	bias n_y = –24.3m	**bias n_x = +6.8m**	σ_y =	**0,78**	σ_x =	**5.16**

Table 3. Coordinate differences, bias and variance test between the measured GCP coordinates and the ones have been read from the geocoded image after calibration

GCP	**Coordinate differences**		**Δy-ny**	**vy*vy**	**Δx-nx**	**vx*vx**
	Δy [m]	**Δx [m]**				
2	–1,1	–1,1	–0,91	0,82	–1,13	1,27
3	–1,27	0,96	–1,08	1,16	0,94	0,87
7	–0,3	0,49	–0,11	0,01	0,47	0,22
8	–0,44	0,01	–0,25	0,06	–0,02	0,00
11	–0,61	–0,25	–0,42	0,17	–0,28	0,08
12	–1,13	0,93	–0,94	0,87	0,91	0,82
16	0,34	0,32	0,54	0,29	0,30	0,09
17	0,61	–0,27	0,81	0,65	–0,30	0,09
20	1,3	–0,32	1,50	2,24	–0,35	0,12
22	0,65	–0,52	0,85	0,71	–0,55	0,30
Σ	–1,95	0,25	0,00	6,98	0,00	3,84
	bias n_y = –0.2m	**bias n_x = +0.0m**	σ_y =	**0,88**	σ_x =	**0,65**

Determination of attitude offset and position offset are two crucial steps in offset calibration. These commands are performed iteratively with intention of decreasing RMS Errors (both for attitude and position). If these offsets are efficiently optimized, our next step is final geocoding procedure. After this procedure successfully finishes, we can read the coordinates of the GCPs from the geocoded image. These coordinates of the GCPs before and after calibration and those determined by tacheometric measurements are shown in table 2, where are shown coordinate differences before calibration as well as their biases and variances. In table 3 are shown the coordinate differences after calibration. Both coordinate differences, before and after calibration, are compared in table 4. It clearly shows the great improvement of spatial accuracy of the geocoded hyperspectral image after calibration.

Table 4. Comparison between the coordinate offsets before and after calibration

Coordinate differences			
before calibration		**after calibration**	
Δy [m]	Δx [m]	Δy [m]	Δx [m]
–23,70	10,20	–1,10	–1,10
–25,43	1,94	–1,27	0,96
–23,80	15,81	–0,3	0,49
–24,96	–2,81	–0,44	0,01
–22,99	9,45	–0,61	–0,25
–23,87	2,67	–1,13	0,93
–24,44	6,38	0,34	0,32
–25,21	8,67	0,61	–0,27
–24,70	8,20	1,30	–0,32
–23,75	8,00	0,65	–0,52

4. Conclusion

As mentioned before, the auxiliary data is the crucial component that needs to be handled in order to achieve acceptable accuracy for intended applications. For this purpose these data (aircraft position and attitude) are obtained by GPS receiver in absolute operational mode and Inertial Measuring Unit. Since the IMU achieves better accuracy over the short term and has the higher output rate than the GPS receiver, [7], this integration is used in calibration procedure for analysis of the position and attitude offsets in order to increase accuracy. The calibration procedure is based on the GCPs determined with cm-level accuracy. As we can see in table 2, there is very strong bias shown, especially on the Y-coordinates, that originates from different geodetic datum. After calibration, these strong biases on both axes are taken into account and their impact on the geocoded image is eliminated. Thus, a great improvement in accuracy after calibration is achieved, which now approximately lies at the m-level. Better accuracy can be reached by using of the more accurate GPS-receiver and applying the Kalman-filter on the IMU/GPS integration, [7].

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