Atmospheric correction algorithm applied to CASI multi-height hyperspectral imagery

L. Martínez, A. Tardà, V. Palà, and R. Arbiol
Institut Cartogràfic de Catalunya (ICC), Parc de Montjuïc s/n, 08038 Barcelona, Spain
Lucas.Martinez@icc.cat

ABSTRACT *In this paper, an atmospheric correction algorithm for airborne hyperspectral imagery data is presented. The algorithm is intended to correct multiple overlapping images over the same area taken from different heights. First, the algorithm obtains the main atmospheric parameters, aerosol optical thickness, and water vapour column content for the whole imaged area. These parameters are computed in an inversion procedure of the Second Simulation of the Satellite Signal in the Solar Spectrum (6S) radiative transfer code, using radiometric ground measurements or image homologous areas plus a single ground measurement. Finally, this code is applied to the whole set in order to obtain atmospherically corrected hyperspectral imagery. The algorithm was applied to a test area located on Banyoles (Spain) on images taken from three different heights with a Compact Airborne Spectral Imager (CASI) sensor, together with field quasi-simultaneous reflectance measurements. In the validation step, the standard deviations obtained with both ground measurements and image homologous areas are similar.*

1 INTRODUCTION

Hyperspectral remote sensing data is a common tool for applications such as agriculture, forestry, water quality, environment, etc. The acquisition of this data with high spatial resolution has been possible for many years by means of airborne sensors. Moreover, new satellites are being developed to provide remote sensing information based on high resolution hyperspectral data. However, airborne sensors have some advantages like the possibility of accurate laboratory re-calibrations, a greater ground resolution and spectral configuration capability and superior flight versatility. In this regard, there is the possibility of acquiring quasi-simultaneous overlapping images from different heights during the same flight.

The ICC-CASI configuration is a CASI 550 system (Table 1) synchronized with an Inertial Navigation System (INS) and a Differential Global Navigation System (DGPS). The integrated system is designed to convert the sensor imagery captured by the CASI into true orthoimages, useful for cartographic purposes (Palà et al., 1999).

The radiometric quality of the remote sensing data is essential to obtain reliable results. Radiance measured by a sensor depends on the illumination geometry and on the reflectance characteristics of the observed surface. However, several atmospheric processes disturb this measurement: gas absorption and both Rayleigh and Mie scattering (Kaufman, 1989). Absorption is an inelastic energetic process and is highly wavelength-dependent. On the other hand, scattering is an elastic interaction process with a smooth wavelength dependency that only changes the electromagnetic wave propagation pathway. Rayleigh scattering is caused by gaseous particles, while Mie scattering is due to aerosols. Scattering causes the so-called adjacent effect: a wrong measurement caused by radiation incoming from the surrounding area where the observed target is located. Therefore, each radiance measurement is contaminated in an amount that depends on the radiance of its neighbouring pixels.

CASI 550 Specifications	
Field of View	40.4° across-track 0.077° along track
Spectral Range	545nm between 400 and 1000nm
Spectral Samples	288 at 1.9nm intervals
Spectral Resolution	2.2 nm FWHM at 650
Aperture	F/2.8 to F/11.0
Dynamic Range	16,384:1 (14 bits
Noise Floor	1.0 DN
Signal to Noise Ratio	790:1 peak
Calibration Accuracy	470 - 800 nm +/-2% absolute
Data Throughput	1.25 Mbyte/second

Table 1 CASI 550 Specifications.

The best results in atmospheric correction are obtained through a radiative transfer approximation (Miesch et al., 2005). However, radiative transfer approaches need an accurate prior estimation of different atmospheric constituents such as water vapour, aerosols and ozone concentration. The ozone concentration has a low spatial and temporal variability. On the other hand, aerosols and water vapour concentrations are extremely space and time-dependent. Simultaneous field measurements can be used in an inversion of the radiative transfer code in order to obtain the optimal atmospheric parameters. In this paper an alternative solution is also proposed. It relies on the fact that in a multi-height and overlapping set of images over the same area small homogeneous targets are captured from different angles and heights. These areas can also contribute to atmospheric parameters estimation in the inversion of the radiative transfer code. Then, these parameters can be used to perform the atmospheric correction of the whole set of images.

In the following sections we make a description of the proposed algorithms and present the results obtained from its application to a dataset acquired in a test flight over Banyoles (Spain). In situ reflectance measurements, taken almost simultaneously to CASI flights, have been used to test this methodology and validate the atmospherically corrected reflectances obtained.

2 METHODOLOGY

2.1 Inversion procedure

The objective is to retrieve the atmospheric optical parameters –Aerosol Optical Thickness (AOT) and water vapour content- for the whole area where the atmospheric correction is performed. For those estimations, the atmospheric state is considered invariant within the area covered by the image. This assumption is quite realistic for the area imaged during the test flight.

Two methodologies are proposed for parameter estimation. First, in an approach similar to that of Guanter et al. (2005), the inversion procedure is performed by minimizing a cost function $\delta_{mes}{}^2$ that measures the difference between atmospherically corrected reflectances and field measurements

$$\delta_{mes}{}^2 = \sum_{j}^{images} \sum_{m}^{measurements} \sum_{\lambda_i}^{wavelenght} \frac{1}{\lambda_i^2}\left(\rho_{j,m,\lambda_i}^{corrected} - \rho_{j,m,\lambda_i}^{field}\right)^2 \qquad (1)$$

where ρ^{field} is the spectral reflectance measured on the field, $\rho^{corrected}$ is the atmospherically corrected spectral reflectance calculated with the radiative transfer code and λ_i is the equivalent wavelength for each sensor band. In a second approach, a new inversion procedure is performed by minimizing a more complex cost function $\delta_{hom}{}^2$ that consists of the difference between atmospherically corrected reflectances calculated on homologous areas observed on different images plus one field measurement.

$$\delta_{hom}{}^2 = \sum_{j,k}^{images} \sum_{h}^{homo} \sum_{\lambda_i}^{wavelenght} \frac{1}{\lambda_i^2}\left(\rho_{j,h,\lambda_i}^{corrected} - \rho_{k,h,\lambda_i}^{corrected}\right)^2 + \delta_{1-mes}^2 \qquad (2)$$

Both cost functions are weighted by λ_i, to take into account the high wavelength dependency of the atmospheric effects and increase the significance of low wavelength values.

The fast 6s radiative transfer code (Vermote et al., 1997) was selected as transfer code. The standard continental model was selected to represent the aerosol types and the standard US62 atmosphere pressure and temperature profiles were selected for the process. Total water vapour amount and AOT were set as the parameters to be calculated.

The field reference pixels selected must have a large spectral range to be significant in the inversion procedure. To overcome this problem, in addition to seven natural or artificial covers found on the field, four man-made covers were deployed in the test site. To minimize the effect related to high backscattering, the whole flight lines were designed parallel to the principal plane.

2.2 Atmospheric correction

Taking into account the interaction phenomena described in Staenz and Williams (1997), it is possible to express the radiance at the sensor, when observing a horizontal surface, as

$$L^* = A\frac{\rho_c}{\left(1-\langle\rho_e\rangle S\right)} + B\frac{\langle\rho_e\rangle}{\left(1-\langle\rho_e\rangle S\right)} + L_a \qquad (3)$$

were ρ_c is the corrected reflectance of the surface, $\langle\rho_e\rangle$ is the corrected reflectance of the neighbourhood, S is the atmospheric albedo, L_a is the radiance backscattered to the sensor, A and B are coefficients related to the direct and diffuse radiance.

Therefore, the corrected reflectance ρ_c, or BOA reflectance, for the observed surface is

$$\rho_c = \frac{\left(L^* - L_a\right)\left(1-\langle\rho_e\rangle S\right) - \langle\rho_e\rangle B}{A} \qquad (4)$$

The parameters A, B, S and L_a characterize both observation and illumination geometries and the atmospheric conditions when the image was obtained. Their values depend neither on the observed surface reflectance, nor on the neighbourhood's. Hence, they are calculated from the magnitudes L_g, which is the radiance entering the sensor from the observed surface, and L_p which is the radiance entering the sensor from the neighbourhood of the observed surface and backscattered by the atmosphere towards the sensor. If the surface has a uniform reflectance, those magnitudes will be

$$L_g = A\frac{\rho_c}{1-S\rho_c} \qquad L_p = B\frac{\rho_c}{1-S\rho_c} + L_a \tag{5}$$

Both L_g and L_p can be obtained by means of radiative transfer codes working on direct form. The values of A, B, S and L_a are directly obtained by solving the corresponding equations systems. The radiative transfer simulations are performed using the synchronous atmospheric data obtained in the inversion procedures. A Look Up Table system for each sensor zenith viewing angle is calculated, and consequently atmospheric correction is possible on the images by using equation 4 with the adequate set of A, B, S and L_a parameters.

The neighbourhood corrected reflectance $<\rho_e>$ will be obtained during the atmospheric correction using in equation 4 the whole neighbourhood as if it were a hypothetic single pixel located in a uniform reflectance environment, so in that expression $<\rho_e>$ will be equal to ρ_c. Also, its radiometry L^* will be calculated using the whole neighbourhood's pixels radiometry. From these hypotheses, the value of $<\rho_e>$ will be

$$<\rho_e> = \frac{L^* - L_a}{A + B + S(L^* - L_a)} \tag{6}$$

3 DATASET AND RESULTS

Airborne ICC-CASI images were acquired on June 29th, 2005 with a Cessna Caravan B20, between 10-11 am. (Table 2) The area selected to be imaged was Banyoles (Spain). The images were calibrated with laboratory coefficients to radiance units, and orthorectified with DGPS and INS data, with a nearest neighbour procedure.

	Low flights	**Middle flights**	**Upper flight**
Overlapping images	3	2	1
Integration time (ms)	22	43	82
Pixel size (m)	1.5	3.0	6.0
Flight height (m)	1120	2240	4480
Flight speed (knot)	116	121	135
Nominal heading	110 or 290		
Number of bands	32	72	144

Table 2 ICC-CASI acquired images description.

Simultaneously, a field campaign was developed to install the man-made covers and to perform the field reflectance measurements using an ASD FieldSpec Pro radiometer (Figure 1). Besides, different natural or artificial covers were measured: three on grass, two on concrete, one on bare soil and one on a lake.

Figure 2 Aerial photo of the targets specifically deployed for radiometric validation.

For the second inversion methodology, 23 areas with adequate spatial homogeneity and spectral reflectance range were manually selected throughout the whole image set. Selected covers were: bare soil, uniform crops, grass, concrete areas, asphalt areas, concrete tennis court and swimming pools. As a field measurement, a bare soil ground target was used

The minimization of the cost functions in (1) and (2) was performed by a simplex method (Press et al. 1986), with climatological data for the initialization of the algorithm. Table 3 shows the total water vapour contents and the climatological visibilities from 6S code, related to AOT.

Inversion data source	**Water vapour (g/cm2)**	**AOT (6S vis) (Km)**
Field measurements	2.50	8.4
Homologous areas + 1 field measurement	2.42	12.4

Table 3 Inversion parameters obtained.

The atmospheric parameters were then used to perform the atmospheric correction of the whole set of images. After that, already corrected images were compared with field reflectance measurements to assess the accuracy of the procedure. Table 4 shows the results of the validation for both methodologies in terms of global shift and σ^2 for all the images.

Inversion data source	Reflectivity shift	Reflectivity σ^2
Field measurements	0.000	0.008
Homologous areas + 1 field measurement	0.001	0.008

Table 4 Validation of the atmospheric correction.

4 CONCLUSIONS

Two methodologies for retrieval of atmospheric parameters by means of an inversion procedure have been compared. Compatible atmospheric parameters are obtained in the inversion process using both methodologies. In validation step, similar standard deviations are also obtained in both cases. We can then conclude that an inversion procedure using homologous areas plus a single field measurement yield accurate atmospheric parameters with less ground information.

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