Atmospheric correction of multiple flightline hyperspectral data (CASI-2)

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Abstract *Multiple parallel airborne flightlines are often necessary to provide the areal coverage desired, but standardisation to a common unit such as reflectance can be difficult, particularly where errors in the transform may be propagated sequentially through adjacent flightlines. This paper proposes a method for transformation to reflectance for such multiple flightlines based on an additional orthogonal flightline. The method is demonstrated for the CASI-2 data provided by the Environment Agency as part of the NCAVEO experiment. The uncorrected and corrected data were used to estimate NDVI using various wavebands and the NDVI estimates used to predict LAI. In all cases, the corrected data produced a slightly larger correlation than the uncorrected data.*

Keywords: *Image normalisation, atmospheric correction, pre-processing, NDVI, CASI*

1. Introduction

Airborne hyperspectral sensing is a powerful tool to study the environment and many studies have shown the potential of this technique. Aerial platforms provide flexibility of scheduling, so particular events or processes can be observed, and they allow the view geometry and spatial scale of sampling to be matched to the phenomena of interest. Imaging spectrometers acquire a uniquely detailed quantitative record of the reflected spectrum of energy from the Earth's surface which can then be used in numerical models as well as in thematic classification. Despite the immense potential of this technique, there are several problems which must be overcome before the technique can be regarded as operational. One of these concerns the normalisation of data from different flightlines.

It is common for an area to be surveyed using multiple narrow flightlines, the radiometry of each of which must be standardised. There are two approaches to this; the first applies an adjustment to each flightline so as to balance its visual appearance in a mosaic; the second applies a transformation to the data from each flightline, so as to convert the digital number values to some property of the surface, for example the directional-hemispherical reflectance factor (DHRF). This equates to a flightline-specific atmospheric correction. The atmosphere exerts an important effect upon the signal in some wavelengths, even from a low-flying aircraft. For example, Anandakumar et al. (2008) showed how the estimation of river depth from CASI-2 data acquired from 1800 m altitude was significantly improved by atmospheric correction.

Multiple flightlines are acquired for two main reasons. First, practical limitations on the sizes of CCD arrays mean that it is not possible to achieve fine spatial resolution and large area coverage from a single sensor. The second reason concerns the normalisation of data within a single flightline to take account of the view angle effect which occurs when the field-of-view of the sensor is large. A common strategy is to minimise this effect by acquiring many overlapping flightlines, such that the range of off-nadir view angles within any single flightline is quite small.

The aim of this paper was to demonstrate a practical technique to standardise data from multiple flightlines, as a step towards the goal of establishing airborne hyperspectral sensing as a viable technique to survey relatively large areas of the Earth's surface in great detail.

2. Data used in the study

2.1 Site description

The data used in this study were obtained as part of the NCAVEO 2006 Field Campaign which took place on 17th June 2006 in the area of Hampshire south-east of Andover. Nine flightlines were acquired using a CASI-2 system operated by the Environment Agency (EA), covering a test area of approximately 9 km x 6 km. Nine flightlines were acquired between 09:46 and 11:16 UTC from an altitude of 1900 m, resulting in a nominal ground resolution of 1 m. The CASI-2 has a swath width of 1500 pixels and was programmed to acquire data in 32 spectral bands between 397 and 986 nm.

Eight flightlines were aligned parallel to each other and oriented approximately north-south. Adjacent flight lines were arranged to overlap so that all pixels could be imaged within a few degrees of nadir. The final flightline was aligned east-west so as to cross the other eight and also pass over the Chilbolton Facility for Atmospheric and Radio Research (CFARR), where many ground instruments were located. During the survey period, the atmospheric conditions gradually deteriorated such that only six of the nine images were suitable for analysis (see Figure 1).

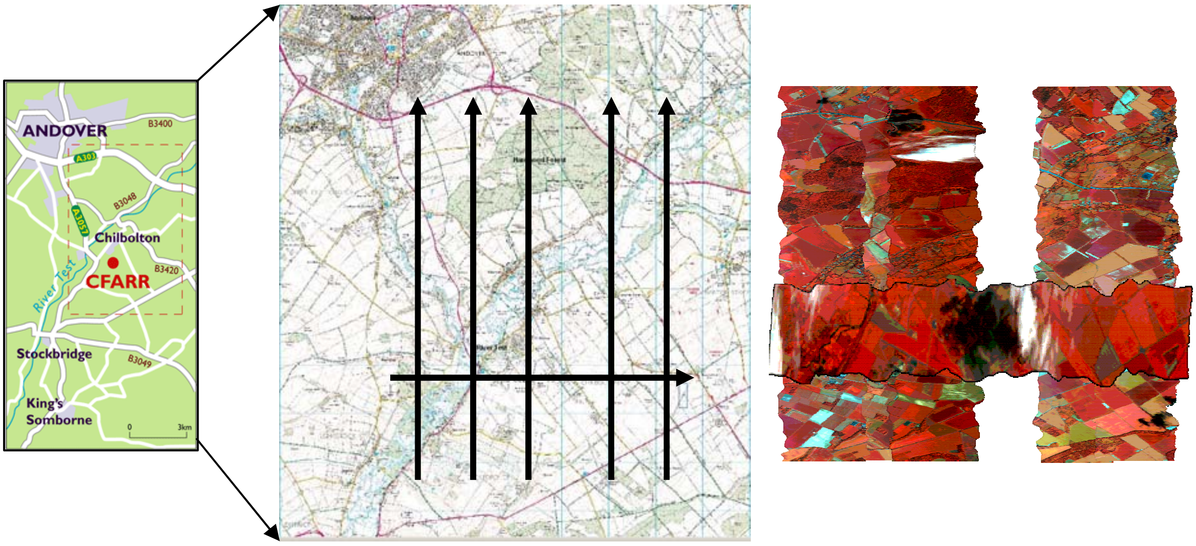

Figure 1: *Location of the study area. The arrows show the flight direction for the six CASI flightlines used in this experiment.*

3. Methodology

3.1 Radiative transfer model

A single north-south flightline was designated the primary flightline as this passed directly over the site for which simultaneous ground measurements were available. Physically-based atmospheric correction was applied to this flightline using the ATCOR-4 program which is based on the radiative transfer model MODTRAN. Horizontal visibility was estimated from ground observations and atmospheric water vapour was measured using a Microtops II sunphotometer. A combination of the radiative transfer model and spectral data from artificial ground calibration targets placed on the ground during the flight were used to perform the atmospheric correction. To assess accuracy visually, spectral reflectance from the corrected CASI was plotted against independent ground spectral reflectance measurements of concrete and asphalt.

3.2 Empirical-based model

An east-west flightline was used to transfer the atmospheric correction to the remaining north-south flightlines to avoid the sequential propagation of error which would occur if each flightline had been corrected in turn based on its neighbour. Precise co-registration was critical, so small image subsets were selected from the overlap area and ground features used to register these to an accuracy of less than half a pixel. Robust regression was used to calculate the gain and offset values needed to extend the reflectance calibration from the orthogonal flightline to the parallel flightlines.

4. Results

4.1 Atmospheric correction of the primary flightline

The accuracy of the ATCOR-4 atmospheric correction of the primary flightline was assessed by comparing the reflectance from the CASI image with reflectance measured on the ground from two surfaces: asphalt and concrete. The mean reflectance values of 3 x 3 pixel windows in each were calculated (Figure 2). The results show good agreement for both surfaces over the central range of wavelengths, but significant differences in the blue region over concrete and in the region 863-992 nm over asphalt.

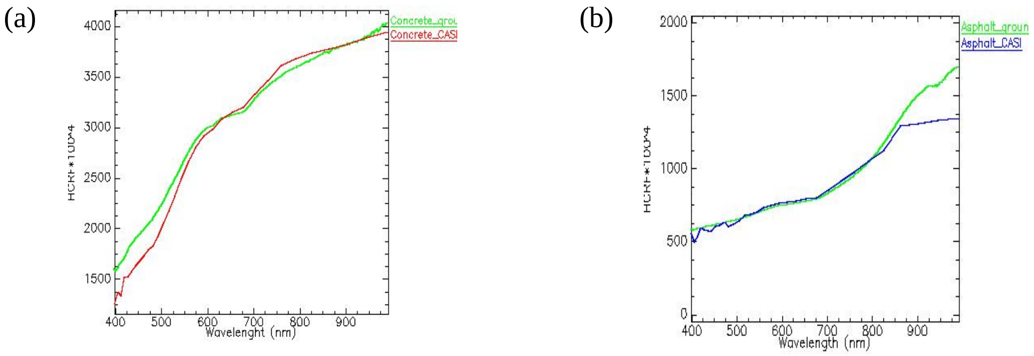

Figure 2: *Comparison of spectral reflectance predicted from the corrected image and measured at the ground for (a) concrete and (b) asphalt*

4.2 Extension to other flightlines

The method used to extend the reflectance calibration to the other flightlines was based on a regression model fitted to a carefully selected area of mixed land cover. The area of overlap between the E-W flightline and the target N-S flightline was first inspected to find a small rectangular area that had a wide range of land covers present and was also clear of obvious problems (cloud cover etc.). The geometric co-location of these coincident image chips was then improved using ground control points, prior to fitting a regression model to the relation between the two images. Although the images were georeferenced already, it was found necessary to perform local area image-to-image registration to improve the registration fit (see Figure 3).

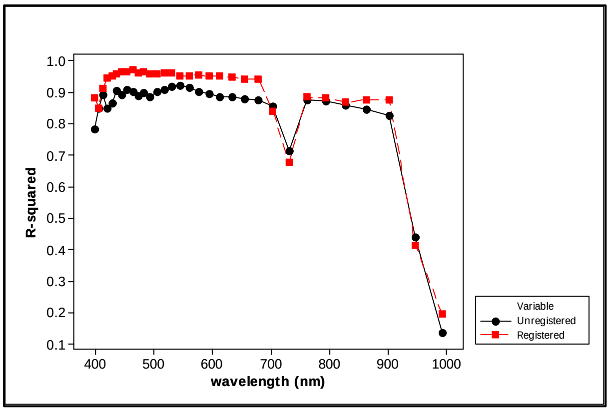

Figure 3: *R^2 relationship for image before and after localised image-to-image registration*

Robust regression was used to estimate the gain (β_1) and offset (β_0) parameters needed to extend the reflectance calibration from the orthogonal flightline to the parallel vertical flightlines. This robust method suppressed the effect of outliers on the fitted model. Table 1 shows the result of applying the robust regression compared to normal linear regression. Figure 4 show the wavelength-dependence of the coefficients of determination ($R^{2)}$ between the orthogonal flightline and the five N-S flightlines (primary flightline not shown). The plot shows three regions of the spectrum in which the goodness-of-fit is relatively poor: the extreme short wavelengths, the region around 720 nm and the extreme near IR, above about 900 nm. The regions of the spectrum most commonly used for vegetation applications (red and near IR) had R^2 values in excess of 0.95 in the red region and over 0.87 in the near infra-red.

Model	Slope	Intercept	R^2
Linear	0.333	-644.12	0.94
Robust	0.343	-685.62	0.97

Table 1: *Comparison of results from linear and robust regression*

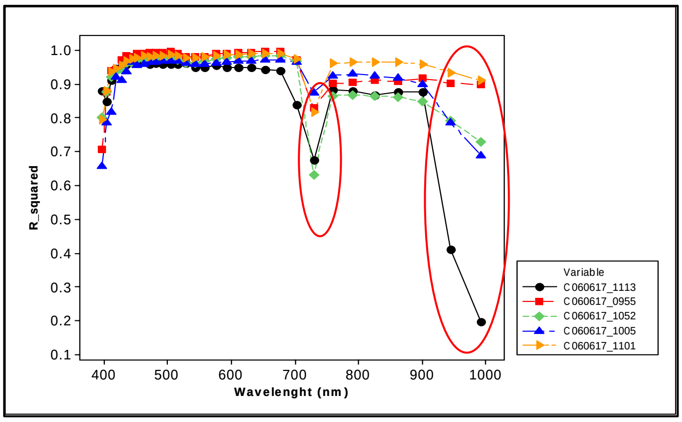

Figure 4: *Relationship between orthogonal flightline and the five N-S flightlines (primary flightline not shown).*

4.3 Application of the method

Many vegetation applications are based on use of the normalised difference vegetation index (NDVI), and one of the primary advantages claimed for this index is normalisation of illumination differences between images. It is therefore of interest to see whether prediction of a biophysical variable such as leaf area index (LAI) from NDVI is affected by conversion to reflectance using the method proposed here. Table 2 shows the results of linear regression between LAI measured on the ground from fields of oats, wheat and barley (*n*=75) and CASI data expressed either as radiance units or as reflectance (HDRF). The results from several different red and near IR wavelengths are shown, as there is no standard combination for NDVI.

		Red centre wavelength							
		612 nm		**632 nm**		**654 nm**		**678 nm**	
		Corr.	*Uncorr.*	*Corr.*	*Uncorr.*	*Corr.*	*Uncorr.*	*Corr.*	*Uncorr.*
Near IR centre wavelength	**760 nm**	0.78	0.73	0.81	0.74	0.83	0.74	0.82	0.74
	792 nm	0.78	0.72	0.80	0.74	0.83	0.76	0.83	0.75
	826 nm	0.79	0.72	0.81	0.74	0.84	0.76	0.84	0.75
	863 nm	0.77	0.72	0.81	0.74	0.83	0.76	0.83	0.75
	902 nm	0.79	0.72	0.81	0.74	0.84	0.74	0.84	0.76

Table 2: *Regression between LAI and NDVI from combination of NIR (760-902 nm) and Red (612-678 nm) for corrected and uncorrected CASI data*

5. Conclusions

A method for standardising data from multiple flightlines has been demonstrated based on a physical radiative-transfer model and a flightline-specific empirical correction. The result was a set of flightlines optimised for qualititive applications (e.g. mosaic generation) but also suitable for use with physical reflectance-based models. The utility of a common ratio-based vegetation assessment method (NDVI) for predicting LAI was always slightly improved by the transformation.

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6. References

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