Retrieval of Surface Reflectance from Hyperion Radiance Data

K. Staenz, R.A. Neville, S. Clavette, R. Landry, and H.P. White
Canada Centre for Remote Sensing, Natural Resources Canada, Ottawa, ON, Canada, e-mail: karl.staenz@ccrs.nrcan.gc.ca
R. Hitchcock
Prologic Systems Ltd., Ottawa, ON, Canada

***Abstract* – Surface Reflectance was retrieved from Hyperion data by a procedure involving data preprocessing steps and atmospheric correction. Several steps are required to remove sensor artifacts in the spectral and spatial domain. These artifacts include a spatial shift in the short-wave infrared (SWIR) data, an along-track striping, a spatial misalignment of the visible near infrared (VNIR) and SWIR data, and a cross-track spectral (smile/frown) effect. A look-up table approach in combination with the radiance transfer code MODTRAN4.2 was applied to preprocessed at-sensor radiance data to retrieve surface reflectance. Results indicate that the spectral calibration data provided do not achieve a proper positioning of the bands' centre wavelengths. Wavelength shifts of up to 1 nm in the VNIR and up to 3 nm in the SWIR remain. This can be seen especially at wavelengths affected by strong gaseous absorptions.**

I. INTRODUCTION

Surface reflectance retrieval in hyperspectral remote sensing is an important step in the data processing chain for the extraction of quantitative information in many application areas [1,2]. In order to calculate surface reflectance from remotely measured radiance, radiative transfer (RT) codes are used for the removal of the atmospheric scattering and gaseous effects. The results depend strongly on the performance and calibration of the sensor, and the selected RT code. These can have an effect on the output of information extraction procedures and, subsequently, affect the accuracy of the retrieved information.

This paper concentrates on the atmospheric correction of Hyperion data with special consideration of sensor performance, especially with respect to radiometric and spectral calibration. A look-up table (LUT) approach using MODTRAN (MODerate resolution atmospheric radiance and TRANsmittance model) [3] was applied to Hyperion at-sensor radiance data to retrieve surface reflectance data. The LUT approach was applied to data of the Coleambally (NSW, Australia) reference site. The entire analysis was carried out on the Imaging Spectrometer Data Analysis System (ISDAS), an advanced hyperspectral analysis software developed at the Canada Centre for Remote Sensing [4].

II. DATA USED

The hyperspectral data for this study was obtained with NASA's Hyperion sensor on 12 January 2002 over Coleambally, a flat agricultural site in the southeast of Australia. The Hyperion sensor has 242 spectral bands spanning the wavelength range from 356 nm to 2577 nm, with nominal bandwidths of 10 nm [5]. This wavelength range is covered by two detector arrays, one for the visible and near-infrared (VNIR: 356 nm to 1058 nm), the other for the short-wave infrared (SWIR: 852 nm to 2577 nm). It has a 0.63-degree across-track field-of-view, which for the altitude of 705 km corresponds to a swath width of 7.6 km and 30-m pixels.

Level 1B data have been used for this study. This data processing level provides a data set with 198 bands covering the VNIR from 427 nm to 925 nm and the SWIR from 912 nm to 2394 nm. Accordingly, VNIR bands 1 to 7 and 58 to 70 as well as SWIR bands 71 to 76 and 225 to 242 have been eliminated (set to 0 or –1).

III. DATA PROCESSING

The necessary preprocessing steps to remove spectral and spatial sensor artifacts and atmospheric effects are outlined in Figure 1.

A. Spatial and spectral artifacts

A shift of one pixel in the line direction was corrected in the SWIR image data prior to noise removal. This shift occurs between pixel position 128 and 129.

Noise (non-periodic along-track striping) was removed in the radiance domain for the VNIR and SWIR data separately. Severe Striping was obvious after transformation of the data into the principal component (PC) domain. PCs 3 to 49 of the VNIR and PCs 2 to 67 of the SWIR data were affected to various degrees. The average of each column per image for each spectral band was calculated and subsequently plotted against the pixel number. A triangular smoothing with a window of up to 10 lines was then applied to the two the radiance data sets. This enabled the computation of a correction factor (gain) for each line to adjust the original mean values to the smoothed ones. The gain was calculated by dividing the smoothed values by the original column means.

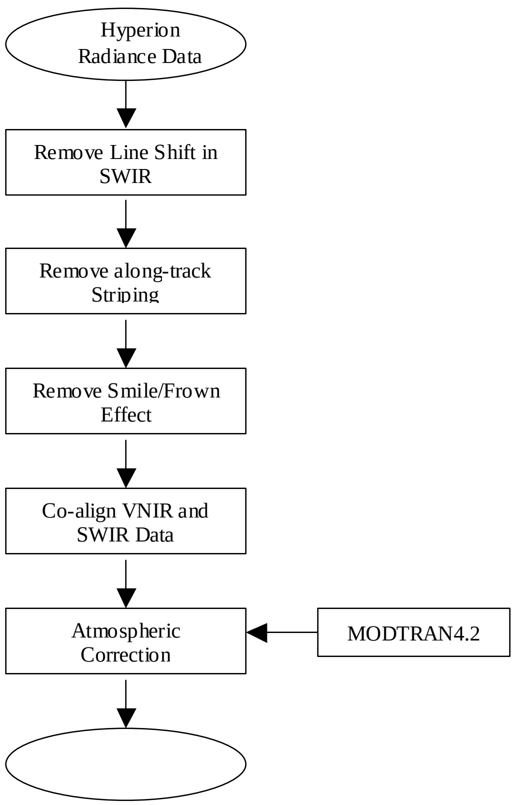

Fig. 1. Preprocessing steps for retrieval of surface reflectance.

Cross-track spectral errors (smile/frown) affect the retrieval of surface reflectance. Accordingly, this effect has to be removed prior to atmospheric correction. Hyperion's two-dimensional detector arrays show a frown effect of 2.6 nm to 3.6 nm and .40 nm to .97 nm in the VNIR and SWIR, respectively [5]. A linear interpolation resampling scheme was applied to the data using the spectral calibration file, provided with the level 1B data, to remove this effect.

A spatial misregistration between the VNIR and SWIR data was detected. A co-alignment between the two data sets was achieved by a counter-clockwise rotation of 0.25º followed by a negative one-pixel shift in the line direction. These operations were carried out on the VNIR data, which were then resampled with a piecewise linear interpolation based on the values of the nearest eight points. The VNIR was matched to the SWIR data due to their lower radiometric fidelity. The co-alignment was carried out prior to atmospheric correction in order to use the 940-nm water vapour absorption in combination with the one located at 1130-nm for scene-based retrieval of water vapour content on a pixel basis.

Checking the overlap region between the VNIR and SWIR detectors revealed a good spectral alignment. The last band in the VNIR and the first band in the SWIR were then removed to eliminate the VNIR/SWIR overlap region.

B. *Atmospheric effects*

The atmospheric correction procedure is based on a LUT approach with tunable breakpoints as described in Staenz and Williams [2], to reduce significantly the number of radiative RT code runs. The MODTRAN4.2 RT code was used in forward mode to generate the radiance LUTs, one for each of a 5% and 60% flat reflectance spectrum. These LUTs were produced for seven pixel locations equally spaced across the swath, including nadir and swath edges, and for single values of aerosol optical depth (horizontal visibility) and terrain elevation, and for a range of water vapour contents. The specification of these parameters and others required for input into the RT codes are listed in Table 1. None of the BRDF options available in MODTRAN4.2 were used for this study.

TABLE 1
INPUT PARAMETERS FOR MODTRAN4.2 RUNS

Atmospheric model	US standard
Aerosol model	Desert
Date of overflight	January 12, 2002
Solar zenith angle	34.7º
Solar azimuth angle	282.7º
Sensor tilt angle	5º
Sensor heading	194º
Terrain elevation above sea level	0.130 km
Sensor altitude above sea level	705 km
Water vapour content	variable
Ozone column	as per model
CO_2 mixing ratio	as per model
Horizontal visibility	50 km

For the retrieval of the surface reflectance, the LUTs were adjusted only for the pixel position and water vapour content using a bi-linear interpolation routine [6], since single values for the other LUT parameters were used for the entire cube. For this purpose, the water vapour content was estimated for each pixel in the scene with an iterative curve fitting technique [7]. The surface reflectance ρ was then calculated for each pixel as follows:

$$\rho = \frac{L - L_a}{A + B + S(L - L_a)}, \qquad (1)$$

where L is the at-sensor radiance provided by the image cube, L_a is the radiance backscattered by the atmosphere, S is the spherical albedo of the atmosphere, and A and B are coefficients that depend on geometric and atmospheric conditions. The unknowns A, B, S, and L_a were calculated from the equations

$$L_{gi} = A\frac{\rho_i}{1-\rho_i S} \quad \text{and} \quad L_{pi} = B\frac{\rho_i}{1-\rho_i S} + L_a \ , \qquad (2)$$

where L_{gi} is the at-sensor radiance reflected by the target and L_{pi} is the at-sensor radiance scattered into the path by the atmosphere and the surrounding targets. These equations can be solved on a per pixel basis for each set of parameters $\{\rho_i$, L_{gi}, and $L_{pi}\}$ obtained from the LUTs by interpolation for the different geometric and atmospheric conditions. With i = 1 and 2 (ρ_1 = 5%, ρ_2 = 60%), this yields a system of four equations with four unknowns.

IV. RESULTS

Results indicate that the provided spectral calibration data do not correct properly the frown effect. Tests revealed generally a reduction of this effect to some degree, but not a complete removal of these across-track spectral errors. The spectral frown errors were increased for some of the wavelength regions, such as for the first few bands in the VNIR. Further tests against a simulated MODTRAN spectrum using the gaseous absorption features at 760 nm (O_2), 940 nm (H_2O) and 1130 nm (H_2O) showed wavelength shifts of up to 1 nm in the VNIR and up to 3 nm in the SWIR. It is not clear at this point if these shifts are only due to the incomplete removal of the across-track spectral errors or if there is an additional spectral shift. Based on these tests, the bands are not centred at their true wavelength positions. This influences the proper retrieval of surface reflectance, especially in the regions affected by strong gaseous absorption. In a final processing step, the data were shifted linearly to the longer wavelength by 1 nm up to 1023 nm and by 3 nm from 1023 nm to 1336 nm. A resulting surface reflectance spectrum is presented in Fig.2. The remaining erroneous spikes can be removed with post-processing of the data, for example, using a flat target approach [8].

V. CONCLUSIONS

Required preprocessing steps prior to surface reflectance retrieval are: removal of spatial shift in the SWIR, across-track striping, and cross-track spectral errors (frown), and co-alignment of VNIR with SWIR data. The surface reflectances were retrieved from Hyperion at-sensor radiance data with a LUT approach in combination with MODRTAN4.2. Results revealed that wavelength shifts of up to 1 nm in VNIR and of up to 3 nm in the SWIR remain. In order to maximize the quality of the retrieved surface reflectance, the smile/frown effect has to be assessed in the future from the data themselves. The calibration data provided did not lead to a satisfactory correction of this effect.

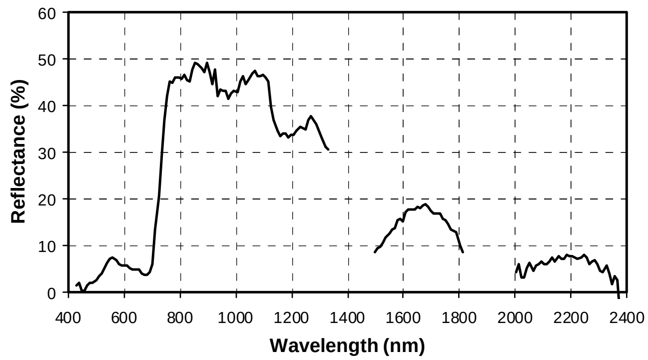

Fig. 2. Vegetation surface reflectance spectrum retrieved from a single pixel.

ACKNOWLEDGMENT

The authors would like to thank J. Pearlman of TRW for making the Hyperion data available to us.

REFERENCES

[1] B.-C. Gao, K.B. Heidebrecht, and A.F.H. Goetz, "Derivation of Scaled Surface Reflectances From AVIRIS Data," *Remote Sensing of Environment*, 44:165-178, 1993.

[2] K. Staenz, and D.J. Williams, "Retrieval of Surface Reflectance from Hyperspectral Data Using a Look-Up Table Approach," *Canadian Journal of Remote Sensing*, 23(4):354-368, 1997.

[3] A. Berk, L.S. Bernstein, and D.C. Robertson, "MODTRAN: A Moderate Resolution Model for LOWTRAN7," *Final Report*, GL-TR-0122, AFGL, Hanscom AFB, Maryland, U.S.A., 1989.

[4] K. Staenz, T. Szeredi, and J. Schwarz, "ISDAS - A System for Processing/Analyzing Hyperspectral Data," *Canadian Journal of Remote Sensing*, 24(2): 99-113, 1998.

[5] USGS, "New Millennium Program's First Earth Observing Mission (EO-1)," *EO-1 Hyperion & Advanced Land Imager (ALI) Data Users Workshop*, USGS, Denver, Colorado, U.S.A., 302 pages, 2001 (http://eo1.gsfc.nasa.gov/miscPages/ALIworkshop.html#Presentations).

[6] W.H. Press, S.A. Teukolsky, W.T. Vetterling, and B.P. Flannery, *Numerical Recipes in C*, Cambridge University Press, Cambridge, England, pp.123-125, 1992.

[7] K. Staenz, T. Szeredi, R.J. Brown, H. McNairn, and R. VanAcker, "Hyperspectral Information Extraction Techniques Applied to Agricultural *casi* Data for Detection of Within-Field Variations," *Proceedings of the International Symposium in the Era of Radarsat and the Nineteenth Canadian Symposium on Remote Sensing*, Ottawa, Ontario, Canada, 8 pages (CD-ROM), 1997.

[8] K. Staenz, R.A. Neville, J. Lévesque, T. Szeredi, V. Singhroy, G.A. Borstad, and P. Hauff, "Evaluation of *casi* and SFSI Hyperspectral Data for Environmental and Geological Applications – Two Case Studies," *Canadian Journal of Remote Sensing*, 25(3): 311-322, 2000.