Correction of spectral curvature effects (smile) in Hyperion datasets by Use of derivative calculations and minimum noise fraction (MNF) transform

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Abstract: Various pushbroom imaging spectroscopy systems experience low-frequency array effects that are often referred to as spectral *curvature effect* or *smile/ frown* and *keystone* interferences [1, 2]. The detector elements in a pushbroom system are arranged on a rectilinear grid, therefore dispersing the slit onto the straight rows of detector elements leads to spatial misalignment of the wavelength and bandwidth [3, 4]. Smile may also be a product of aberrations in the collimator and imaging optics [3]. Hyperion hyperspectral sensor on board the Earth-Observing-1 (EO-1) spacecraft is a pushbroom imaging spectrometer [5-7]. Throughout the Hyperion operations, shifts of less than 1 nm have been observed in the SWIR wavelengths and 2.6 – 4.25 nm shifts in the VNIR detector wavelengths [8, 9]. Since the smile effect may render spectral absorption positions, the atmospheric correction may be insufficient, leading to a noisy reflectance product [9-11]; as a result, the thematic spectral based products may be erroneous [12] e.g., thematic misclassification of the data (Figure 1).

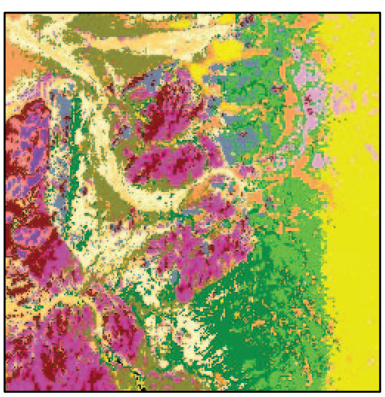

Figure 1: Classification results for a VNIR Hyperion reflectance image of the research site.

Figure1 presents Hyperion classification of rock types in the research site. Hyperion distinguished between most of the different rock types, excluding the right hand side of the image, for which only one class was assigned. Hyperion pre-launch smile estimates are inapplicable as the smile changes with time [8]. On the other hand, MNF-1 commonly used as a smile indicator does not fully represent the smile effect [3]. therefore, previous attempts to implement corrections to the MNF, such as column mean corrections (as in global destriping), fitting low-order polynomials as in “cross track illumination”, or even removing MNF-1 from the data, were ineffective and resulted in significant distortion of spectral and spatial data [3, 12]. A method for the detection and correction of spectral curvature effects (smile) in Hyperion images, termed *“Trend Line Smile Correction”* (TLSC), is presented. The method is based on the assumption that there is a partial correlation between data spectral non-uniformity due to smile and the gray scale gradient commonly appearing in the first MNF image (MNF-1). However, MNF-1 consists of both spatial and spectral information. Therefore, it is hypothesized that correcting MNF-1 according to exclusively spectrally derived parameters will account for the smile effect in the data. The correction methodology includes a smile detection procedure that is performed by spectral comparison of the radiance image to the radiative transfer absorptions and by locating the minimal smile column (MSC) in the data. A set of normalization factors calculated from the spectral derivative at the right hand side of the O_2 absorption feature (760nm) were used as internal indicators to scale the initial MNF-1. A second order polynomial function, referred as *Trend Line* (TL), was fitted to the column mean derivative values of O_2 absorption. The TL function was then scaled to fit the MNF-1 values. Comparison between derivatives calculated for the O_2 absorptions of both Hyperion and MODTRAN [9] was used to locate of the minimal smile columns (MSCs). These columns, which are the ones list disturbed by smile, later served as reference factors in the correction methodology. Contrary to the accustomed polynomial fit, the adaptation was simply preformed by arithmetic addition and subtraction. Moreover the MSC in MNF space was used for fine-tuning. Selected MNF bands (including the corrected MNF-1) were used to reconstruct the image back to radiance space [13]. Similar spectral smile detection methodologies that utilize atmospheric absorption features were suggested [4, 8, 14-16] . The presented technique differs from these methods both in the detection and correction approaches. The methodology was tested on Four Hyperion images, covering the vicinity of the Arava Rift Valley, Isarel and Jordan. Evaluation of the smile effect correction performance was carried out in three stages: (1) matching O_2 and H_2O absorption features across the dataset with MODTRAN absorption features; (2) comparison with other commonly used methods; (3) comparing spectral retrieval of selected targets with thematic mapping of the Dana Geology National Park area in southeastern Jordan. At each stage, the TLSC results consistently and significantly outperformed the non-corrected data and other methods tested. Derivative matching was preformed both for O_2 (672 nm) and H_2O (833 nm) absorption features. TLSC reduced the cross- track variations in average by 8 times for both O_2 (at 760 nm) and H_2O (at 823 nm) absorption features and consistently surpassed other tested methods. In addition TLSC significantly reduces spikes near 940nm water vapor absorption region, implying that although TLSC does not deal directly with band-to-band smile differences, by using MNF the correction is applied to all bands. Diminution of spikes near the atmospheric water vapor absorptions aseptically at 940 µm, contributed significantly to the reliability of the reflectance product. Consequently the final classification map produced using both TLSC VNIR and the SWIR spectral regions (Fig. 2).

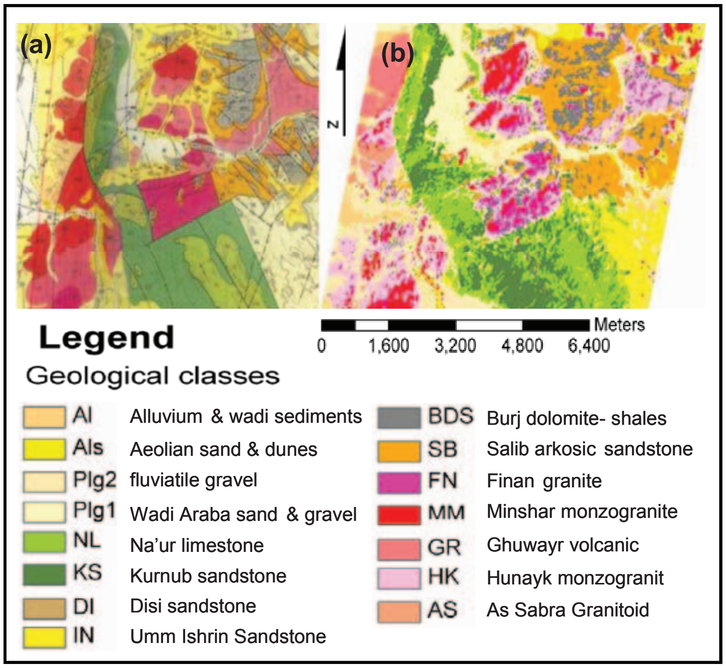

Figure 2: (a) Geological map of the research area (Rabba, 1994) and (b) Classification results for all bands (VIS and SWIR) following the Trend Line smile correction.

Conclusions: Theoretically, the Hyperion data should provide improved geological information that currently cannot be obtained by any other space borne system. Nevertheless, the Hyperion data were found to be relatively noisy (average SNR of 40), in which significant smile effects were embedded that were difficult to handle by the common end-user. The success of TLSC in correctly revealing geological features over four particular scenes is encouraging. It is likely that correction of Hyperion data over other homogeneous arid areas would yield positive results. It is admitted, however, that until the proposed method be successfully tested on other environments and acquisition conditions it is not robust. The TLSC should be examined for the cases of (a) airborne imaging spectrometers; (b) low-to-medium smile; (c) rough terrain; and (d) in the presence of particular spatial patterns such as those of clouds or coastal lines. These all are subject to future research. Finally, it is our hope that the effectiveness of TLSC will improve the applicability of Hyperion data and possibly, of future pushbroom hyperspectral spaceborne missions for citizen science and social networks end-users. The authors wish to bring to an Israeli-Jordanian scientific cooperation for the evolvement of the research in the coming future.

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