DESTRIPING OF MISCALIBRATED AISA IMAGES

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Abstract:
The analysis of hyperspectral images belongs to the main tasks in Remote Sensing. The foregoing linear radiometric correction of registered digital numbers basically assigns the spectral and spatial dependent response of a hyperspectral pushbroom sensor to a physical meaning - radiance. Slopes and offsets of the correction are often determined in laboratory and in-flight calibrations, but may vary over time. This results in striping artefacts which aggravates succeeding processing steps such as atmospheric correction, classification and segmentation.

In this work, a new approach is presented, that automatically removes these stripes calculating improved calibration factors without any prior knowledge or user interaction. The algorithm is based on the assessment of spectral and spatial probability distributions and is constrained by specific minimisation principles.

Morphological and spatial filtering techniques and additionally a Signal-to-Noise-Ratio related decision tree are implemented to reduce computational effort and to stabilise the solution depending on local spatial entropy.

To objectively evaluate the performance of the new approach, the technique was applied to broadly used image processing examples that has been artificially and randomly degraded by sets of multiplicative and additive noise of different distributions as well as miscalibrated AISA DUAL (VNIR and SWIR) scenes.

The results clearly show the benefits of the new approach and, concurrently, provide correction facilities for other miscalibrated pushbroom sensor data.

1. Introduction

Hyperspectral pushbroom sensor use detector arrays for image acquisitions. Different properties of the detectors demand a precise radiometric calibration. The radiometric calibration assigns known incident at-sensor radiance to measured digital number (DN). The association is often realised by a linear least squares regression. The estimated regression coefficients (slope and offset) are the used in the reverse process – the radiometric scaling - to assign measured DN to unknown incident at-sensor radiance. Uncertainties in the estimation of regression coefficients or variations in the responses of detectors in comparison to last calibration may lead to miscalibrations that are visually perceptible as image stripes.

However, miscalibrations aggravate subsequent analyses and have to be reduced (Datt et al., 2003). Miscalibration can be divided into two basic types – additive (offset) and multiplicative (slope) degradation. Offsets are used to incorporate detector-dependent dark current. In contrast, slopes are used to directly assign radiance to DN.

The aims of any striping reduction should be stripe suppression and preservation of the physical fingerprint of imaged surface material. In this work a multistep approach is proposed which significantly reduces stripes and preserves the spectral characteristics of imaged surface cover materials. It consists of a linear slope reduction and an offset reduction as well as of specific post-processing steps that are consecutively executed and interim evaluated by the evolution of the Signal-to-Noise-Ratio (SNR). If a previous reduction step has lowered the SNR, then this step will be revoked. This is useful to avoid overcorrections.

Both reductions are performed per band. The slope reduction considers a single detector element and the offset reduction relates to adjacent detector elements. Spatial and spectral probability distributions are incorporated which is supported by striping related redundancies.

After the reductions of stripes a spectral rescaling is performed that aims to adjust the spectral level of a band by considering areas of lowest reduction.

Remaining trends or reduction related frequency undershoots are suppressed in a next, detrending related step.

To desensitise proposed reductions in presence of edges, an edge filtering approach was developed that excludes edges before succeeding reductions if they don’t dominate or represent the striped image. For this, Minkowski metrics, gradient operators and edge extraction algorithms were combined (Canny, 1986; Haralick et al., 1987; Rogass et al., 2009).

To study the impacts of different linear miscalibrations on the performance of the proposed method, a specific set of grey valued images was randomly striped by linearly varying the slope and/or offset. In addition, a set of 3 hyperspectral, miscalibrated AISA DUAL (SPECIM, 2011) scenes were processed.
2. **Materials**

Four grey valued images and 3 hyperspectral AISA DUAL (SPECIM, 2011) scenes were selected to evaluate the performance of the proposed destriping approach. The grey scaled images were obtained from the image database of the Signal and Image Processing Institute (SIPI) of the University of California (Weber, 1997) and are 512 x 512 pixels in size (Figure 1).

![Grey scaled image samples](image1.png)

**Figure 1.** Grey scaled image samples from the USC SIPI image data base considered in the following as a) ‘Lenna’, b) ‘Mandrill’, c) ‘Aerial’ and d) ‘Sailboat on lake’

The grey valued images were artificially randomly Gaussian white noise striped by slope and/or offset of different noise levels (Box and Muller, 1958). 80 different noise levels and 20 different noise sets (slope and offset, slope only, offset only, slope only and a priori knowledge and offset only and a priori knowledge for all 4 images) were applied on the images. Hence, 1600 different images were analysed with slope degradations ranging from about 0.0001 to 1789 and offset degradations ranging from -10000 to 10000. The aim of the project, Monitoring of Landscape Water Balance (MoLaWa), was to couple hyperspectral and microwave remote sensing data to quantify soil water content and to analyse its impact on agricultural vegetation in specific case study regions in Eastern Germany, such as ‘Fichtwald’. To accomplish this, three AISA DUAL datasets were acquired on September 23rd 2010 between 1 p.m. and 3 p.m (Figure 2). The airborne AISA DUAL (SPECIM, 2011) system consists of two separate pushbroom sensors covering the visible and near infrared (VNIR of AISA Eagle 400 – 970 nm) and the short wave infrared (SWIR of AISA Hawk 970 – 2450 nm). The platform is aircraft stabilised. The images were acquired in a mean flight height of 1620 m above ground giving a ground resolution of 2 m. 2.3 nm for the Eagle and 6.3 nm were used as spectral binning for this flight. However, after application of recent calibration set visually perceivable striping patterns exhibited that may be caused by sensor miscalibration.

![Hyperspectral AISA DUAL sample scenes](image2.png)

**Figure 2.** Hyperspectral AISA DUAL sample scenes covering partly case study ‘Fichtwald’ in Eastern Germany

3. **Methods**

Radiometric calibrations are often performed in laboratory and basically assign known incident at-sensor radiance to measured digital number (DN). The association is usually realised by a linear regression that minimises the difference between modelled at-sensor radiance and known at-sensor radiance. The regression coefficients are also used in the reverse process to assign measured DN to at-sensor radiance that is considered as radiometric scaling. Uncertainties in the estimation of the regression coefficients or temporal changes in detector characteristics may then lead to visually perceptible stripings. However, in the following an approach is proposed which significantly reduces striping and preserves spectral characteristics of sensed surface cover materials. The approach consists of multiple steps which are consecutively executed (Figure 3).

![Workflow of proposed destriping per band](image3.png)

**Figure 3.** Workflow of proposed destriping per band

Before and after each reduction step the SNR is calculated (Gao, 1993). The SNR is used to decide whether preceding processing step has to be revoked or can be applied. For this purpose, interim results are stored. Proposed approaches to reduce miscalibrations are conditioned by the assumption that miscalibrations and the total Point Spread Function (PSF) are scene and band constant.
3.1 Edge masking

Edges which are not strict across (column or detector element) or along track (row or time) cause uncertainties in the proposed miscalibration reduction approach. If they don’t dominate or represent the image content these uncertainties can be minimised, e.g. by a binary edge exclusion.

In case of miscalibrated hyperspectral images the Hyperspectral Edge Detection Algorithm (HEDA) can be adapted to calculate binary edge maps (Rogass et al., 2010). For this, the implemented Busyness Multiple Correlation Edge Detector (Rogass et al., 2010) should be only applied in striping direction. In case of single banded images a similar adaption of the Canny algorithm (Canny, 1986) can be applied. Succeeding morphological dilations (Haralick et al., 1987; Rogass et al., 2009) additionally minimise edge adjacency effects caused by Point Spread Function (PSF) related blooming of edges into adjacent regions. The application of the reverse edge map gives than an edge filtered image.

3.2 Slope reduction

In the following a multistep slope reduction approach is proposed that does not require information of other columns and has to be conducted per band. However, the slope per detector element and band contributes each pixel of an image column the same fraction. Differenting the column values leads to the mathematical elimination of offsets. These differences reflect both the slope and to some extent the detector resolution. To estimate the slope, it is in a first step necessary to extract sorted, unique column values. Then, the smallest difference represents the slope times the smallest difference of unique values (SDUV) of a perfectly calibrated band. SDUV can be assessed as median average of all differences of unique column values. It follows from this that the slope can be estimated as ratio of the smallest difference and the SDUV.

Additionally, the shapes of column related histograms (estimation of the probability distribution) are evaluated. If the number of histogram bins and the frequency category of the maxima are equal for adjacent columns, then slope reduction should be not applied for considered column, because it can be assumed that different slopes cause ‘stretches’ of the histogram and a shift between their maxima.

After application the reciprocal slope on this column and conduction of slope reductions for all columns the SNR is calculated. If SNR indicates that slope reduction has improved the image quality, then the slope reduction is not revoked. To preserve the radiometric level of the band, a radiometric rescaling is performed after slope and offset reduction.

3.3 Offset reduction

Contrary to the slope reduction the offset reduction incorporates information of adjacent columns. If two adjacent image columns contain homogeneous regions of similar spectral characteristics and are only slightly different according viewing geometry then differences of adjacent columns contain offset information. The higher the frequency of a bin (frequency category) of the histogram of column differences the higher the likeliness of the bin to contain offset information. From this it follows that the offset can be estimated as the average of frequency weighted bin averages of column differences. The impact of outliers can be suppressed by using rather the median as the mean.

After application of the offset reduction by subtraction the SNR is calculated and used as indicator if preceding reduction can be finally applied or has to be revoked. In a next step the radiometric rescaling is performed to preserve spectra characteristics.

3.4 Rescaling

The rescaling aims at preservation of spectral characteristics of sensed surface cover materials that were potentially changed by foregoing reductions. This can be performed by detecting lowest reduction zones and by applying transformations comprising scaling information of lowest reduction zones. For this, the reduction vectors are evaluated in a moving window. For each window a ratio is calculated between the mean of the first and last reduction of the window and the reduction in the middle of the window. The window with the ratio closest to one gives then the positional index for radiometric rescaling. At this column index the whole band is rescaled by comparing the minimum and the maximum before and after reductions.

3.5 Detrending

The trend reduction is only in low SNR scenarios necessary. It aims at the minimisation of brightness gradients (may be caused by material, illumination and viewing geometry dependent surface responses on incident light) as well as of potential offset reduction related frequency undershoots. First, column averages are calculated. This average vector is smoothed to remove outliers and mean normalised to avoid distortions in areas that are not affected by trends. The smoothed and mean normalised average vector is then applied by row wise division.

3.5 Assessment of destriping performance

The grey valued images were artificially striped and, hence, ground truth was available. To avoid potential drawbacks that are associated with relying on a single type of evaluation, a set of specific image quality indicators were calculated before and after destriping. The global Peak-Signal-to-Noise-Ratio (PSNR) (Rogass et al., 2010; Wang and Bovik, 2009), the global Shannon Entropy (Rogass et al., 2010, Frank and Smith, 2010) and the local Modified Structural Similarity Index (MSSSIM) (Tsai and Chen, 2008; Wang and Bovik, 2009; Wang et al., 2004) were selected to objectively evaluate destriping outputs in comparison to striped inputs or ground truth. The PSNR considers the spectral ratio between band maximum and standard deviation, the Shannon Entropy incorporates spectral and spatial frequencies distributions and the MSSIM combines local structure, luminance and contrast metrics. All three image quality indicators were equally weighted.
4. Results and discussion

4.1 Results for grey valued images

Selected grey valued images cover a broad range of spectral and spatial image properties. The ‘Lenna’ image has a homogeneous grey value distribution, but contains a long natural stripe. The ‘Mandrill’ image is dominated by edges. The ‘Aerial’ image has a leptokurtic grey value distribution. Contrary to the 3 other grey valued images the ‘Sailboat on lake’ image is balanced due to grey value distribution and edge quantity.

Figure 4. Exemplary striped images (left) and destriping results (right) for a) ‘Lenna’, b) ‘Mandrill’, c) ‘Aerial’ and d) ‘Sailboat on lake’

The destriping of all 1600 grey valued, artificially degraded images that are exemplarily shown in Figure 4, revealed an overall accuracy of the destriping of about 93 % averaged for all image quality indicators introduced in chapter 3.5. The impact of the stripe type and the stripe level was less than 6 % and indicates the robustness of proposed approach. However, it is not likely that hyperspectral scenes will contain column parallel natural stripes as in the ‘Lenna’ image and may not be significantly dominated by edges as in the ‘Mandrill’ image. 97 % overall accuracy and 4 % striping type and level impact were achieved for likely images such as ‘Aerial’ and ‘Sailboat on lake’. Nevertheless, long natural stripes affect offset reductions that might be minimised by an additional rescaling of natural stripes.

4.2 Results for hyperspectral scenes

Results for the hyperspectral scenes were equal to the grey valued images. Ground truth was not available. It follows from this that only the rate of changes of image quality indicators could be calculated. The AISA scenes were radiometrically recalibrated by about 5 %. Reduction related changes in the SNR indicated that these scenes were dark current miscalibrated. Different tests on inter-scene striping correlations showed a high average correlation of 0.85. It follows from this that the sensor worked stable and the stripings were caused by miscalibration.
Examining the results visually and subjectively may reveal that all stripes were removed and miscalibrations were reduced (compare Figure 5). With regard to the results for the grey valued image samples it is assumed that about 97% of a perfect calibration has been achieved. Additionally, the spectral levels and shapes have not been significantly changed (compare Figure 6). This indicates a successful radiometric rescaling.

Figure 5. Exemplary striped images of sections in the middle of an AISA DUAL scene (VNIR-band 65 - 541 nm - a, SWIR-band 283 - 1190 nm - c) and their respective radiometrically recalibrated results (VNIR - b, SWIR - d) as well as a transect plot (e) through the middle of the same section for same VNIR and SWIR bands

Figure 6. Exemplary radiance plot before destriping (red) and after destriping (green)
5. Conclusion

The proposed approach for the reduction of miscalibration was widely tested and evaluated by different metrics. High calibration recovery rates of about 97% for linear miscalibrations have been achieved. It was shown how linear miscalibration-related striping can be reduced without losing image quality or generating spectral artefacts. Additionally, the robustness was tested and could be confirmed. It follows from this that proposed approach is capable to reduce miscalibrations of other pushbroom sensors that will be tested in the future.

References


