Radiometric harmonization utilizing pseudo-invariant features

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Satellite image mosaicing and the need for radiometric harmonization

The growing number of available optical remote sensing data providing large spatial and temporal coverage enables the coherent and gapless observation of the earth's surface on the scale of whole countries or continents. To produce datasets of that size, individual satellite scenes have to be stitched together forming so-called mosaics. Here the problem arises that the different images feature varying radiometric properties depending on the momentary acquisition conditions. The interpretation of optical remote sensing data is to a great extent based on the analysis of the spectral composition of an observed surface reflection. Therefore the harmonization of all images included in a large image mosaic is necessary to ensure consistent results concerning the application of procedures to the whole dataset. Here an algorithm is described which enables the automated spectral adjustment of satellite images to a reference scene. The proposed algorithm was put to stable and satisfying operational use to process a high number of SPOT-4/-5, IRS LISS-III and Landsat-5 scenes in the frame of the European Environment Agency's Copernicus/GMES Initial Operations (GIO) High-Resolution Layer (HRL) mapping of the HRL Forest for 20 Western, Central and (South)Eastern European countries. It was further evaluated on its reliability concerning the application to newer Sentinel-2 multispectral imaging products. The results show that the algorithm is comparably efficient for the processing of satellite image data from sources other than the sensor configurations it was originally designed for.

Pseudo-invariant features

In order to estimate the parameters of the linear fitting function which describes the relationship between master and slave scene image, objects and areas that can be considered (spectrally) invariant over time are of particular interest. The features used for the least-square estimation are denoted as pseudo-invariant as the inter-band composition of their spectral responses can be considered equivalent concerning different times of scene acquisition, but the absolute value of the pixels digital numbers differ in the individual scenes depending on acquisition conditions. Schott et al. (1988) state that features of that kind usually correspond to man-made structures, which can be confirmed for the intermediate feature mask (PIF mask) generated and as seen in Figure 1.

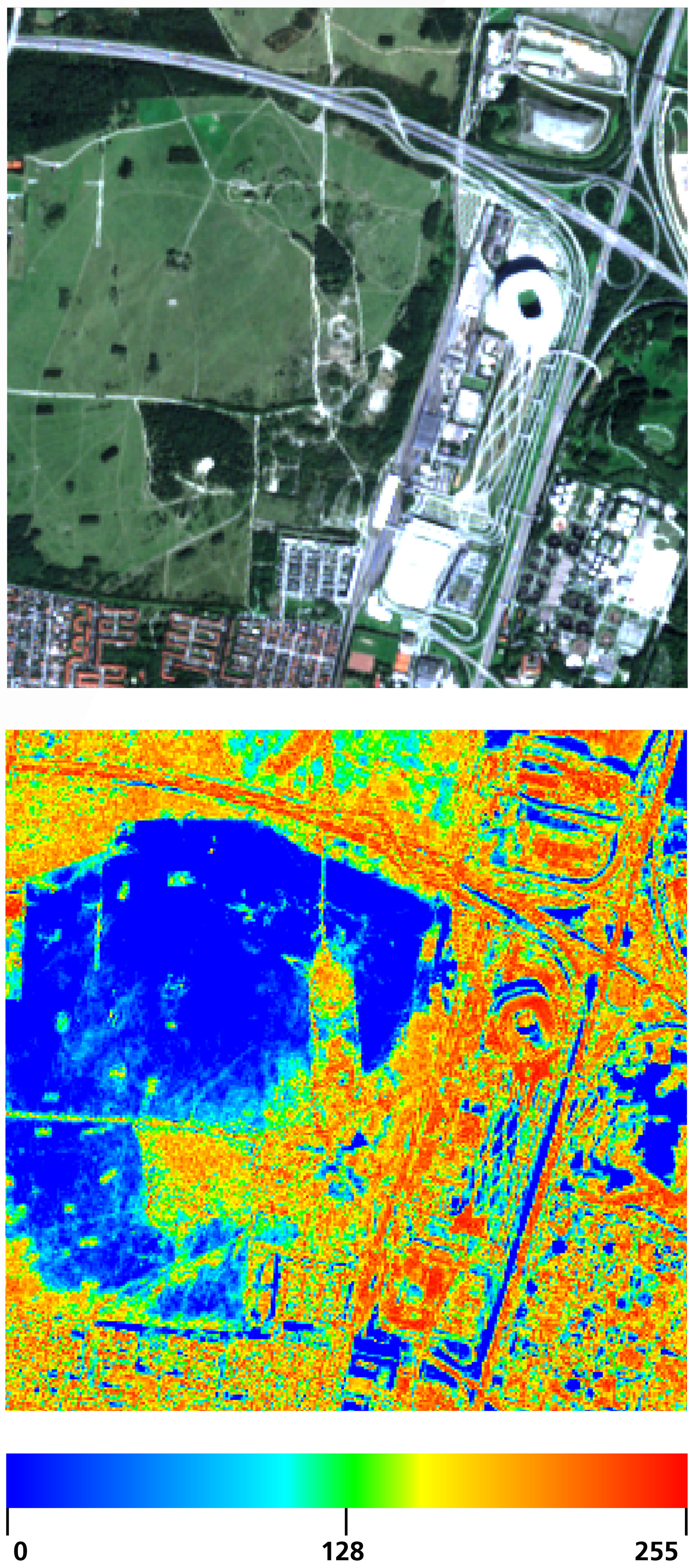

Figure 1. Example overlap area of two satellite images featuring mixed coverage of man-made structures and vegetation (top image) and corresponding pseudo-invariant feature mask (bottom image). The feature mask in this case is quantized to 8 bit with pixels bearing values of 255 being very reliable pseudo-invariant features and pixels bearing values nearing 0 being of inferior quality concerning radiometric harmonization.

A manual selection of high-quality pseudo-invariant features as suggested in Rahman et al. (2015) is not feasible with regards to the formulated goal of integrating the algorithm in an automated processing chain. Therefore the algorithm was developed to automatically detect appropriate pixels and writing them to a PIF mask image including a quality measure value expressing spectral invariance of a particular pixel. Pixels exhibiting a high PIF value are then used as observations to estimate a linear fitting function via least-square estimation. In detail the algorithm conducts the following steps to generate the pseudo-invariant feature mask:

1. The overlapping image area of a georeferenced master and slave image is automatically determined. In case of sub-pixel shift a nearest neighbour resampling is done to ensure the correspondence between the image rasters.

2. Within the overlap region the inter-band ratios for all possible band combinations between the master and the slave images are calculated on a pixel-wise basis, summed up and normalized using following equation (1).

$$M = \frac{\sum_{i=1}^{k-1}\sum_{j=i+1}^{k}\left\|\left[0.5+\frac{0.5\times(A_i-A_j)}{A_i+A_j}\right]-\left[0.5+\frac{0.5\times(B_i-B_j)}{B_i+B_j}\right]\right\|}{(k-1)!} \qquad (1)$$

where

$$A = master\ image$$
$$B = slave\ image$$
$$k = equal\ number\ of\ bands\ for\ each\ image$$
$$(in\ case\ of\ Sentinel\ 2\ 10m\ datasets\ k == 4)$$

3. The mask image is normalized to an 8-bit range and scaled by a factor of 16 as in equation (2).

$$PIF = (255 - M * 255) * 16 \qquad (2)$$

Equation (1) delivers normalized values in the range [0,1] where pixels exhibiting highly invariant spectral compositions feature a value of 0, pixels showing a low radiometric consistency a value of 1 vice versa. The scale factor of 16 is applied in order to stretch the dynamic range of high valued pixels to enable a more precise thresholding of the PIF mask concerning features actually used in the linear fitting process.

Results

Relative error of mean radiance per band		
	Unadjusted image	**PIF adjusted image**
Band 1	25.51%	15.22%
Band 2	14.25%	5.48%
Band 3	12.88%	4.59%
Band 4	6.38%	2.03%

The results of the radiometric adjustment process for an example subset as well as the original reference image and the unadjusted mosaic can be seen in Figures 2-4.

The relative error of mean radiance for all bands of the example images is presented in the table above. It shows that the proposed algorithm can be used to highly improve radiometric homogeneity of individual satellite scenes.

The relative error values lie within the expected threshold of radiometric differences. Certain uncertainties can be expected by the fact that while specfic spectral compositions of pixels are linearly adjusted, the overall phenology of individual satellite scenes can strongly differ. Therefore pixels featuring comparable spectral characteristics are adjusted correctly but corresponding pixels in overlapping images can exhibit varying spectral compositions.

The high value regarding Band 1, which corresponds to the blue channel, results from waterbodies that generally do not appear as strong pseudo-invariant features and therefore do not contribute to the adjustment parameter calculation. This vice verca affects the effectiveness of radiometric harmonization regarding these particular water pixels.

Figure 2. Reference master image to which slave images are adjusted.

Figure 3. Overlapping satellite images with the reference scene on the bottom half and the corresponding slave scene in the top half.

Figure 4. Radiometrically harmonized overlapping satellites images using pseudo-invariant feature adjustment.

The conducted experiment shows that the proposed algorithm, already operationally applied for the spectral harmonization and mosaicing of multi-sensor satellite images from the SPOT, IRS and Landsat-5 missions, also performs as intended for the state-of-the-art Sentinel-2 multispectral data products, delivering satisfying adjustment results concerning visual assessment as well as statistical evaluation under certain conditions. It processes large input images within an acceptable timeframe. It can therefore be used to process large quantities of satellite images, providing large scenes and mosaics with a homogeneous radiometry which is essential for the derivation of high level remote sensing data products and analysis tasks.

References:

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