Using a wavelet based method for high resolution satellite image fusion

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Abstract

A procedure based upon the wavelet transform to improve the spectral quality of high resolution image fusion techniques has been tested and compared with respect to three classical standard methods: the Brovery transform, the IHS substitution based and the PCA substitution based. The wavelet approach combines a high resolution panchromatic image and a low resolution multispectral image by adding wavelet planes of the panchromatic image to the intensity component of the low resolution image. All methods are tested over three IRS satellite images from different areas, as well as over LANDSAT 7 satellite images. The wavelet based method is the most efficient in preserving the spectral information contained in the original multispectral images.

Keywords: image fusion, merging, wavelets.

1 Introduction

The number and quality of commercially available multispectral sensors and the data they provide are continually improving, but there is always compromise between achieving high spatial resolution, necessary for those applications that require high degree of detail, and high spectral resolution when a better feature discrimination level is needed. However, there are some situations that simultaneously require high spatial and spectral resolutions in a single image. The techniques of data fusion, or data merging, provide an alternative to that constraint [1], being used to combine low-resolution multispectral satellite imagery with higher resolution panchromatic or radar imagery, improving their visual quality and interpretability.

In this sense, advanced analytical or numerical data fusion techniques are being developed in order to obtain multispectral images with the highest spatial resolution available [2]. Different methods have been proposed for merging panchromatic and multispectral data [3]. The most common procedures are the Brovery transform, the PCA (Principal Component Analysis) transformation based method, and the IHS (Intensity, Hue, Saturation) color space based method. A common characteristic of these methods is that they often produce spectral degradation of the final merged image.

Lately, and with the aim of improving these techniques, a new approach to image merging that uses a multi-resolution analysis based upon the discrete two-dimensional wavelet transform has been proposed [4]. The wavelet approach can be considered as an improvement of the classical IHS method and it is expected to better preserve the spectral characteristics of the multispectral image. The aim of our applied study is to quantitatively and qualitatively evaluate and compare the wavelet approach with respect to the standard methods, tested over different sets of images, from IRS and LANDSAT satellites, and from diverse areas.

2 Materials and methods

2.1 Images

In this study, we have used a high resolution image data set from three areas with different landscape characteristics acquired by the IRS-1C/1D satellite, as well as a lower resolution set acquired by the LANDSAT 7 satellite, so we could evaluate sensor dependent and geographic differences. The table 1 shows the technical parameters of panchromatic and multispectral sensors from both satellites.

SATELLITE	**IRS-1C/1D**		**LANDSAT 7**	
Sensor	**PAN**	**LISS-III**	**PAN**	**TM**
Spectral Bands	0,50-0,75μm	1 Green:0,52-0,59μm 2 Red: 0,62-0,68μm 3 NIR: 0,77-0,86μm 4 SWIR:1,55-1,70μm	0.52-0.90μm	1: 0,45-0.52μm; 2: 0.53-0.61μm 3: 0.63-0.69μm; 4: 0.78-0.90μm 5: 1.55-1.75μm; 6:10.4-12.5μm 7: 2.09-2.35 μm
Spatial Resolution	5.8 m	23 m	15 m	30 m
Radiometric Resolution	6 bit	7 bit	Best 8 of 9 bits	

Table 1: Characteristics of the images acquired by the sensors on-board IRS & LANDSAT 7 satellites.

2.2 Standard Methods

The IHS color transformation method is the most widely used. Initially, the low resolution multispectral image is registered and resampled to match the high resolution panchromatic image, so the resulting output image has the same dimensions as the extracted high resolution image. The RGB image (three spectral bands) is then transformed into the intensity, hue and saturation (IHS) color space, the intensity component is substituted by the high resolution image and then, the reverse transformation IHS-to-RGB is performed.

The PCA method is quite similar in essence to the IHS method, but it can be used with any number of spectral bands. The first component is replaced by the high spatial resolution image and then, the inverse PCA transformation is applied to return the data to the original image space. In both approaches is important that the original and the replacement components are radiometrically correlated.

The Brovery transform applies to the digital counts of three spectral bands from the multispectral image resampled at the resolution of the panchromatic image with higher resolution. The three methods assume that the spectral range of the panchromatic image covers the spectral range of the sum of the multispectral image bands, which it is not exactly true.

2.3 The Wavelet Method

Wavelet techniques are increasingly being used for the processing of images. The algorithm used in this study was based on multiresolution wavelet decomposition. The image is decomposed into multiple channels based on their local frequency content, obtaining new images each one of them with different degree of resolution [5].

Thus, the wavelet transform of a distribution *f*(t) can be expressed as

$$W(f)(a,b) = |a|^{-\frac{1}{2}} \int_{-\infty}^{+\infty} f(t)\psi\left(\frac{t-b}{a}\right)dt$$

where *a* and *b* are scaling and translational parameters, respectively.

Each base function $\psi\left(\frac{t-b}{a}\right)$ is a scaled and translated version of a function called mother wavelet. These base functions are $\int \psi\left(\frac{t-b}{a}\right) = 0$

Given an image P , to decompose it into wavelet planes we should construct the sequence of approximations:

$$F_1(\mathrm{P}) = \mathrm{P}_1 \ , \quad F_2(\mathrm{P}_1) = \mathrm{P}_2 \ , \quad F_3(\mathrm{P}_2) = \mathrm{P}_3 , \quad ...,$$

In order to construct this sequence, successive convolutions are performed with a filter obtained from an auxiliary function or scaling function. The use of this function leads to a convolution with a 5x5 mask (right):

$$\frac{1}{256}\begin{pmatrix} 1 & 4 & 6 & 4 & 1 \\ 4 & 16 & 24 & 16 & 4 \\ 6 & 24 & 36 & 24 & 6 \\ 4 & 16 & 24 & 16 & 4 \\ 1 & 4 & 6 & 4 & 1 \end{pmatrix}$$

The wavelet planes are computed as the differences between two consecutive approximations P_{l-1} y p_l.

Letting $W_l = P_{l-1} - P_l$ (l = 1,...,n), in wich $P_0 = P$, we can write the reconstruction expression

$$P = \sum_{l=1}^{n} W_l + P_r$$

Wavelet based image merging may be performed in two ways: 1) Replacing some wavelet coefficients of the multispectral image by the corresponding coefficients of the high-resolution image; and 2) by adding high resolution coefficients to the multispectral data. The second option preserves all of the spatial information in the multispectral image, and it allows again two posibilities to extract the high resolution information: adding to the RGB componentes or adding to the intensity component. We used this last approach because it is more straightforward and because it would basically affect to the spatial information, but not to the spectral. Details of an initial panchromatic image and its first three wavelet planes are showed on figure 1.

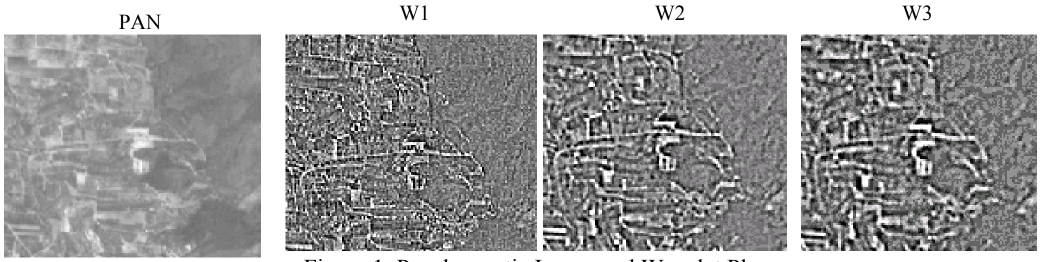

Figure 1. Panchromatic Image and Wavelet Planes.

Figure 2 shows the complete procedure followed. First, the low resolution multispectral image is registered to match the panchromatic image, then three of the bands assigned to the RGB components are transformed into the IHS representation. The panchromatic high resolution image is decomposed into *n* wavelet planes, which are added to the intensity component of the multispectral image. The new values are transformed back into the RGB representation and, as a part of the post-processing enhancing techniques, a natural color transformation algorithm is applied to create a blue synthetic band and be able to view the resulting image as a natural composite color image. After georeferencing the image to the UTM cartographic coordinates, a high-pass

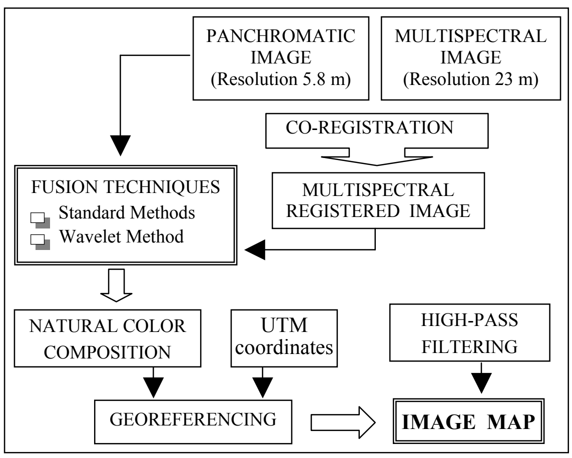

Figure 2. Satellite data processing steps involved in the image fusion technique

convolution is applied.

3 Results

Spatial and spectral quality are the two important indices that are used to evaluate the quality of any fused image. Although some methods have been developed to assess the spatial quality [6], this is still a difficult topic to evaluate. In this study, we used the correlation coefficient between the results and the original multispectral images and the

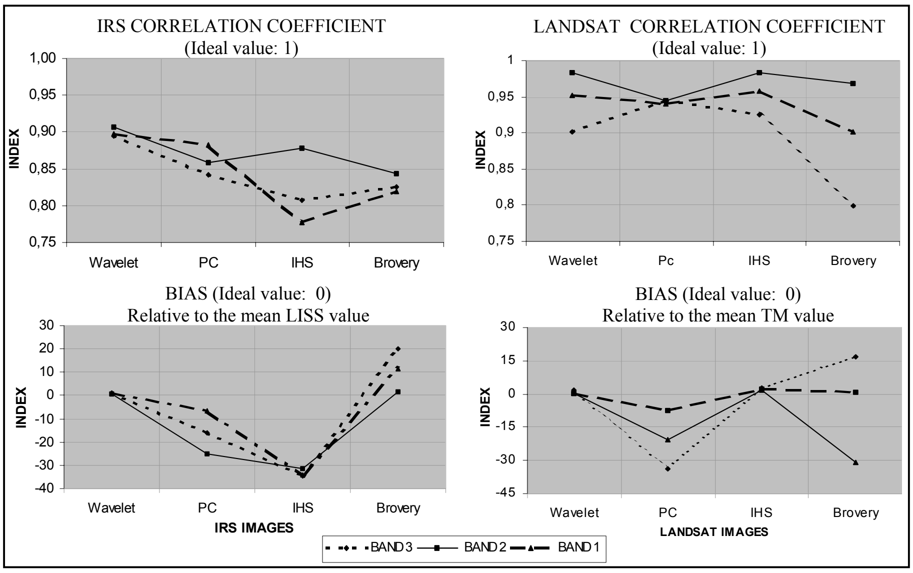

Figure 3. Correlation Coefficient and *Bias* of the IRS and LANDSAT images.

bias or difference of the mean value between the original and the merged image, as indices of the spectral degradation introduced by the different methods. Figure 3 shows the mean values of these indices for the two sets of images and for each of the four merging methods tested. In the three areas of the IRS images, the correlation and bias is always better using the wavelet decomposition method, while in the Landsat images, both the wavelets and the HSI approaches provide similar spectral results, always better than the other two. In Figure 4, where a detail image of color representations of the original and merged images using the four tested methods can be observed, it is evident that the best spectral similarity with the original multispectral image corresponds to the wavelet method. However, the spatial characteristics of the panchromatic image are well preserved in all cases.

4 Conclusions

The standard data fusion techniques distort the spectral characteristics of the multispectral data. The additive wavelet method improves the spatial quality of the multispectral image while preserving its spectral content to a greater extent. In the case of the high resolution IRS images, the application of this method notably improves the final result, while for the tested Landsat images results are equivalent to those obtained with the IHS method.

This technique can be useful in the interpretation and analysis of multispectral imagery, and hence, mapping capabilities of remote sensing data may become more efficient. With upcoming improved sensors, the importance of multisensor image fusion and interpretation will increase and open new possibilities in Earth observation for operational applications involving protection and development of the Earth's enviroment.

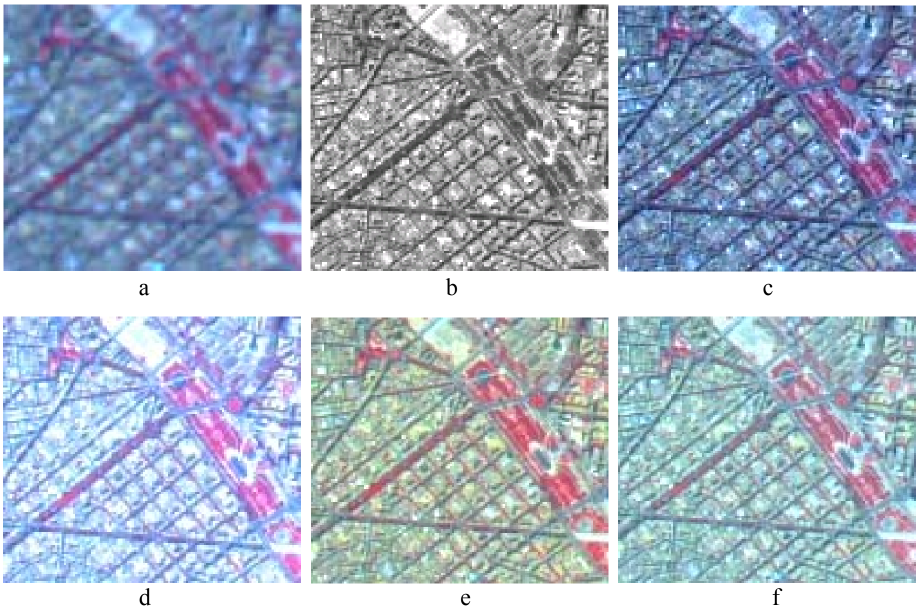

Figure 4. (a) Original multispectral LISS III image from Valencia (detail); (b) Original Panchromatic image; and results of the fusion process using the following methods: (c) Wavelet ; (d) IHS; (e) Brovery; and (f) PCA.

5 References

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