Remotely Sensed Image Fusion Using The Wavelet Transform

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Abstract – Image fusion aims at the integration of complementary information from multisensor data so that the new images are more suitable for computer-processing tasks and visual interpretation. This paper presents a variation of an image fusion method that uses a multi-resolution analysis based upon the wavelet transform. In order to evaluate its performance the proposed method is compared with the IHS and another wavelet method. The Wavelet method provides a better preservation of spectral characteristics than IHS method.

INTRODUCTION

The concept of image fusion varies from one scientist to another. In this work the term image fusion will be considered as a procedure that combines complementary data to provide a hybrid image of greater quality. It has been suggested to use the terms merging and combination in a much broader sense than fusion, but here all of these terms have the same meaning.

The combination of images with complementary information opens a broad field of applications such as in geology, agriculture, land use, forestry, change detection, etc. However, image fusion has not reached an operational status due to the difficulty of generalizing fusion techniques. In general, such technique depends on the application.

The type of fusion that this work will be dealing with is the integration of high resolution and multi-spectral information. The idea is to obtain a hybrid high-resolution multi-spectral image that attempts to preserve the radiometric characteristics of the original multi-spectral data as much as possible. In this context, many methods of image fusion have been proposed. Garguet-Duport et al (1996) proposed an approach based on wavelet transform to combine SPOT XS with PAN data to produce multispectral imagery with 10 m spatial resolution. Yocky (1996) also uses multi-resolution wavelet decomposition to integrate TM-5 images and Panchromatic SPOT. Li et al (1995) presents an image fusion method based on wavelet transform and applies it to merge a variety of sensor images.

The objective of this paper is to study and evaluate an image fusion approach, which is a variation of the methods proposed by Garguet-Duport et al. (1996) and Yocky (1996).

The proposed method handles images from different sensors and can be applied to integrate multispectral and panchromatic images of a variety of resolutions.

The method has been tested on SPOT, TM-5, ETM+, CBERS images for different areas (forestry, urban, agriculture, geological) and, in most of the cases, we have obtained very encouraging results. In order to evaluate the performance of the proposed method, its results is compared with the IHS method (Carper et al, 1990), which is the most traditional method for remotely sensed image fusion, and with Li's wavelet method (Li et al 1995).

MULTIRESOLUTION ANALYSIS

The term spatial resolution is used to refer to the size of the smallest observable object. If one can observe fine details in an image with good precision it can be said that this image has good resolution.

In a multi-resolution analysis process the original image is decomposed in different levels of resolution creating a set of sub-bands. The wavelet transform is one kind of operation that can be used in this analysis.

The wavelet transform decomposes an image f in many sub-bands of different resolution levels. These sub-bands (wavelet coefficients) represent the low-resolution (a) and detail information (d) of the original image. For digital signals the output a, representing the low frequency components, comes from the convolution of the signal f with a low-pass filter h and the convolution of the same input signal f

with a high-pass filter *g* produces the output *d* that represents the high frequency components.

At this point we have two new representations of the original signal: *a* and *d*. If we take the already filtered signal *f* and perform the same convolutions again we are moving to a coarser scale. This leads to a natural multi-resolution representation of the original signal where the smooth part plus the details combine to form the signal at a finer scale level and so on. Fig. 1 shows a schematic representation of a multi-resolution decomposition of an image.

In Mallat´s implementation (Mallat, 1989) for an image, the original image is initially decomposed in 4 sub-bands called LL, HL, LH and HH. HH is a low-resolution version of the original image and LH, HL and HH are images of details in the horizontal, vertical and diagonal directions. The filtering is recursively applied to the outputs of the LL sub-band until the desired level is reached. The resolution decreases by a factor of two at each decomposition level. No information is lost by using this procedure and perfect reconstruction of the original image is still possible as long as the chosen filters allow it. Fig. 2 shows the wavelet decomposition scheme, which contains the LH, HL and HH bands of the image at different scales as well as the LL band.

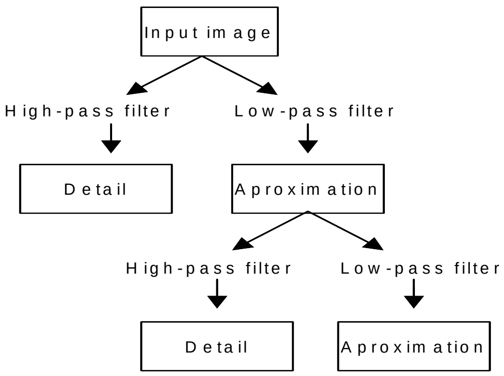

Fig. 1 – Cascade decomposition of a signal *f (x, y)*.

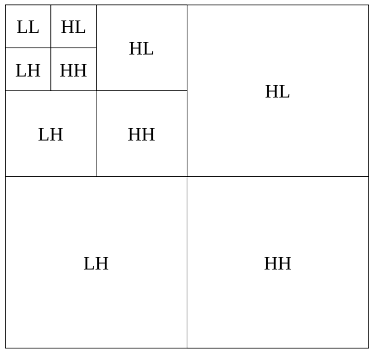

Fig. 2 – The wavelet decomposition scheme, in three levels. Adapted from Mallat (1989).

IMAGE FUSION APPROACH

Fig. 3 presents the schematic diagram of the proposed fusion method. Firstly, the images are radiometrically and geometrically corrected in order to achieve conformity (Pohl e Touron, 1999). The high-resolution image has its mean and variance equalized for each spectral band generating three new panchromatic images equivalent to each spectral band. Then the wavelet transforms of the images are computed.

The basic procedure of fusion is performed by replacing the LL band of the high-resolution image decomposition at the coarsest level by the LL band of the low-resolution image decomposition that contains spectral information. As the sub-bands LL must have the same size, the high-resolution image is decomposed in *L* levels while the multi-spectral images are decomposed in *L-S* levels. *S* stands for the relation between the spatial resolutions of the two images. For example, if the resolutions of the images to be merged are 15 and 30 m this relation will be:

$$S = \log_2 \frac{30}{15} = 1,$$

which means that the low-resolution image needs to be decomposed one level less than the high-resolution image.

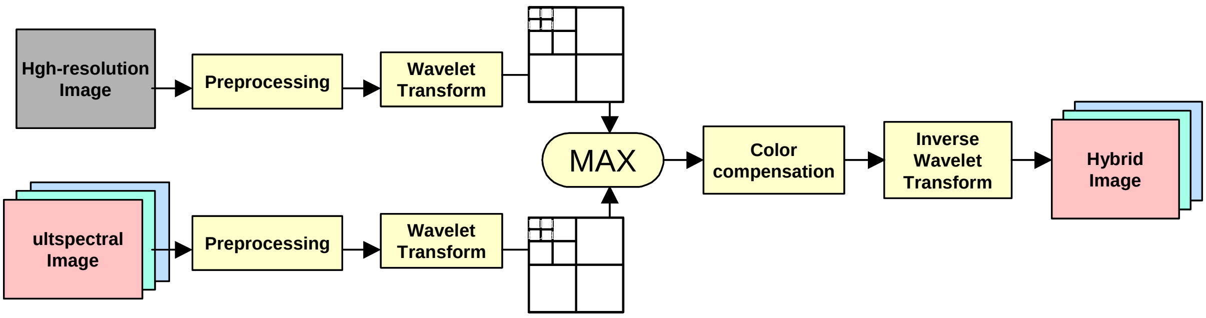

Fig. 3 – Schematic diagram of the fusion method..

The larger absolute values of the detail sub-bands correspond to salient features in the original images such as edges, lines and region boundaries. Taking this into account, some fusion algorithms select the maximum absolute values of the wavelet coefficients and substitute them in their corresponding positions of the hybrid decomposition image. Afterwards, the hybrid image is constructed by calculating the inverse wavelet transform.

Depending on the application and the type of image, the composite image may not have the radiometric characteristic preserved. Yocky (1996) pointed out some drawbacks of these basic fusion approaches. In order to attack these problems we propose the following procedure.

Similar to Garguet-Duport (1996) and Yocky (1996) the LL sub-band of the high-resolution images is replaced by the LL sub-band of the multi-spectral image. To compute the detail bands (HL, LH and HH) of the hybrid decomposition image we have used the correlation measure between the LL bands of both decompositions to control the maximum selection rule. Le k, j, D^{XS}, D^{P} and D^{H} be the correlation coefficient between the LL bands, the decomposition level, the detail sub-bands of the multi-spectral, high-resolution and hybrid images, respectively. The calculation of the new wavelet coefficients values follows this rule:

$$D_j^H = \max(D_j^{XS}, D_j^P) + (1 - k_j) D_j^{XS}$$

Therefore, part of the detail information of the low-resolution image can be added in order to preserve the spectral information.

RESULTS AND COMMENTS

The method has been tested on images of different areas (agriculture, urban) and for different sensors (ETM, TM-5, SPOT, CBERS). Due to the shortage of space we will show only results obtained for images covering a region around Brasilia city – Brazil, WRS 221/71, taken from Landsat 7 ETM+, bands 8 (pan), 5(R), 4(G) and 3(B) and acquired on 31 July 1999.

Evaluation tests were conducted following Wald’s methodology (Wald et al., 1997). For image simulation, we have used low-pass filters projected based on Banon´s idea (Banon, 1990).

Table I presents statistical information (mean, variance and correlation) corresponding to the original bands 5, 4 and 3 of the sensor ETM+ and synthetic images obtained with IHS and wavelet methods (present work; Li et al, 1996). The numbers in the first column are the corresponding spectral bands.

TABLE I

STATISTICAL DATA RESULTS

Band	Mean	Variance	Correlation
ETM 5	81,1	979,8	1,00
IHS 5	78,7	810,2	0,92
Wavelet 5	80,7	939,1	0,97
Li 5	80,4	932,1	0,94
ETM 4	66,3	446,6	1,00
IHS 4	65,3	528,1	0,93
Wavelet 4	66,1	435,2	0,98
Li 4	65,6	443,1	0,96
ETM 3	62,2	445,6	1,00
IHS 3	61,0	444,8	0,92
Wavelet 3	62,0	423,0	0,97
Li 3	61,5	411,0	0,93

In Table I, one can observe that the statistical information of the composite images using the proposed method is very similar to that of original images.

Figs. 4 and 5 show the difference, in absolute values, between the averages and variances of the original and synthetic images for each band. Figs. 6, 7, 8 and 9 show the original image, and the hybrid images obtained from the proposed, IHS and Li´s methods, respectively.

Observing Figs. 4 and 5, one comes to the conclusion that the composite images derived from the proposed method and from Li´s method showed good preservation of spectral information. This can be confirmed in Figs. 6, 7, 8 and 9, which also show that the structures of the panchromatic image have been injected in the multi-spectral image in all fusion methods.

However, one can observe that the synthetic image derived from IHS method does not preserve the spectral information as much as the one from the wavelet method, particularly for bands 4 and 5. This can be explained by the fact that the component I of the IHS transformation is totally replaced by the panchromatic band, which can contain spectral information quite different from that stored in the component I. On the other hand, in the wavelet methods the spectral information of each band is added to the high-resolution band separately, without using any average operation.

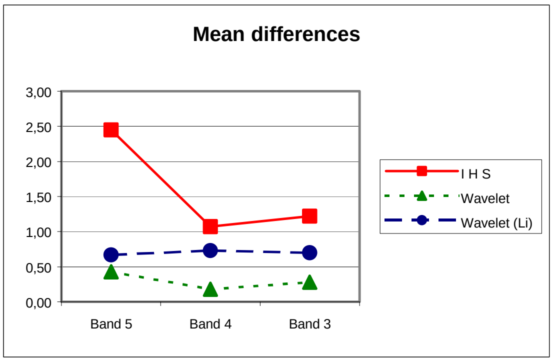

Fig. 4 - Mean differences between synthetic and original images.

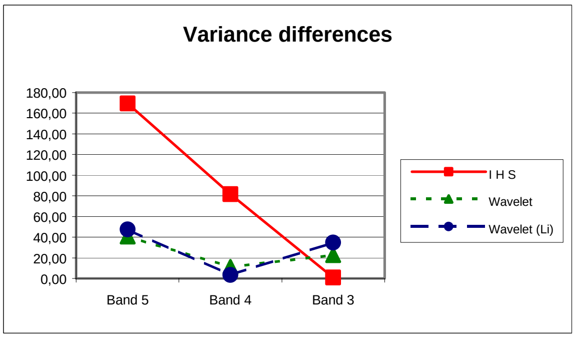

Fig.5 - Variance differences between synthetic and original images.

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Fig. 6. - Color composition of original bands (5R 4G 3B).

Fig. 7. - Proposed wavelet fusion synthetic bands composition.

Fig. 8. - IHS fusion synthetic bands composition.

Fig. 9. - Wavelet (Li) fusion synthetic bands composition.