SATELLITE IMAGE FUSION WITH WAVELET DECOMPOSITION

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ABSTRACT

To verify the features of an object or an area, there is a need to merge panchromatic images with high spatial resolution and multispectral images with high spectral resolution. Standard fusion methods like IHS transform are not satisfactory, because they distort spectral characteristics of the multispectral data. In wavelet methods, the aim is to decompose the image into subbands, which have the low resolution image and detail information and inject the high-resolution information to the multispectral image. In this study, wavelet transform technique known as "à trous" algorithm is used and results have been evaluated using SPOT and IRS data. Methods based on wavelet transform give clearly better results by means of preservation of spectral characteristics.

I. INTRODUCTION

The use of satellite remote sensing and its applications have been improved in last a few years parallel to satellite and computer technology. Although, today's sensor systems have high resolution imaging capability, they have still constraints, because of the observation system itself. While data with high spatial resolution is one band only, the multispectral data with high spectral resolution has low spatial resolution. However, to verify the features of an object or an area, resolution in both should be high. So there is a need to use data from different instruments, which have different properties. This need brought up the problem of merging images with high spatial resolution and high spectral resolution. The goal is to merge different properties of images of same area and come up with a resulting image having both. For example, SPOT provides high-resolution panchromatic data (10m), and low resolution multispectral data (30m). As a result of the data fusion, high-resolution in multispectral image is achieved. A number of methods have been proposed for merging panchromatic and multispectral data, [1,2]. The most common procedure is intensity-hue-saturation (IHS) transform method, however it causes spectral degradation. This is particularly crucial in remote sensing if the images to merge were not taken at the same time. In the last few years, multi-resolution analysis has become one of the most promising methods for the analysis of the images. Several authors proposed a new approach to the problem of image merging, which uses a multi-resolution analysis procedure based upon the discrete 2-D wavelet transform, [4-8]. In this study, different fusion methods have been studied and the comparison is done by means of spectral quality. Wavelet-based methods preserve the spectral characteristics of the multispectral image better than standard IHS method. To decompose the image into wavelet coefficients, discrete wavelet transform algorithm known as "à trous" is used which allows to use a dyadic wavelet with non-dyadic data in a simple way.

II. STANDARD MERGING METHOD

The standard merging method, IHS is based on the color space transformation of RGB to intensity-hue-saturation components. Block diagram of standard merging method is given in Figure.1 and the steps to perform are the following.

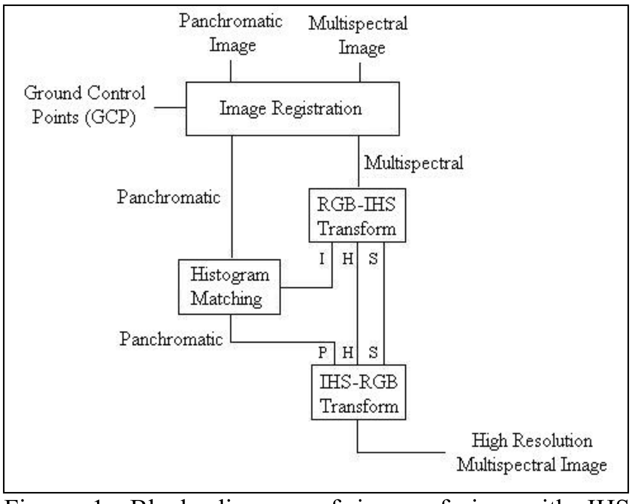

Figure 1. Block diagram of image fusion with IHS transform method.

1) Registration of the multispectral image to the panchromatic image within 0.25 pixels using ground control points.
2) RGB to IHS transformation
3) Histogram matching between the panchromatic image and the intensity component of the multispectral image to take the differences at the time of acqusition into account.
4) Chance the intensity component with panchromatic image and get inverse transformation back to RGB.

However, there are different algorithms using different calculations for intensity component of the IHS transformation. The definition known as Smith's triangle model is used in this paper.

$$I = \frac{R+G+B}{3} \quad (1)$$

III. WAVELET DECOMPOSITION

Wavelet decomposition is being used widely for the processing of images in remote sensing. Multiresolution analysis based on the wavelet theory permits the injection of detail information between different levels of scale and resolution. The decomposition of the image gives multiple bands based on their local frequency content. Wavelet transform of the image provides good localization in both frequency and spatial domain. At each decomposition step the resulting image will have lower resolution. The continuous wavelet transform of the signal f(x) is

$$W(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} f(x)\, \psi^{*}\left(\frac{x-b}{a}\right) dx \quad (2)$$

where $\psi(x)$ is the mother wavelet, a is the scale and b is shift parameter.

A. Multiresolution Analysis

Multiresolution analysis results from the embedded subsets generated by interpolations at different scales. In (2), a is 2^j for increasing integer values of j. From the function , f(x), a ladder of approximation spaces is constructed with

$$\cdots \subset V_3 \subset V_2 \subset V_1 \subset V_0 \cdots \quad (3)$$

such that, if $f(x) \in V_j$ then $f(2x) \in V_{j+1}$. The function f(x) is projected at each step j onto the subset V_j. This projection is defined by $c_j(k)$, the scalar product of f(x) with the scaling function $\phi(x)$ which is dilated and translated.

$$c_j(k) = \left\langle f(x), 2^{-j}\phi(2^{-j}x - k)\right\rangle \quad (3)$$

Using the scaling function, filter coefficients h(n) can be calculated from eq.4

$$\frac{1}{2}\phi\left(\frac{x}{2}\right) = \sum_n h(n)\phi(x-n) \quad (4)$$

B. The " à trous" Algorithm

The discrete wavelet transform can be done with several different algorithms. However, not all algorithms are well suited for all the problems. Mallat's algorithm uses orthonormal basis, but the transform is not shift-invariant, which will be a problem in data fusion. To achieve the shift-invariant decomposition, "à trous" algorithm is used. It is a redundant transform, decimation is not carried out. The sampled data $\{c_0(k)\}$ are the scalar products at pixel k of the function f(x), with a scaling function $\phi(x)$ which corresponds to a low pass filter. The approximation in scale i, is calculated with (5) from i-1.

$$c_i(k) = \sum_l h(l)\, c_{i-1}(k + 2^{i-1} l) \quad (5)$$

$$w_i(k) = c_{i-1}(k) - c_i(k) \quad (6)$$

The wavelet planes are computed as the differences between two approximation planes using (6). The difference between two scales is the detail information between two resolution levels. The decomposition using "à trous" algorithm gives n wavelet planes each having same number of samples, carrying details and a residual image with low resolution. The reconstruction formula is ;

$$c_0(k) = c_{n_p}(k) + \sum_{j=1}^{n_p} w_j(k) \quad (7)$$

$c_{np}(k)$, is the residual image and $w_j(k)$ are the wavelet planes from each scale. If B_3 spline is used for the scaling function, filter coefficients calculated from (4) in 2-D are

$$\frac{1}{256}\begin{pmatrix} 1 & 4 & 6 & 4 & 1 \\ 4 & 16 & 24 & 16 & 4 \\ 6 & 24 & 36 & 24 & 6 \\ 4 & 16 & 24 & 16 & 4 \\ 1 & 4 & 6 & 4 & 1 \end{pmatrix} \quad (8)$$

IV. IMAGE FUSION METHODS

In wavelet decomposition, c_i are the successive versions of the original image. The first wavelet planes of the high-resolution panchromatic image have spatial information that is not present in the multispectral image. The injection of this detail information into multispectral image results with high resolution in both spatial and spectral domain.

A. Substitution of Wavelet Planes of RGB (WRGB)

This method is based on substituting the first few wavelet planes of panchromatic and multispectral image. So, high-resolution information is carried onto the multispectral image. First three steps of the procedure is similar to IHS transform method. Then, PAN image and RGB bands of multispectral image are decomposed into n wavelet planes

$$PAN = \sum_{l=1}^{n} w_{Pl} + PAN_r \quad (9)$$

$$R = \sum_{l=1}^{n} w_{Rl} + R_r$$
$$G = \sum_{l=1}^{n} w_{Gl} + G_r \qquad (10)$$
$$B = \sum_{l=1}^{n} w_{Bl} + B_r$$

The next step is to replace the first wavelet planes of R, G, and B decompositions by the planes of panchromatic image and perform the inverse wavelet transform. The block diagram of the method is in Figure 2.

$$R_n = \sum_{l=1}^{n} w_{Pl} + R_r$$
$$G_n = \sum_{l=1}^{n} w_{Pl} + G_r \qquad (11)$$
$$B_n = \sum_{l=1}^{n} w_{Pl} + B_r$$

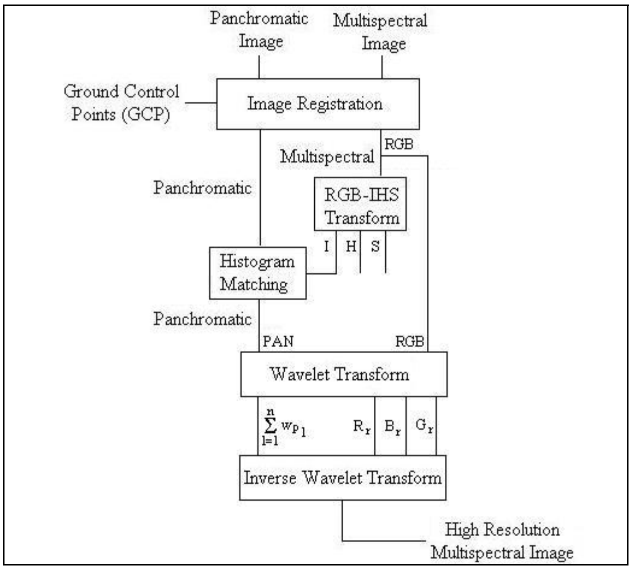

Figure 2. Image fusion with WRGB method.

B. Substitution of Wavelet Planes of Intensity (WI)

In this method wavelet decomposition is applied to the intensity component of the multispectral image instead of R, G and B (eq.12). The wavelet planes of I is replaced by the planes of panchromatic image and inverse transform is performed (eq.13). The resulting intensity component, I_n is used in transformation back to RGB.

$$I = \sum_{l=1}^{n} w_{Il} + I_r \qquad (12)$$

$$I_n = \sum_{l=1}^{n} w_{Pl} + I_r \qquad (13)$$

The block diagram of the method is in figure 3.

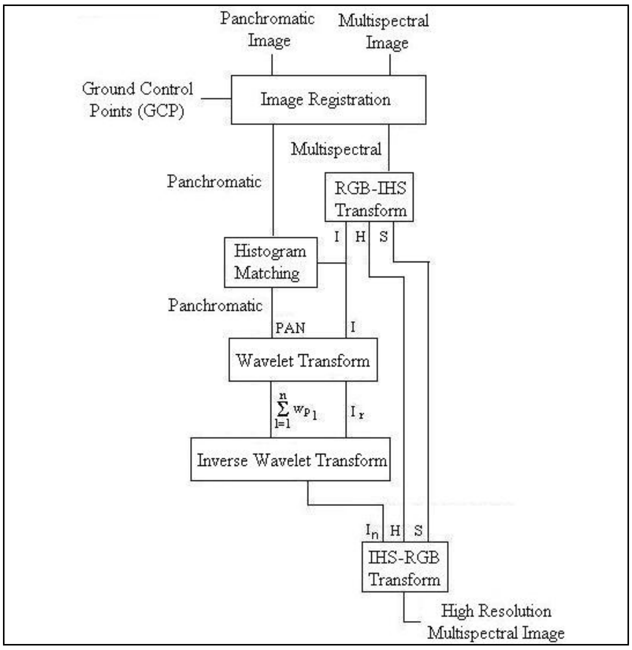

Figure 3. Image fusion with WI method

IV. APPLICATION AND RESULTS

The data used in this study is SPOT-XS multispectral and IRS-1C panchromatic data from 13 June 1993 and 22 August 1996 respectively. While spatial resolution of the SPOT data is 20m, resampled IRS data is 5m. The test site covers mostly urban area and the airport of Istanbul.

At the end of the fusion process, resulting multispectral image has 5m spatial resolution, but there is no data set to compare the results. The only way is to downsample both and use 80m / 20m data to get 20m multispectral image, which can be compared to the original SPOT-XS data.

The merging quality can be appreciated through two criteria, one is visual quality and the other is preservation of the spectral characteristics. The enhancement of the spatial resolution in multispectral images should not chance the spectral characteristics. To evaluate the performance of the methods, two indices based on correlation coefficient and the index deviation are used.

$$\rho r(L/H) = \frac{\sum_{j=1}^{MxN} (H_j - \overline{H})(L_j - \overline{L})}{\sqrt{\sum_{j=1}^{MxN} (H_j - \overline{H})^2 \ \sum_{j=1}^{MxN} (L_j - \overline{L})^2}} \qquad (12)$$

$$\delta = \frac{1}{MN} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} \frac{\left| H(m,n) - L(m,n) \right|}{L(m,n)} \qquad (13)$$

The correlation coefficient characterizes the resemblance of the two images, while the index deviation allows to evaluate the spectral residual between the merged and the original image. These two images have the same spectral content when the correlation coefficient is one and the index deviation is zero. The results can be seen in Fig. 4.

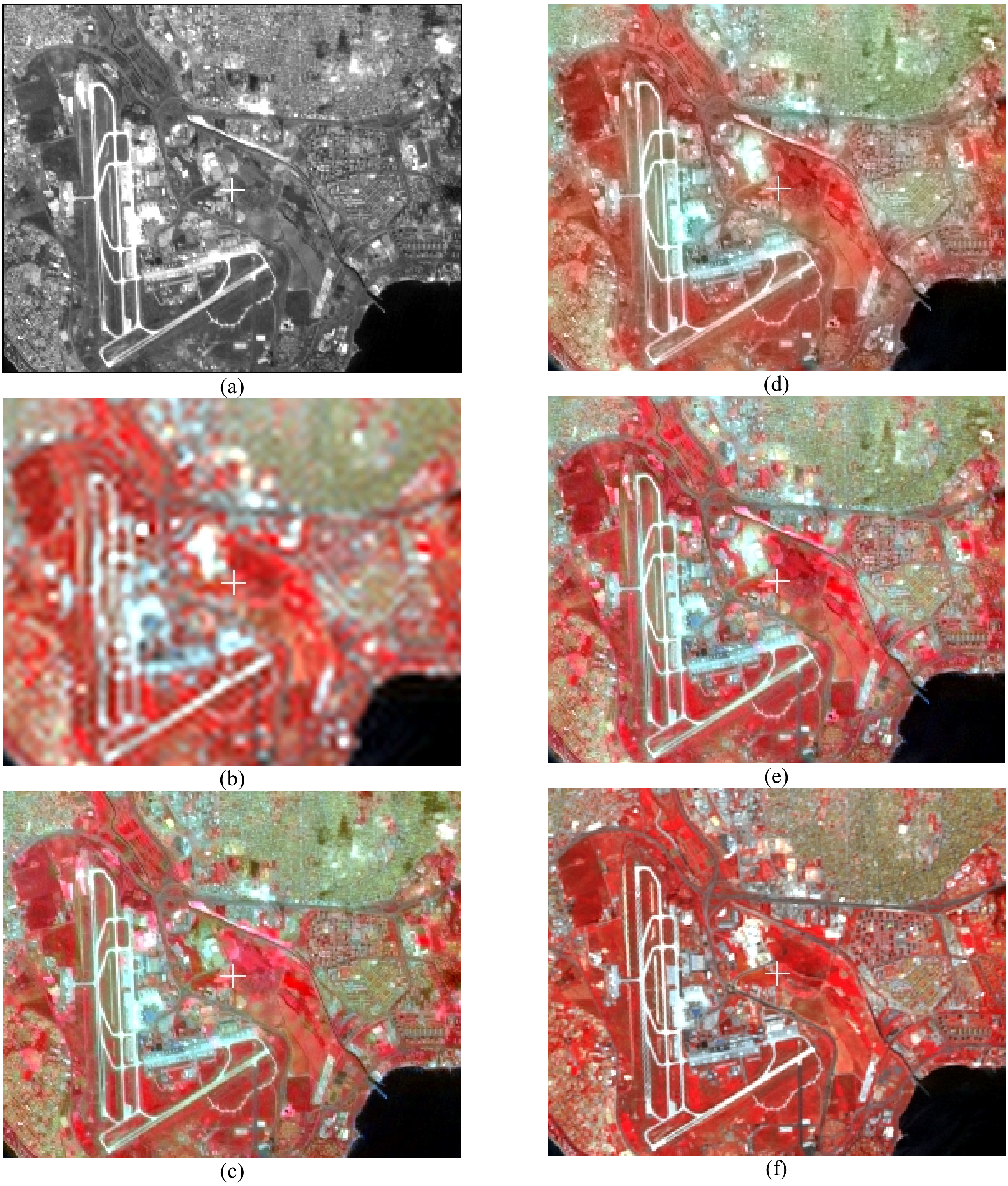

Figure 4. (a) IRS PAN (20m) (b) SPOT XS (80m) (c)IHS (d) WRGB (e) WI (f) SPOT XS original image (20m)

The first two are the undersampled panchromatic and multispectral images from IRS and SPOT respectively. Next three are the results of different methods, IHS, WRGB and WI. The last one is the original multispectral image. Fig. 4 shows that the spatial resolution is improved by merging different images. The correlation coefficient and index deviation results are in Figure5 and Figure 6. The correlations of the wavelet-based methods are higher than the standard merging algorithm with IHS transform. When wavelet decomposition is used on the intensity component instead of RGB bands, the results get better. This means that WI method preserves the spectral characteristics of the multispectral image to a greater extent than others. For perfect reconstruction of the original image, although the target would be a correlation of 1.0 and a deviation of zero, IRS PAN and SPOT XS data were acquired in different epochs so this is not possible, the correlation values are around 0.8, which is reasonable. Fig 5 and Fig 6 show that for each band if we go from IHS to WI method while the correlation coefficient of the merged and the original image increases, index deviation value decreases, which means spectral characteristics of the image is preserved better.

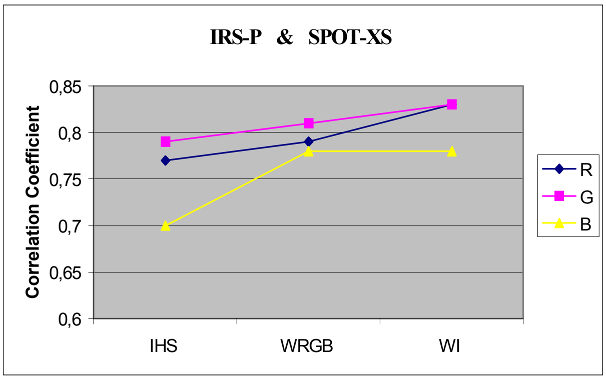

Figure 5. Correlation coefficient results for three bands with IHS, WRGB and WI methods.

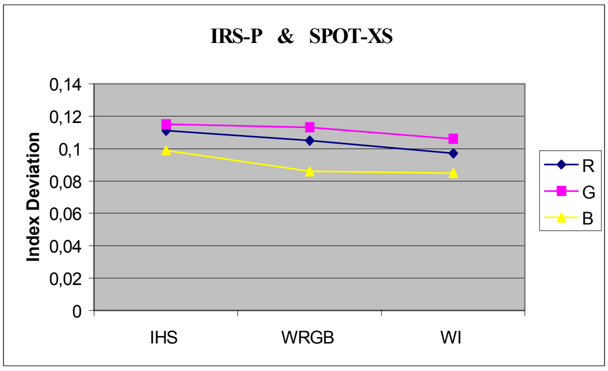

Figure 6. Index deviation results for IHS, WRGB and WI

V. CONCLUSION

In this paper, some of the techniques proposed for satellite image fusion have been studied. The visual quality of the results are nearly same. Both standard method IHS and the wavelet decomposition methods achieved in resolution improvement. But for remote sensing applications it is important not to chance the spectral characteristics, while enhancing the spatial resolution. WI method, which consists of extracting detail information from the panchromatic image by using wavelet decomposition and combining this with the intensity component of the multispectral image; preserves the spectral information to a better extent than the standard IHS method.

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