

FUSION OF MULTISPECTRAL AND PANCHROMATIC IMAGES BY COMBINING BILATERAL FILTER AND IHS TRANSFORM

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ABSTRACT

A new fusion method based on Intensity-Hue-Saturation (IHS) transform and multistage bilateral filtering for multispectral (MS) and panchromatic (PAN) images is presented. The missing high frequency information of MS image is obtained by the decomposition of PAN image using bilateral pyramid. The fused image is obtained by the summation of these detail layers weighted by intensity component to the multispectral image. The proposed method is compared with the widely used IHS, Additive Wavelet Luminance Proportional (AWLP) and A Trous Wavelet Based Context Based Decision (ATWT-CBD) fusion methods. The resulting images as well as evaluation metrics demonstrate that the proposed algorithm has better performance.

Index Terms— image fusion, IHS transform, additive wavelet transform, bilateral filter

1. INTRODUCTION

Many remote sensing systems provide MS images with low spatial resolution, and PAN images with low spectral quality. Image fusion is a way to obtain a single MS image of higher spatial resolution by preserving the high spectral quality of the MS image [1].

Some of the widely used methods for the fusion of multispectral and panchromatic images are IHS transform based method [2] and Principal Component Analysis (PCA) based method [3]. These methods can increase the spatial resolution, but, they generally distort the spectral quality of the original MS image.

In recent years, multiresolution based methods, such as wavelet based fusion methods have been suggested [4-5]. In these methods, the MS and PAN images are decomposed into detail and approximation subbands, and the detail subband of PAN image is injected into the detail subband of MS image by a predefined rule, then the fused image is obtained by the inverse wavelet transform. If the wavelet transform is not shift invariant, such as the Discrete Wavelet

Transform (DWT) algorithm of Mallat, some spatial distortions can be seen in the fusion image.

To avoid this problem many shift-invariant wavelet transform based algorithms have been proposed such as the a trous wavelet transform based additive and substitutive methods by Nunez et al. [5].

In substitutive method, PAN and MS images are decomposed into wavelet planes and The MS planes are replaced by the PAN image planes. In the additive method the PAN images planes are directly added to the MS bands.

Hybrid methods based on IHS/PCA and decimated and undecimated wavelet transforms have also been introduced to improve the fusion performance [6,9]. The detail subbands of the intensity component or the first principal component of the MS image are replaced with the detail subbands of the PAN image in the wavelet domain. Another development in the fusion area may be cited as the used of different fusion rules such as [7] which proposes the addition of the PAN details to the low resolution MS image using a context driven model. The wavelet planes are obtained either Generalized Laplacian pyramid (GLP) or ATWT [8].

Bilateral filter is an edge preserving smoothing filter which consists of two Gaussian filters: range and spatial filters [10]. It has already been applied to many image processing applications such as denoising, texture illumination and separation, tone mapping detail enhancement and data fusion [11]. In this paper, we propose a combination of IHS fusion method and bilateral filtering for the fusion of multispectral and panchromatic data.

The paper is organized as follows: section 2 and 3 review the MS and PAN data fusion methods based on additive wavelet transform: ATWT, ATWT-CBD and AWLP and image decomposition by bilateral filter, respectively. Section 4 introduces a new image fusion method bases on bilateral filter and IHS transform. Fusion results and evaluation metrics for Quickbird images are given in section 5 and general conclusions are presented in section 6.

2. FUSION OF MS AND PAN IMAGES

2.1. A Trous Wavelet Transform (ATWT) Based Pansharpening

In this transform the image is convolved with a cubic-spline filter “h” to obtain an approximation image [5]. In order to carry on decomposition, the mask h is filled with zeros and the new mask is applied to the approximation layer. The difference of two approximation level is called the wavelet plane at that level and can be given as,

$$\begin{aligned} p_l &= p_{l-1} * h_{l-1} \\ w_l &= p_{l-1} - p_l \end{aligned} \quad (1)$$

where initially $p_0=I$ (original image) and w_l and p_l is the wavelet and approximation plane at level l, respectively. The reconstructed image can simply be obtained by adding the wavelet planes to the approximation image of the last layer.

In additive ATWT based fusion method, the PAN wavelet planes are added directly to the MS image,

$$F = \sum_{l=1}^n w_{pl} + MS \quad (2)$$

where F is the fused image.

2.2. ATWT-CBD Based Pansharpening

CBD injection method in [7,8] proposes to add the wavelet planes not directly but weighting them by (3)

$$\alpha_c^l(i, j) = \begin{cases} \left\{ \frac{\sigma_{MS}(i, j)}{\sigma_{PAN}(i, j)}, c \right\}, & \rho(i, j) \geq \theta^{(l)} \\ 0, & \rho(i, j) < \theta^{(l)} \end{cases} \quad (3)$$

where σ_{MS} and σ_{PAN} are the local variances of MS images and PAN image degraded to the resolution of MS images, respectively, and $\rho(i,j)$ local correlation coefficient between MS bands and degraded PAN image. All the local statistics are calculated on a square window of size $N \times N$ centered on pixel (i,j) . $\theta^{(l)}$'s are the threshold values defined generally different for each band as $\theta^{(l)} = 1 - \rho_{IP}$ where ρ_{IP} is the global correlation coefficient between the lth band of the MS image and the degraded PAN image.

The fused image is obtained by

$$F = \sum_{l=1}^n \alpha_c^l w_{pl} + MS \quad (4)$$

2.2. AWLP Based Pansharpening

This method is based on the combined use of ATWT and IHS methods and aims to inject the high frequency information proportional to their original values. In this way the radiometric signature between the bands of the MS image is better preserved. It was first proposed (AWL) in

[6], and then later extended to images with more than three bands (AWLP) in [9].

In AWL method first IHS transform is applied to the MS image. Then the histogram of PAN image is matched with Intensity (I) component of MS image. Finally, inverse IHS is applied to the H, S and new I component obtained by summing up the wavelet planes of matched PAN image and original I component [6].

$$L_{new} = \sum_{l=1}^n w_{pl} + L \quad (5)$$

AWLP method which is the extension of AWL for more than three bands is given using a weighted injection scheme such as [9],

$$F_p = MS_p + \frac{MS_p}{(1/L) \sum_{p=1}^L MS_p} \sum_{j=1}^n w_{pj} \quad (6)$$

where the weighting coefficient enables the injection of details in a manner proportional to the original MS bands. The denominator of the weight factor can be interpreted as the intensity component given by the IHS transform.

3. MULTISTAGE BILATERAL FILTER

The bilateral filter output for a current pixel location p of an image I is given as [10],

$$BF[I]_p = \frac{1}{W_p} \sum_{q \in S} G_{\sigma_s}(\|p - q\|) G_{\sigma_r}(\|I_p - I_q\|) I_q \quad (7)$$

with the normalization parameter

$$W_p = \sum_{q \in S} G_{\sigma_s}(\|p - q\|) G_{\sigma_r}(\|I_p - I_q\|) \quad (8)$$

and the Gaussian kernel as

$$G_{\sigma}(x) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{x^2}{2\sigma^2}\right) \quad (9)$$

where G_{σ_s} is the spatial Gaussian kernel which decreases the influence of distant pixels and G_{σ_r} is the range Gaussian kernel which decreases the effect of the pixel q when its intensity value differs from the actual pixel p and S is the neighboring pixel locations.

Using the bilateral filter, an image may be decomposed into detail and base layers as,

$$D[I]_p = [I]_p - BF[I]_p \quad (10)$$

Here BF denotes the base layers, while D denotes the detail layers.

An image pyramid may be constructed if the base layer is filtered by the bilateral filter with the spatial parameter σ_s ,

doubled and the range parameter σ_r is halved at each level as;

$$D^i[I]_p = BF^{i-1}[I]_p - BF^i[I]_p \quad (11)$$

where, i denotes the decomposition level with initially $BF^0[I]_p = I$. For L levels of decomposition it is possible to reconstruct the original image by following equation:

$$I = \sum_{i=1}^L D^i[I]_p + BF^L[I]_p \quad (12)$$

4. PANSHARPENING BY COMBINED BILATERAL-IHS METHOD

The steps of the pansharpening algorithm are in the following:

- Register the low resolution multispectral image to the high resolution panchromatic image as to have the same size.
- Evaluate the intensity component of R, G, B and NIR bands of the multispectral image [2]

$$I_p = \frac{R_p + G_p + B_p + NIR_p}{4} \quad (13)$$

- Decompose the panchromatic image into n detail layers and a base layer using the multistage bilateral filter.

$$D^i[PAN]_p = BF^{i-1}[PAN]_p - BF^i[PAN]_p \quad (14)$$

where PAN is the panchromatic image and R, G, B and NIR are the four bands of the multispectral image.

- Add the detail layers to the multispectral image by (15)

$$F_p = MS_p + \frac{MS_p * \sum_{i=1}^n D^i[PAN]_p}{I_p} \quad (15)$$

5. EXPERIMENTAL RESULTS

5.1. Visual Analysis

The method is applied to several QuickBird images available at <http://glcf.umiacs.umd.edu/data/quickbird/> [12]. MS and PAN images are 2.8 and 0.7m spatial resolution, respectively. After pansharpening of MS image, the new image is expected to have 0.7m spatial resolution. Since 0.7m spatial resolution MS does not exist, quantitative comparison will not be accurate. Therefore, using the protocol of Wald [13], PAN and MS images are degraded to 2.8m and 11.2 m resolution by lowpass filtering and decimation. Pansharpening algorithm is applied to these degraded images and the resulting image is compared to the

original MS image of 2.8 m resolution. The MS image is interpolated to the size of PAN image using bicubic interpolation. Pansharpening algorithm is applied to the PAN and MS images degraded to resolutions 2.8m. and 11.2m resolution, respectively and the resulting image is compared to the original MS image. Also, HIS and two winners of 2006 IEEE fusion contest [14] :AWLP and ATWT-CBD based methods are applied and compared to our method.

Degraded PAN (2.8m resolution) and MS (11.2m resolution) images and original MS (2.8m resolution) image are shown in Fig.1 a., b., and c., respectively. Fig.1 d-g shows the fusion results using G-IHS, AWLP, ATWT-CBD and the proposed bilateral-IHS method, respectively.



Fig.1. a) PAN (2.8 m., 256*256), b) Resampled MS image (11.2 m, 256*256), c) original MS image (2.8 m, 256*256), fusion results for d) G-IHS e) AWLP f) ATWT-CBD g) Bilateral-IHS

5.2. Quantitative Analysis

Correlation coefficient (CC) between two images is defined as [14],

$$CC(A, B) = \frac{\sum_{m,n} (A_{m,n} - \mu_A)(B_{m,n} - \mu_B)}{\sqrt{\sum_{m,n} (A_{m,n} - \mu_A)^2 (B_{m,n} - \mu_B)^2}} \quad (16)$$

where μ_A and μ_B are the mean values of the images A and B, respectively.

CC should be as close to 1 as possible. The difference between correlations will show how much the spatial quality is kept.

Root Mean Square Error (RMSE) between each band of the original and the fused images can be defined as [14],

$$RMSE = \sqrt{\frac{1}{MN} \sum_{i=1}^M \sum_{j=1}^N (A - B)^2} \quad (17)$$

RMSE should be as close to 0 as possible.

The Relative Average Spectral Error (RASE) index characterizes the average performance of the method in the spectral bands considered [14] and is given as

$$RASE = \frac{1}{M} \sqrt{\frac{1}{N} \sum_{i=1}^N RMSE^2(B_i)} \quad (18)$$

where M is the mean radiance of the N bands (B_i) and RMSE is the root mean square error of each band.

The Relative Global Dimensional Synthesis Error (ERGAS) [14] will be

$$ERGAS = 100 \frac{h}{l} \sqrt{\frac{1}{N} \sum_{i=1}^N \left(\frac{RMSE^2(B_i)}{M_i^2} \right)} \quad (19)$$

where h and l are the resolution of high and low spatial resolution images, respectively. M_i is the mean radiance of each band.

The lower values of the RASE and ERGAS indexes, indicates higher spectral quality of the fused images.

Universal Image Quality Index (Q-average) [15] models any distortion between two images as a combination of loss of correlation, luminance distortion, and contrast distortion.

$$UIQ = \frac{\sigma_{AB}}{\sigma_A \sigma_B} \frac{2\mu_A \mu_B}{\mu_A^2 + \mu_B^2} \frac{2\sigma_A \sigma_B}{\sigma_A^2 + \sigma_B^2} \quad (20)$$

Q_{AVG} is defined as the average value of the UIQ's of each band. A higher value indicates better spectral quality.

The quantitative comparison of the fusion methods by the quality indexes mentioned above can be seen in Table 1.

Table 1. Quantitative comparison of the fusion methods for the image shown in Fig.1

		GIHS	AWLP	CBD	Bilateral IHS
CC	Band 1	0.9220	0.9508	0.9428	0.9537
	Band 2	0.9353	0.9592	0.9568	0.9639
	Band 3	0.8847	0.9427	0.9416	0.9512
	Band 4	0.9385	0.9647	0.9703	0.9717
	Average	0.9201	0.9544	0.9529	0.9601
RMSE	Band 1	20.9061	15.3630	16.0275	14.4823
	Band 2	19.4180	14.4160	14.2346	13.0432
	Band 3	19.1889	14.1294	13.4815	12.3106
	Band 4	21.3799	18.7884	14.9810	14.6196
	Average	20.2232	15.6742	14.6812	13.6139
RASE		29.5387	22.7469	21.5092	19.9325
ERGAS		7.4766	5.7779	5.4170	5.0301
QAVG		0.8918	0.9521	0.9521	0.9590

Taking into consideration both visual and quantitative analysis, bilateral-IHS is better than all the considered methods. Bilateral-IHS method preserves the spectral quality of the MS image, while increasing its spatial quality.

6. CONCLUSIONS

A new pansharpening method based on bilateral filtering and IHS transform is proposed. Since bilateral filtering takes into consideration not only the samples which are close in location but also in amplitude values, bilateral filtering based decomposition of the panchromatic image eliminates the redundant injection of high frequency information which is common in ATWT based fusion methods. Moreover, due to the use of IHS transform, the high frequency information is injected proportional to the original values of the MS bands, thus the radiometric information is better preserved. Comparisons with other widely used methods confirm that bilateral-IHS method has better performance.

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