Remote Sensing Image Fusion Approach Based on Brovey and Wavelets Transforms

Reham Gharbia[1,5], Ali Hassan El Baz[2], Aboul Ella Hassanien[3,5], and Mohamed F. Tolba[4]

[1] Nuclear Materials Authority, Cairo, Egypt
[2] Faculty of Science, Damietta University, Egypt
[3] Faculty of Computers and Information, Cairo University, Egypt
[4] Faculty of Computers and Information, Ain Shams University, Egypt
[5] Scientific Research Group in Egypt (SRGE), Cairo, Egypt
http://www.egyptscience.net/

Abstract. This paper proposes a remote sensing image fusion approach based on a modified version of Brovey transform and wavelets. The aim is to reduce the spectral distortion in the Brovey transform and spatial distortion in the wavelets transform. The remote sensing data sets has been chosen for the image fusion process and the data sets were selected from different satellite images in south western Sinai, Egypt. Experiments were conducted on a variety of images, and the results of the proposed image fusion approach were compared with principle component analysis and the traditional Brovey approach. The obtained results show that the proposed approach achieves less deflection and reduces the distortion. Several quality evaluation metrics were used for the proposed image fusion like standard deviation, correlation coefficient, entropy information, peak signal to noise ratio, root mean square error and structural similarity index. Experimental results obtained from proposed image fusion approach prove that the use of the Brovey with wavelets can efficiently preserve the spectral information while improving the spatial resolution of the remote sensing.

1 Introduction

Remote sensing satellites offer a huge amount of data which has a variety characteristic of temporal, spatial, radiometric and Spectral resolutions. For the optimum benefit of these characteristics. It should be collected in a single image. Optical sensor systems and imaging systems offer high spatial or multispectral resolution separately and there is no single system offers spatial or multispectral resolution. Many remote sensing applications such as land change detection needs, classification, etc. need high spatial and multispectral resolutions at the same time and there are constraints to realize this issue by using satellites directly [1–6]. Image fusion purpose is to combine multi-image information in one image which is more suitable to human vision or more adapt to further image processing analysis [1, 2].

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This paper introduces a remote sensing image fusion approach based on a modified version of Brovey transform and wavelets to reduce the spectral distortion in the Brovey transform and spatial distortion in the wavelet transform. This paper is organized as follows: Section (2) introduces the preliminary about the Brovey and wavelets. Section (3) discusses the proposed image fusion technique approach. Section (4) shows the experimental results and analysis. Finally, Conclusions are discussed in Section (5).

2 Preliminaries

2.1 The Brovey Transform Technique

Brovey technique was introduced by Bob Brovey [12]. The mathematical formulas of the Brovey transform (BT) can be showed as a combination of the Panchromatic(Pan) and multispectral (MS) images. Each MS image is multiplied by a ratio of the Pan image divided by the sum of the MS images. The fused R, G, and B images are defined by the following equations [13]:

$$R_{new} = \frac{R}{(R+G+B)} \times PAN \quad (1)$$

$$G_{new} = \frac{G}{(R+G+B)} \times PAN \quad (2)$$

$$B_{new} = \frac{B}{(R+G+B)} \times PAN \quad (3)$$

Many researchers were applied the BT to fuse RGB images with a high resolution image (Pan) [14–17, 22]. For example, Zhang et al. in [22] show the Effects of BT and WT on the information of SPOT-5 imagery and show that WT improves the spatial resolution, but it decreases spectral information. The BT is limited to three bands and the multiplicative techniques introduce significant radiometric distortion. In addition, successful application of this technique requires an experienced analyst [17] for the specific adaptation of parameters. This prevents development a user friendly automated system, which increases the spatial details of the multispectral images through arithmetical technique with the panchromatic image. The BT will probably lead to color distortion especially when the spectral range of the input images are different or when they have significant long term temporal changes.

2.2 The Wavelets Transform

The wavelets representation functions are efficient with localized features. The wavelet transform is a multiresolution analysis (MRA) which depended on the discrete wavelet. The wavelets are characterized by using two functions which are the scaling function $f(x)$, and the wavelet function or *mother wavelet*. Mother wavelet $\psi(x)$ undergoes translation and scaling operations to give self similar wavelet series as shown in equation (4) [18].

$$\psi_{(a,b)} = \frac{1}{\sqrt{a}}\psi(\frac{x-b}{a}), (a, b \in R) \quad (4)$$

Where a is the parameter scale and b is the parameter translation. The implementation of wavelet transform requires discretisation of its scale and translation parameters by using the following equation:

$$a = a_0^j, b = ma_0^j b_0 where m, j \in Z \quad (5)$$

Then, the wavelet transform can be defined as follow:

$$\psi_{j,m}(x) = a_0^{\frac{-j}{2}}\psi(a_0^{-j}x - mb_0) j, m \in z \quad (6)$$

If the discretisation is on a dyadic grid using $a_0 = 2$ and $b_0 = 1$, it is called standard discreet wavelet transform (DWT) [19]. The wavelet transform of a 2-D image involves recursive filtering and subsampling. At each level, there are three details images. They denoted as LH (containing horizontal information in high frequency), HL (containing vertical information in high frequency), and HH (containing diagonal information in high frequency). The decomposition also produces one approximation image, denoted by LL, that contains the low frequency information. The wavelet transform can decompose the LL band recursively [20]. The image fusion based on wavelet transform provides high spectral quality of the fused satellite images. However, the fused image by Wavelet has much less spatial information. The spatial and spectral resolution have the same important role in remote sensing applications. But the use of wavelet transform in image fusion improves spectral resolution.

3 The Proposed Image Fusion Approach

3.1 Preprocessing Stage

Preprocessing stage contains three process, registration and upsampling processes. At the registration process, the multispectral images register to panchromatic image by using ground control points. We register the multispectral image as the same of panchromatic image by selecting about 30 points in both images. The registration was done within subpixel $RMSE$ (Root Mean Square Error). This process is very important and need to be done very precisely because the image fusion using wavelet transform technique is very sensitive to image registration process. If there is a little displacement between two images, the resulted fused image will have bad quality. At the second upsampling process, the upsampling of the multispectral images as the same size of panchromatic image is done by using bilinear method. Histogram matching process is the last process in this stage, the histogram matching was applied on the panchromatic image to ensure the mean and standard deviation of the panchromatic image and multispectral images are within the same range.

3.2 Image Fusion Stage

The proposed image fusion algorithm is described in Algorithm (1).

Algorithm 1 Image fusion algorithm

1: Apply the Brovey transform on the multispectral images (R, G, and B) and the panchromatic image and produce new images (R_{new}, G_{new} and B_{new}).
2: Decompose the high resolution image (i.e. Pan image) into a set of low resolution with the wavelet transform by the following equation:

$$f(x,y) = \sum c_{i,j}\phi_{i,j}(x,y) + \sum_{k=1}^{i}\sum_{j} w_{k,i}\psi_{k,j}(x,y) \quad (7)$$

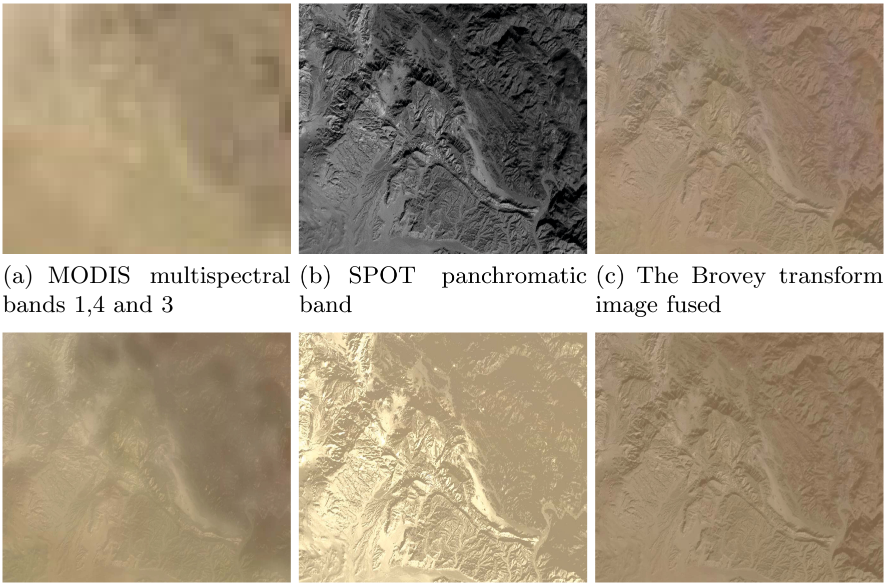
3: The wavelet transform with the same decomposition scale is applied to obtain the wavelet coefficients of the new image (R_{new}, G_{new} and B_{new}).
4: Replace a low frequency of Pan image with low frequency of MS band at the same level.
5: The Proposed wavelet coefficients fusion scheme is carried to reconstruct new image's wavelet coefficients, which contains the best information coming from the source coefficients.
6: The reconstruct image wavelet coefficients are adjusted using window based consistency verification [6].
7: The last output image is generated by applying inverse wavelet transform (IWT) with reconstructed wavelet coefficients.

In the equation (7), the first item shows the subimage of low frequency and the last item shows the subimage of high frequency [21].The decomposition of discrete wavelet transform decomposes the original image with orthogonal wavelet transform into four child images which denote low frequency information, horizontal direction information, vertical direction information and diagonal direction information respectively, also called Low-Low ($LL1$), Low-High ($LH1$), High-Low ($HL1$) and High-High ($HH1$) which are denoted details image. Then the low frequency image is denoted by the approximation image, it will be decomposed into four new child images further. By the wavelet decomposition, the image is decomposed into a multi-resolution level in which every level has distinct frequency and spatial properties. The sixth level is selected by experimental.

4 Results and Discussion

The study area locates on south western Sinai of Egypt.The MODIS and Landsat-7 ETM+ multispectral as MS image and panchromatic of Spot satellite have been selected as test data. The remote sensing data is acquired in two different type image. the first type is the panchromatic (black and white) of SPOT satellite (Satellite Pour lObservation de la Terre) which has spectral band

(0.51-0.73 m) with 10 m spatial resolution. The second type, the multispectral images. MODIS and ETM+ data are used in this paper. The moderate resolution imaging spectrometer (MODIS) instrument is designed to fly on the EOS (Earth Orbiting System) morning and afternoon platforms, with daily global coverage. The MS images take from MODIS satellite with resolution 250m. A subscene of MODIS image taken on (25 May 2012). The bands used are 1,4 ,3 respectively R,G and B used as the first original image. The second data set ETM+ subscene. The bands used are 2,4 ,7 respectively R,G and B. The spatial resolution of ETM+ multispectral is 60m.



(a) MODIS multispectral bands 1,4 and 3
(b) SPOT panchromatic band
(c) The Brovey transform image fused
(d) The IHS image fused
(e) The PCA image fused
(f) The proposed image fusion image fused

Fig. 1. Comparative analysis with several image fusion techniques on MODIS & Spot data

In order to evaluate the proposed image fusion technique. The comparison between the proposed image fusion technique based on the Brovey transfom and wavelet transform, and the different image fusion techniques was performed. Two data sets are selected from different satellite images. Two data sets MODIS & Spot and ETM+ & Spot are used to test the effectiveness of the proposed image fusion technique. Fig.1 shows the experimental results on the first data set (MODIS and Spot images). The original remote sensing images are MODIS multispectral bands 1,4 and 3 (Fig.1(a)) with resolution of 250 m and pan image is SPOT panchromatic band (Fig.1(b)) with resolution of 10 m. The two images have different imaging principle and different spatial resolutions; they show quite distinct features and carry complementary information. For comparison, several other techniques are also used to fuse the two source images. Fig.1(c) shows the result of the Brovey transform image fusion technique Fig.1(d) shows the result of using IHS image fusion technique and Fig.1(e) shows the result of image fusion based on PCA technique, finally Fig.1(f) shows the result of using the proposed hybrid image fusion technique.

While Fig.2 shows the results of the experimental were Conducted on the second data set (ETM+& Spot images). The original remote sensing image is ETM+ image (combination of bands 2,4 and 7) Fig.2(a), Fig.2(b) shows the Pan image (Spot panchromatic band), Fig.2(c) shows the result of the Brovey transform image fusion technique, Fig.2(d) shows the result of IHS image fusion technique, Fig.2(e) shows the result of using PCA image fusion technique, finally Fig. 2(g) shows the result of using proposed hybrid image fusion technique.

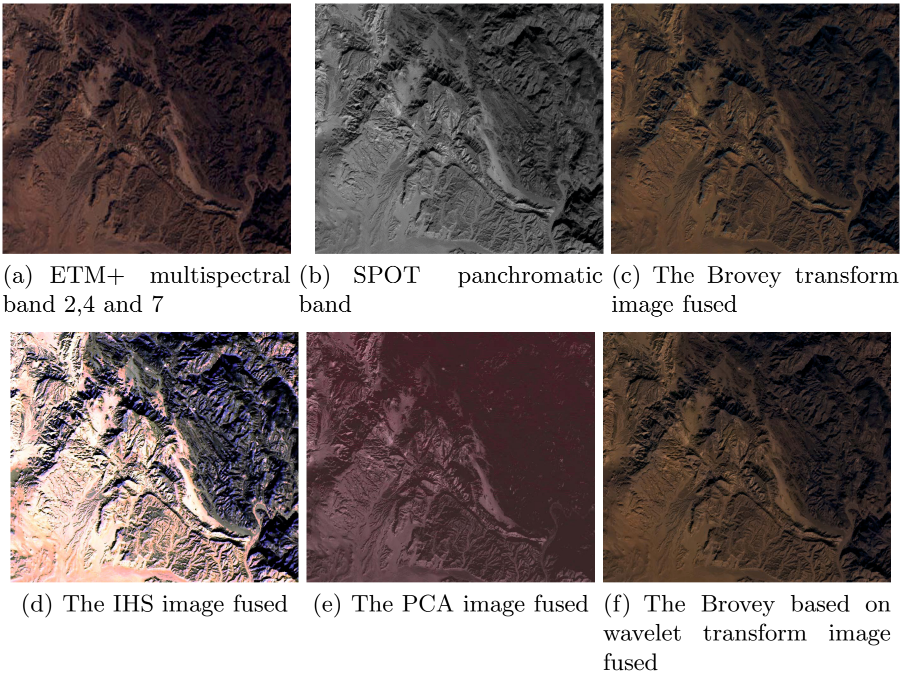
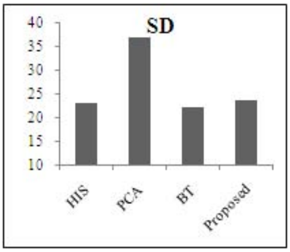


Fig. 2. Comparative analysis with several image fusion techniques on ETM+ & Spot data

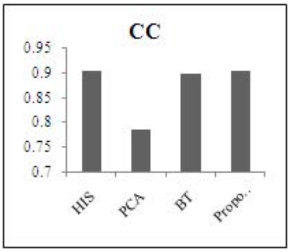
With analyzing the images resulting from image fusion techniques visually, which are considered the easiest and simplest way but it is not enough to judge objectively at the images. We will find that the resulting image of the proposed hybrid image fusion technique more pronounced than other fused images. We find that the IHS image fused has spectral distortion while image fused by using

Table 1. Comparative analysis results of the MODIS and Spot data set

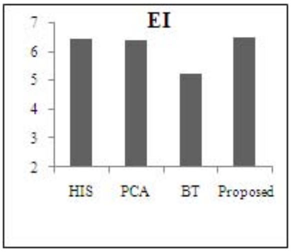
Image	SD	EI	CC	RMSE	PSNR	SSIM
IHS	23.0724	6.4567	0.9043	21.1778	34.872	0.7567
PCA	36.8083	6.3922	0.7856	33.6084	32.8663	0.4977
BT	22.1601	5.2419	0.8985	19.5886	35.2108	0.7616
proposed	23.6531	6.5124	0.9044	20.5332	35.0062	0.7642



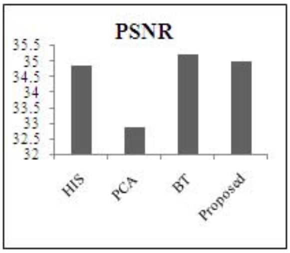
(a) Standard Devination (SD)



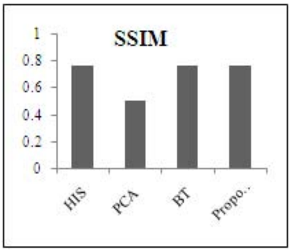
(b) correlation coefficient (CC)



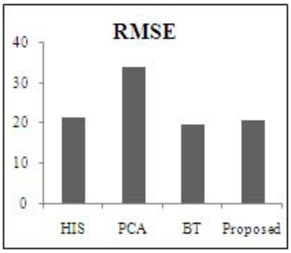
(c) Entropy Information (EI)



(d) Peak Signal to Noise Ratio (PSNR)



(e) Structural Similarity Index (SSIM)



(f) Root Mean Square Error (RMSE)

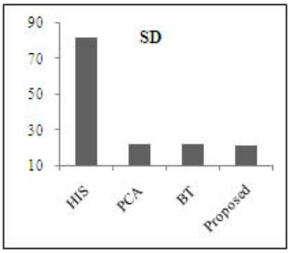
Fig. 3. Statistical analysis of image fusion techniques on MODIS & Spot data

PCA has blurry and spectral distortion. The output fused image of the proposed technique has spectral and spatial less distortion than the images of the result of the image fusion technique. The output fused image of the proposed technique is high multispectral resolution image with spatial resolution 10m.

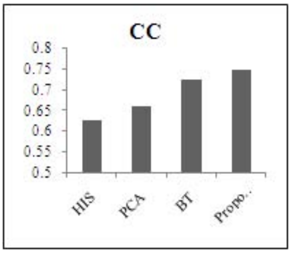
The statistical analysis is the important technique in the analyzing and evaluating image quality. Statistical Analysis uses some parameters, which helps in the interpretation and analysis of spatial and spectral information [25]. There are a lot of these parameters, like; the standard deviation (SD) measures the value of the deviation from the mean of the image and the discrete degree between each pixel and the mean value of one image. The technique has the biggest value

Table 2. Comparative analysis results of the ETM+ and Spot data set

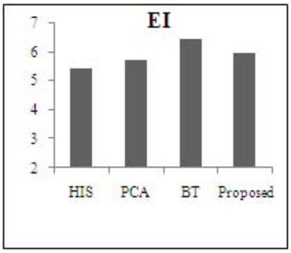
Image	SD	EI	CC	RMSE	PSNR	SSIM
IHS	81.819	5.4307	0.6268	99.9033	28.135	0.106
PCA	22.3808	5.7156	0.6604	22.6968	34.5712	0.4744
BT	22.3662	6.4593	0.7231	16.6527	35.916	0.5
proposed	28.5334	7.0785	0.7964	22.8563	34.546	0.3816



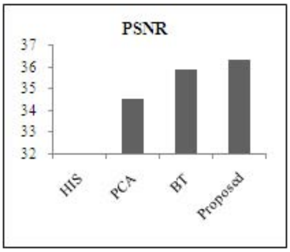
(a) Standard Devination (SD)



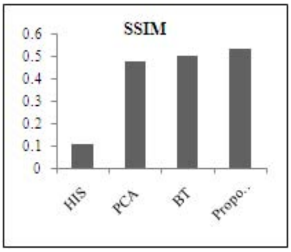
(b) correlation coefficient (CC)



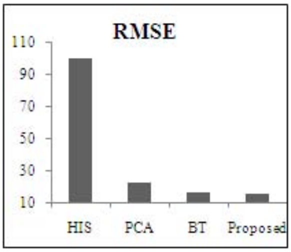
(c) Entropy Information (EI)



(d) Peak Signal to Noise Ratio (PSNR)



(e) Structural Similarity Index (SSIM)



(f) Root Mean Square Error (RMSE)

Fig. 4. Statistical analysis of image fusion techniques on ETM+ & Spot data

of SD, it is The most fragmented. The correlation coefficient (CC) measures the Convergence between the original image and the result images. The correlation coefficient (CC) between the original multispectral images and the equivalent fused images. The best correlation between fused and original image data shows the highest correlation coefficient value. The entropy information (EI) measures the content of information.the Entropy measuring the richness of information in fused image. The Peak Signal to Noise Ratio ($PSNR$) measures the quality reconstruction of image. The structural similarity index ($SSIM$) measures the similarity between two images [27–29]. Finally, the Comparison is made between the fused image by using many ways, including PCA, IHS. The Brovey transform, fused image using the technique proposed hybrid and original multispectral image, to determine the best technique of them.

5 Conclusion

This study introduced image fusion technique for multispectral image and *Pan* image and assessed the quality of the resulting synthetic images by visual interpretation and statistical analysis. The proposed image fusion technique is better than all the other traditional image fusion techniques. The objective is enhancing the spatial resolution of the original image, and to retain the spectral information that is contained in the original multispectral image. We conclude that the traditional image fusion techniques have limitation and do not meet the needs of remote sensing therefore our way is the only hybrid systems. Hybrid techniques in pixel level are more efficiency technique than traditional techniques. Experiments conclude that PCA achieves good results, but it needs some improvement.

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