Combination of IHS and Spatial PCA Methods for Multispectral and Panchromatic Image Fusion

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Abstract—Intensity-Hue-Saturation (IHS) and Principal Component Analysis (PCA) are two famous methods to which image fusion algorithms can be reported when merging panchromatic (Pan) and multispectral (MS) images, acquired with different spatial and spectral resolutions. The IHS is a well-known pan-sharpening approach widely used for its efficiency and high spatial resolution. However, it can distort the spectral characteristics of the multispectral images. The spatial PCA method can preserve spectral information of Multispectral images. In this paper, a new hybrid algorithm is proposed which uses both the spatial PCA and IHS methods to improve the result of the merged images. Visual and statistical analyzes show that the proposed algorithm clearly improves the merging quality in terms of: RASE, ERGAS, SAM, correlation coefficient and UIQI; compared to fusion methods including, IHS, Brovey, PCA and HPM.

I. INTRODUCTION
Images are observed in different portions of electromagnetic spectrum in remote sensing systems; therefore, the remote sensing images have different spectral and spatial resolution. Because received energy depends to spectral and spatial resolution and adequate signal to noise ratio should be satisfied, the multispectral images, with high spectral resolution, have a lower spatial resolution compared with panchromatic (PAN) image with a higher spatial resolution, and wide spectral bandwidth. With proper algorithms, it is possible to extract spectral and spatial information from multispectral and PAN image and collect these information in one image. This process is called image fusion.

Conventional algorithms for the fusion can be classified into three main groups: 1) Substitution methods, such as IHS and PCA (Principal Component Analysis) fusion methods [1], [2] 2) Arithmetic combination, such as Brovey, SVR (Synthetic Variable Ratio) and RE (Ratio Enhancement) [3]. 3) Multi-resolution fusion methods, which introduce spatial features from the high-resolution images into the multispectral (MS or color) images, such as HPF, HPM, RIM, wavelets, Gaussian Laplacian pyramid techniques [4]-[6].

The IHS and Brovey based image fusion algorithms distort the spectral information of MS image in the fused result. This distortion of the spectral information during the fusion process is not acceptable in most applications, such as classification and clustering procedures [2].

PCA and HIS are the most commonly used image-fusion methods based on the spectral transform, But, these methods can cause spectral distortion in the results [7]. To avoid the weak points of the standard PCA technique, Spatial PCA transform was proposed [8] which can preserve more spectral information of MS images in the fused result. However Spatial PCA method can distort the spatial information in the fused result.

HPF [9] and HPM [10] fusion algorithms have shown better performance in terms of the high-quality synthesis of spectral information. The principle of these methods is to extract the high-frequency information from the PAN image and inject it into the MS image formerly resampled to match the PAN pixel size. Box car filters are used as a low pass filter in these methods. However, the ripple in the frequency response of box car filters has some negative impact [6].

The multi-resolution fusion techniques such as undecimaed wavelets (udW) [11], [12] and Nonsubsampled contourlets (NSCT) [13] have been discussed widely in the recent studies because of their advantages over the other fusion techniques. But these techniques are Appropriate for cases of image fusion where the resolution ratio between the low resolution MS images and the Panchromatic (PAN) image is a power of two [6]. So, an efficient algorithm which can fuse the images where the resolution ratio is not power of two should be developed.

To avoid the weak points of the IHS (distortion of spectral information) and Spatial PCA (distortion of spatial information) methods, we proposed a new combined method which takes advantage of both methods. So proposed algorithm can preserve both spatial and spectral information of initial MS and PAN images in the fused image. The
experimental results show that the proposed algorithm significantly improves the fusion quality in terms of RASE, ERGAS, SAM, correlation coefficient, and UIQI compared to other fusion methods.

II. INTENSITY-HUE-SATURATION METHOD

IHS transform converts a multispectral image with red, green and blue channels (RGB) to intensity, hue and saturation relatively independent components [4]. The intensity displays the brightness in a spectrum, the hue is the property of the spectral wavelength, and the saturation is the purity of the spectrum. This transform may be used for the fusion of multisensor images.

The fundamentals of IHS fusion are [4]: (1) aligning the input multispectral image to the high resolution image; (2) transforming the input multispectral image from RGB to IHS color space; (3) substituting the intensity component with the high-resolution image; and (4) transforming the new substituted IHS components into RGB color space [14] This process leads to a fused and enhanced spectral image.

III. SPATIAL PCA

Land covers tend to behave in a similar fashion in adjacent bands of the electromagnetic spectrum, so redundant information can be detected in MS images [2]. In general, the first principal component (PC1) collects the common information of all the bands used as input images in the PCA [2]. This common information can be considered as the spatial information. The fact that pixels are highly correlated with their neighbors also suggests that images contain redundant information. It means that we can split an image up into sub-images and apply PCA to these sub-images [8].

When standard PCA fusion technique is used, the PAN image replaces the PC1 image, so the whole spatial detail information of this image is present in the resulting fused image [2]. This means that the standard PCA is closer to the PAN image than the other methods. In fact, when PCA is used, injection of spatial information into the MS images is more than desirable and this can lead to spectral distortion in the results.

To avoid the weak points of the standard PCA, we can apply PCA transform in spatial domain. The first principal component (PC1) collects the information that is common to all the pixels used as input data in the PCA, i.e., the spectral information, while the spatial information that is specific to each pixel is picked up in the other principal components. Fig. 1 shows the general procedure to fuse MS and PAN images, with a spatial resolution ratio of 1:n [2]. This process leads to a fused and enhanced spectral image.

In the past few years, several researchers proposed different PAN and MS image-fusion methods based on hybrid concept to integrate the advantages of two fusion methods. Undecimated Wavelet PCA (udWPC) [2], Undecimated Wavelet IHS (udWI) [2], IHS-wavelet [15], IHS-retina-inspired [4], FFT-enhanced IHS [16], and Improved adaptive PCA [17] are the most commonly used hybrid methods. But, because of wavelets or NSCTs which are used in these methods, they can fuse images where the resolution ratio between the low resolution MS images and the Panchromatic (PAN) image is a power of two. So these are not appropriate for some cases such as LANSAT and SPOT images with resolution ratio 1:3.

In general, transforms which are applied in spatial domain (such as wavelets, spatial PCA …) well preserve spectral information and those which are applied in spectral domain (such as IHS, PCA …) well preserve spatial information. So, to take advantage of both methods, we can combine spatial PCA and IHS. This proposed method has no limitation in image fusion.

Inspired by the IHS-Wavelet model [2], proposed hybrid model is described in Fig. 2 (we use spatial PCA instead of wavelets in our model). The general procedure for fusion of MS and PAN images, with the spatial resolution ratio of 1:n, is as follows:

1) Resample the low-resolution multispectral image to the same size as the high-resolution panchromatic image by the bi-cubic polynomial fit.
2) Apply the IHS transform to MS bands.
3) Generate a new PAN image whose histogram matches that of the I image.
4) Fuse I and new PAN by spatial PCA method. The result of this fusion is new I.
5) Substitute the I by the new I acquired in step 4.
6) Apply inverse IHS transform to new PC components.

This hybrid method can maintain spatial and spectral information simultaneously.
V. EXPERIMENTAL RESULTS AND DISCUSSIONS

SPOT 10-m and LANDSAT (TM) 30-m images were used for our experiments to evaluate and compare the performance of the following fusion methods:

- Brovey transform, based on the chromaticity transform [6].
- Standard IHS, using the Smith’s triangle model [14].
- Standard PCA, using correlation matrix [2].
- HPF method which uses box car filters [9].
- HPM method which uses box car filters [10].

Spatial PCA, described in section III.

Visual comparison of the fused images is the first step of quality assessment. The visual performances of the 4,3,2 bands of LANDSAT data are shown in Fig. 3.

As can be seen from Fig 3. (d) and (e), spatial PCA and HPM methods, preserved the spectral information well, but the edges of the fused image have not been sharpened enough. As depicted in Fig.3 (f) and (g), the spatial details have been pretty good enhanced in the merged image using standard PCA and IHS methods, but some colors have been predominated on the others.

The Brovey has injected a high degree of the spatial detail of the PAN image, but distortion of the spectral information is not acceptable at all (see Fig. 3 (h)).

As Fig. 3 (c) shows, an image with both high spectral and spatial resolution is obtained by the proposed method.

In addition to the visual inspection, the performance of each method should be analyzed quantitatively. Recently proposed by Alparone et al. [18], the QNR index evaluates the quality of the fused image without requiring the reference MS image and combines the two radiometric and geometric distortion indexes.

\[
QNR = (1 - D_s)(1 - D_s)
\]

(1)

Table I shows the performance comparisons of the fused images by QNR index. \(D_s\) is the spectral index and the low value of the \(D_s\) shows that spectral information is preserved very good. The low value of \(D_s\) shows that high degree of spatial information is injected into the MS.

As Fig. 3 (c) shows, an image with both high spectral and spatial resolution can be achieved by the proposed method.

As Table II shows, the quality indexes obtained by applying proposed methods are all pretty good compared with those obtained by applying other methods.

VI. CONCLUSIONS

A new combined method based on PCA and IHS transform is proposed in this paper. Studies show that, IHS method preserves spatial information well, and spatial PCA maintain the spectral information more than other methods.
Figure 2. Proposed hybrid algorithm
Figure 3. (a) Original PAN. (b) Original MS. (c) Proposed Hybrid method. (d) Spatial-PCA. (e) HPM. (f) PCA. (g) IHS. (h) Brovey.

**TABLE I. QNR INDEX**

<table>
<thead>
<tr>
<th></th>
<th>IHS</th>
<th>PCA</th>
<th>Brovey</th>
<th>HPM</th>
<th>Spatial PCA</th>
<th>Proposed Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_A$</td>
<td>0.121</td>
<td>0.123</td>
<td>0.140</td>
<td><strong>0.028</strong></td>
<td>0.029</td>
<td>0.030</td>
</tr>
<tr>
<td>$D_3$</td>
<td>0.088</td>
<td><strong>0.076</strong></td>
<td>0.087</td>
<td>0.196</td>
<td>0.107</td>
<td>0.079</td>
</tr>
<tr>
<td>QNR</td>
<td>0.802</td>
<td>0.810</td>
<td>0.785</td>
<td>0.781</td>
<td>0.867</td>
<td><strong>0.893</strong></td>
</tr>
</tbody>
</table>

**TABLE II. QUALITY METRICS AT INFERIOR LEVEL**

<table>
<thead>
<tr>
<th></th>
<th>IHS</th>
<th>PCA</th>
<th>Brovey</th>
<th>HPM</th>
<th>Spatial PCA</th>
<th>Proposed Hybrid Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>0.839</td>
<td>0.860</td>
<td>0.855</td>
<td>0.878</td>
<td>0.948</td>
<td><strong>0.962</strong></td>
</tr>
<tr>
<td>ERGAS</td>
<td>4.25</td>
<td>4.22</td>
<td>4.86</td>
<td>3.08</td>
<td>2.81</td>
<td><strong>1.84</strong></td>
</tr>
<tr>
<td>RASE</td>
<td>8.14</td>
<td>8.11</td>
<td>8.15</td>
<td>6.21</td>
<td>4.25</td>
<td><strong>3.35</strong></td>
</tr>
<tr>
<td>Q4</td>
<td>0.811</td>
<td>0.821</td>
<td>0.766</td>
<td>0.817</td>
<td>0.839</td>
<td><strong>0.888</strong></td>
</tr>
<tr>
<td>SAM</td>
<td>5.15</td>
<td>4.88</td>
<td>5.08</td>
<td>3.36</td>
<td>2.74</td>
<td><strong>1.15</strong></td>
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</table>
To take advantage of both methods, a new hybrid method was proposed in this paper which can preserve more spectral and spatial information simultaneously. Finally, the fusion results of the proposed method were compared to the results of some well-known methods at high and inferior level. The visual results showed that hybrid method can achieve better performance. In addition to the visual inspection, the performance of each method was analyzed quantitatively. The statistical analyses tools such as RASE, ERGAS, SAM, correlation coefficient and Q4 was demonstrated that the proposed algorithm increased spectral and spatial information contents and reduced the color distortion compared to the counterpart fusion methods.

References