A FUSION METHOD FOR MULTISPECTRAL AND PANCHROMATIC IMAGES BASED ON HSI AND CONTOURLET TRANSFORMATION

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ABSTRACT

Fusion of multispectral and panchromatic remote sensing images is a procedure to obtain spatial resolution and quality of the panchromatic image as well as preserving spectral information of the multispectral image. In this paper, we present a new fusion method based on HSI (Hue-Saturation-Intensity) and Contourlet transform. First, we convert the multispectral image from the RGB color space into the HSI color space. Then, by applying Contourlet transform to the panchromatic image and the I component of the multispectral image, we utilize an improved fusion rule based on PCA for the low-frequency sub-images, and engage the maximum fusion rule for the high-frequency sub-images. Finally, a fusion image is obtained by the inverse HSI transform. The experimental results show that the proposed fusion method not only enhances the spatial resolution of the fusion image, but also preserves the spectral information of the original multispectral image.

1. INTRODUCTION

The fusion of remote sensing images aims at integrating the information conveyed by data acquired with different spatial and spectral resolutions for photo analysis, feature extraction, modeling, and classification [1]. A notable application is to integrate the multispectral (MS) and panchromatic (PAN) remote sensing images collected from the space. The MS images contain abundant spectral information; however their spatial resolution is lower than the PAN images. Therefore, they obtain poor performance on the spatial details. On the other side, as the PAN images engage higher spatial resolution than the MS images, they contain more spatial details. But there is no spectral information in the PAN images. Thereafter, the fusion of MS and PAN images is to obtain spatial resolution and quality of the PAN image as well as preserving spectral information of the MS image.

Various image fusion methods have been developed, such as the HSI [2], PCA (Principal Component Analysis) [3], Brovey transform, wavelet transform [2], and some combinations of above methods [4][5]. Chavez [6] proposed the highpass filtering procedure to fuse MS and PAN images by extracting the PAN image spatial detailed information and injecting them into the MS one. María et al. [4] proposed a method for fusing the same kind of images by using improved HIS and PCA mergers based on wavelet decomposition. With the development of new multiresolution analysis, such as Contourlet transform, some methods adopted the advantages of Contourlet transform. For example, Yang et al. [5] utilized the improved GHIS and PCA based on Contourlet transform. However, the above methods drop the low frequency sub-images of the PAN image, thus the fused image may lose some spatial details.

In this paper, we propose a new fusion method based on HSI and Contourlet transforms. In the low frequency, we use the improved self-adaptive PCA method to select the weights of two images, and then employ a region-based-weighted method to fuse the images. Moreover, in the high frequency, we adopt the maximum rule. The experimental results show that the new fusion method not only obtains the high spatial resolution of the PAN image, but also preserves the spectral information of the MS image. Comparing to the standard HSI [4] [7], Contourlet transform [8], and the combination of the HSI and Contourlet transform [5], the proposed new fusion method presents better performance.

The rest of this paper is organized as follows: In Section 2, we firstly review the Contourlet transform theory; In Section 3, we propose a new fusion method based on HSI and Contourlet transform; In Section 4, we present the experimental results and the performance assessment by subjective and objective methods; Finally, Section 5 gives the conclusions.

2. BACKGROUND

2.1. Contourlet transform

Do and Vetterli [8] propose a “true” two dimensional transform that can capture the intrinsic geometrical structure which is a key in visual information. The commonly used separable extensions of one-dimensional transform methods, such as Fourier and wavelet transforms, have limitations in capturing the geometry of image edges. The ideal image representations have the following features: multiresolution, localization, critical sampling, directionality, and anisotropy [8]. Among these features, the first three are successfully provided by separable wavelets, and the result of Contourlet transform offers a high degree of directionality and anisotropy.

With a rich set of basis functions, contourlets represent a smooth contour with fewer coefficients compared with discrete wavelets. As the resolution becomes finer, the limitation of discrete wavelets is that it needs many fine “dots” to capture the contour [8]. However, contourlets effectively explore the smoothness of the contour by different elongated shapes and in a variety of directions following the contour.
Fig. 1 shows the decomposition of Contourlet transform. The Contourlet transform using a combination of a Laplacian Pyramid (LP) and a Directional Filter Bank (DFB). Bandpass images from the LP are fed into the DFB to capture directional information. The scheme can be iterated on the coarse image. The combined result is a double iterated filter bank structure, named as contourlet filter bank, which decomposes images into directional subbands at multiple scales [5][8].

![Fig. 1. The Contourlet filter bank.](image)

As a multiscale and directional decomposition, the Contourlet transform can be used to fuse MS and PAN images. The steps are similar to the wavelet transform, shown as follows:

1) Using the Contourlet transform to transform the MS and the PAN images.
2) Replacing the detailed images of the MS image with those of the PAN image, or equivalently replacing the approximation of the PAN image with the approximation of the MS image.
3) Performing the inverse Contourlet transform on the new combined set of images to obtain the fused image.

### 3. A NEW FUSION METHOD BASED ON HSI AND CONTOURLET

A fused image should obtain high spatial resolution while preserving the spectral information of the original MS image. After applying the Contourlet transform to the PAN image and the I component, we get their low-frequency and high-frequency sub-images, respectively. Therefore, our proposed fusion rule utilizes different fusion rules for different frequencies. In the low-frequency, we use the improved region-based and PCA weighted fusion rule, and in the high-frequency, we use the maximum fusion rule.

#### 3.1. Low-frequency fusion rule

For the low-frequency part, we use the improved region-based and PCA weighted fusion rule. Let \( I_1(x, y) \) and \( I_2(x, y) \) denote the low-frequency sub-image of the PAN image and that of the MS’s I component after applying the Contourlet transform, respectively. As only considering a single pixel will lead to the uncertainty of fusion result, we propose a new fusion rule based on region variance. Let \( \sigma^2_k(x, y) \) \((k = 1, 2)\) denote the variance of a 7×7 region centered in pixel \((x, y)\) of image \(k\). In order to preserve the spectral information in the MS image, we use the following fusion rule for the low-frequency sub-images by considering the variances of corresponding regions. If the variance of the PAN sub-image is larger than that of the I component sub-image, we use the weighted model to inject the spatial details into the fused image while preserving the spectral information. Otherwise, the I component sub-image will be employed to obtain the most spectral information. So the fusion operators are as follows:

\[
f(x, y) = \begin{cases} 
\lambda_1 I_1(x, y) + \lambda_2 I_2(x, y) & \text{if } \sigma^2_1(x, y) \geq \sigma^2_2(x, y), \\
I_2(x, y) & \text{otherwise}
\end{cases}
\]

where \( \lambda_1 \) and \( \lambda_2 \) denote the weight. In order to get more spatial details, \( \lambda_1 \) should be greater than \( \lambda_2 \), and it can be described as follows:

\[
\begin{align*}
\lambda_1 &= \max(\lambda_1(1)/\text{sum}(V_1), \lambda_1(2)/\text{sum}(V_1)), \\
\lambda_2 &= \min(\lambda_1(1)/\text{sum}(V_1), \lambda_1(2)/\text{sum}(V_1))
\end{align*}
\]

#### 3.2. High-frequency fusion rule

During an image’s contourlet decomposition, the large absolute value of the Contourlet transform high-frequency coefficient shows the image’s detailed information. Therefore, we apply the maximum rule as the fusion operator:

\[
f(x, y) = \begin{cases} 
H_1(x, y) & \text{abs}(H_1(x, y)) \geq \text{abs}(H_2(x, y)), \\
H_2(x, y) & \text{otherwise}
\end{cases}
\]

Here, \(H_1(x, y)\) and \(H_2(x, y)\) denote the high-frequency sub-images of the PAN and the MS images after applying the Contourlet transform, respectively.

#### 3.3. The new fusion method

The proposed fusion scheme is illustrated in Fig. 2. The steps of the proposed new fusion method can be described as follows:

1) Convert the MS image from the RGB color space into the HSI color space, and obtain the H, S, and I components, respectively;
2) Generate a new PAN image by matching the I component with the histogram match method;
3) Apply Contourlet transform to the new PAN and I images;
4) Using the fusion rules mentioned in Subsection 3.1 and 3.2 to fuse the low-frequency and high-frequency sub-images, respectively;
5) Perform inverse Contourlet transform to obtain the fused I component;
6) Apply the inverse HSI transform to the H, S, and the fused I components, and thus obtain the final fused image.
4. EXPERIMENTAL RESULTS AND PERFORMANCE EVALUATION

To evaluate the performance of the proposed fusion method, we conducted an experiment in which the low resolution MS image is shown in Fig. 3(a), and the high resolution PAN image is shown in Fig. 3(b). The fusion image using the standard HSI transform is illustrated in Fig. 3(c), the fusion image using the standard Contourlet transform is illustrated in Fig. 3(d), the fusion image by combining the HSI transform and Contourlet transform is shown in Fig. 3(e), and Fig. 3(f) is the fused image using our proposed new fusion method.

From the fused images we observe that the new fusion method not only enhances the spatial resolution, but also preserves the spectral information of the original MS image. Although the HSI fusion method improves the spatial resolution, it induces color distortion, such as the lake region of the fused image in Fig. 3(c) (in the right up corner), its color is dark blue in the original MS image, while its color becomes light blue after HSI fusion, so this method cannot preserve the spectral information effectively. Using the Contourlet transform preserves the spectral information to some extent; however it contains less spatial information, this drawback induces blur of the fused image. Through combining the HSI and Contourlet transforms, the fused image loses some spatial information as this method does not employ an effective fusion rule. The proposed fusion method obtains more spatial information while preserving the spectral information.

The human perception of the fused image is most important [10]. However, this method is subjective. To evaluate fusion results quantitatively, some statistical parameters, such as information entropy, average gradient, and deviation index, are employed to describe the contained information in the fused images [3].

1) Information entropy

Information entropy is an important index to measure the information deposited in images. According to the principle of Shannon information theory, the entropy of image can be defined as:

$$E = - \sum_{i=0}^{L-1} p_i \log_2 p_i .$$

(5)

where $L$ is the total gray level of image, and $p_i$ is the probability of gray $i$ in the image.

Fig. 3. The original images and fused images: (a) the original MS image; (b) the original PAN image; (c) the fused image using the HSI transform; (d) the fused image using the Contourlet transform; (e) the fused image using the HSI and the Contourlet transform; (f) the fused image using our proposed new fusion method.
### Table 1. The quantitative evaluation of various image fusion methods.

<table>
<thead>
<tr>
<th>Statistical result</th>
<th>Band</th>
<th>MS</th>
<th>PAN</th>
<th>HSI</th>
<th>Contourlet</th>
<th>HSI+Contoulet</th>
<th>New method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information Entropy</td>
<td>R</td>
<td>7.4985</td>
<td>6.8639</td>
<td>7.4629</td>
<td>7.5224</td>
<td>7.5542</td>
<td>7.5650</td>
</tr>
<tr>
<td></td>
<td>G</td>
<td>7.6363</td>
<td>6.4086</td>
<td>7.6378</td>
<td>7.6524</td>
<td>7.6544</td>
<td>7.5844</td>
</tr>
<tr>
<td>Deviation Index</td>
<td>R</td>
<td>-</td>
<td>-</td>
<td>0.3059</td>
<td>0.1061</td>
<td>0.0976</td>
<td>0.1755</td>
</tr>
<tr>
<td></td>
<td>G</td>
<td>-</td>
<td>-</td>
<td>0.3121</td>
<td>0.0846</td>
<td>0.0992</td>
<td>0.1803</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>-</td>
<td>-</td>
<td>0.2757</td>
<td>0.0938</td>
<td>0.0999</td>
<td>0.1772</td>
</tr>
</tbody>
</table>

3) Deviation index

Deviation index is introduced to measure the deviation extent between the fused image and the original MS image. It is defined as follows:

\[
\Delta = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} \frac{|MUL(i,j) - F(i,j)|}{MUL(i,j)},
\]

in which \(MUL\) denotes the original MS image, and \(F\) denotes the fused image.

Table 1 shows the evaluation results with the above three parameters. We observe that the new fusion method gets greater information entropy than those of the HSI transform and the Contourlet transform. However, compared to the combination of HSI and Contourlet methods, the information entropy of the new method is a little bit smaller, may be the combination method fuses more spectral information from the original MS and gets greater information entropy, whereas it leads to the loss of the spatial details. As for the average gradient, the new fusion method obtains the maximum value. Note that the average gradient reflects the clear degree of a fused image, and it is a very important evaluation standard. From the value of average gradient we can see that by using the proposed new fusion method the fused image obtains more spatial details and enhances the spatial resolution. Using the Contourlet transform gets the smallest deviation index, but its average gradient is the smallest. Although the deviation index of the new method is greater than that of the method combining the HSI and Contourlet transform, but it is smaller than that of the HSI transform. After all, our proposed new method not only enhances spatial information, but also preserves spectral information of the original MS image. Both the subjective and objective evaluations show that the new fusion method is effective in remote sensing image fusion.

## 5. CONCLUSIONS

In this paper, we propose a new remote sensing image fusion method based on HSI and Contourlet transform. We adopt different fusion rules to low-frequency and high-frequency sub-images adaptively. In low-frequency, we employ an improved region-based-weighted method, and we use the PCA method to choose weights. In the high-frequency, we engage the maximum fusion rule. From experimental results and quantitative evaluation, we affirm that the new fusion method can enhance the spatial information as well as preserving the spectral information of the original MS image.

### ACKNOWLEDGEMENTS

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## 6. REFERENCES


