Image Fusion Based on Curvelet Transform and Principal Component Analysis

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Abstract
For the fusion of infrared and visible images, the curvelet transform was performed on the two source images to obtain the transform coefficients on different scales and various directions. For low frequency coefficients, the weighted average method is adopted. For high frequency coefficients, in order to ensure more useful information retained and fewer errors reduced, the adaptive weighted algorithm feature product was adopted in this paper. And the fusion image was obtained through the inverse curvelet transform. The first principal component can be reconstructed according to the fusion image. The fused components and other components are performed together by the inverse PCA transform to obtain the final fusion image. The final reconstructed to obtain the fusion result. The fusion image obtained is evaluated in subjective and objective factors. Experiment results show that the algorithm has a better fusion result from the perspective of either subjective visual effect or objective statistical data.

Key words: Curvelet Transform, Feature Product, Principal Component Analysis, Image Fusion.

1. INTRODUCTION

Image fusion refers to the image processing and computer technology of the same target which will be collected in different mode, and the best information is extracted. Finally, a more comprehensive, more accurate and high quality image is synthesized. In recent years, the technology of image fusion has been developed rapidly, and its application range is very widely (Tan, Bao, and Li, 2004). It has significant application value, such as the fields of remote sensing, anti-terrorism, security, navigation, traffic monitoring, environmental protection, medical image analysis, clear image reconstruction, disaster detection and prediction (Zhu and Zhang, 2000).

With the development of image fusion technology, the more mature fusion technology in the field of image fusion: HIS transform, PCA transform, wavelet transform, multi-scale decomposition, etc.. An image fusion algorithm based on the accumulated gradient and PCA transform is proposed in the paper (Li and Lu, 2003). The algorithm uses local accumulative gradient criterion to make the selection of local detail coefficients of image fusion, uses PCA transform selection or averaging rule to achieve image fusion of local approximate coefficients based on the transform of source images of dual tree complex wavelet. At last, the corresponding fusion image can be obtained by using dual tree complex wavelet inverse transform base on the fusion detail coefficients and approximation coefficients. A color image fusion algorithm based on PCA and wavelet transform is proposed in the paper (Lu, Wu, and Jiang, 2007). The image is divided into clear block and fuzzy block. With the clear block, we select the block as the corresponding block area. With the fuzzy block, a method of selecting the pixel values based on the feature points is established. We select the characteristic value of the larger points in the two images as the pixel point, and thus the final fusion results are obtained.

In order to improve the accuracy of image fusion, a new method for image fusion based on curvelet transform and feature product is proposed. By combining the quantity of the feature product, it can be used to get more features.

The original multi--spectral image transformed by PCA is formed the quadrature component arranged by energy. Then the first principal component of the panchromatic image and multi-spectral image are handled with histogram matching, so that it has the same mean and variance as the first principal components. The curvelet coefficients of different resolution can be obtained by applying curvelet transform to the multi-spectral image and matched panchromatic images, such as low frequency and high frequency coefficients. The low frequency and high frequency fusion coefficient are obtained by applying different fusion rules. Then the fusion image can be obtained by the curvelet inverse transform, thus the first principal component can be gotten. Finally, the main component and other components gotten by curvelet inverse transform are obtained by Principal component inverse transform, and the final fusion image is obtained. The simulation results show that the fusion image is clearer, the spectral distortion is less, the details are more prominent, and the spectral information of the multi-spectral images is preserved effectively, and the information is increased.

(1) The orthogonal component of the energy array, which is also called the main component of the image, is formed by applying PCA transform of the original multi--spectral image.
(2) Making histogram matching to the panchromatic image with the first principal component of multi-spectral image, thus it has the same mean and variance as the first principal components.

(3) The curvelet coefficients of different resolution can be obtained by applying curvelet transform to the multi-spectral image and matched panchromatic images, such as low frequency and high frequency coefficients. Then we use different approach to get the coefficients of low frequency and high frequency coefficient matrix. With the low frequency part, the weighted average method is selected. With the high frequency part, The feature weight Jide adaptive weighting algorithm is selected.

(4) The low frequency and high frequency fusion coefficient are obtained by applying different fusion rules. Then the fusion image can be obtain by the curvelet inverse transform, thus the first principal component can be gotten.

(5) Finally, the main component and other components gotten by curvelet inverse transform are obtained by Principal component inverse transform, and the final fusion image is obtained.

2. FEATURE PRODUCT

In image fusion, it is very important to choose what kind of criteria to select. The feature extraction criterion is commonly used as follows: wavelet coefficient maximum, local gradient, local variance and energy criterion, etc.. Therefore, the single feature amount is not comprehensive, and the information is easy to be lost. Therefore, it is more than a combination of features to be used as the image fusion criterion.

According to the characteristics of multi-spectral image and panchromatic image fusion, image is obtained by the second generation curvelet transform, and its high frequency coefficients and image clarity have a certain relationship. Taking \((x, y)\) as the center, the high frequency coefficients \(H_{j, r}(i, j)\) can be gotten in the layer \(j\) and direction \(r\). Taking the window size as \((2m+1)\times(2m+1)\), the window of the wavelet energy \(E_w\), average gradient \(G_u\) and standard deviation \(S_u\) can be gotten according to the formula.

1. Local energy \(E_w\)

\[
E_w(u, v) = \frac{1}{(2m+1)^2} \sum_{i=-m}^{m} \sum_{j=-m}^{m} \left| D^j_{i, v} (u+i, v+j) \right|^2
\]

Where, \(D^j_{i, v}\) is the Coefficient of \((u, v)\).

2. Average gradient \(G_u\)

\[
G_u = \frac{1}{(2m+1)^2} \sum_{i=-m}^{m} \sum_{j=-m}^{m} \sqrt{\Delta u + \Delta v}
\]

Where, \(\Delta u\) and \(\Delta v\) are the coefficients of the direction of \(u\) and \(v\) respectively.

3. Standard deviation \(S_u\)

\[
S_w = \sqrt{\frac{1}{(2m+1)^2} \sum_{i=-m}^{m} \sum_{j=-m}^{m} \left| I(i, j) - \bar{I} \right|^2}
\]

Where, \(I(i, j)\) is the pixel value at the point \((u, v)\), \(\bar{I}\) is the mean.

These three characteristics are measured and characterized by the product of these three characteristics:

\[
A_{j, r}(i, j) = E_w \times G_u \times S_w
\]

Generally speaking, the bigger of the local energy, the local gradient, and the local standard deviation, the clearer the image is, the more better the image quality is. Local energy reflects the image edge or texture is clearer, and the local gradient reflects the small details of the image contrast and texture changes and the clarity of the image, the standard deviation reflects the image gray value of the image gray. In this paper, the characteristics of the three parameters are used as the fusion criterion, and the better results can be obtained.

\[
F_{j, r}(i, j) = E_w \times G_u \times S_w
\]

3. PCA FUSION RULE

Principal component analysis, which is called the PCA transform fusion method, can be described as follows. The multi-spectral images regard as input component are used to principal component analysis, and then make histogram matching to the panchromatic image with the first principal component of multi-spectral image, thus it has the same mean and variance as the first principal components. The first component of the first component of the high resolution after stretching is replaced by the first component of the multi-spectral graph. The new data obtained from high spatial resolution data and high spectral resolution data contains the high resolution and high spectral resolution of the source image, which preserves the high frequency information of
the original image. In this way, the details of the target details in the fusion image are clearer, and the spectral information is more abundant, and the specific process of the algorithm is as follows:

1. Calculate the co-variance matrix of the N band multi-spectral image
2. Calculate the eigenvalues $\lambda_i$ and the feature vector $\phi_i (i = 1, 2, ..., n)$ by co-variance matrix
3. The eigenvalues are arranged in a sequence of large to small, i.e. $\lambda_1 > \lambda_2 > ... > \lambda_n$, the feature vector $\phi_i$ is also changed accordingly;
4. Calculate the values of the main components of the image.

The flow chart of the fusion is shown in Figure 1.

**Figure 1.** Flow chart of PCA

4. IMAGE FUSION ALGORITHM BASED ON CURVELET TRANSFORM

We take the two source images that are registered rigidly as an example, i.e. the multi-spectral image and panchromatic image.

The different resolution curvelet coefficients can be obtained when the multi-spectral image and the matched panchromatic images are handled by curvelet transform, such as the low frequency and high frequency coefficients. Weighting algorithm, which can effectively prevent the useful information lost to retain useful information.

The image is divided into high frequency and low frequency. High frequency refers to the image of the intensity of the region, reflected in the image, that is, the effect of the edge and some noise. Low frequency is the background of the image, which includes the main energy of the image and reflects the overall characteristics.

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The flow chart of the fusion is shown in Figure 2.

**Figure 2.** Flow chart based on Curvelet transform
5. PRINCIPAL COMPONENT TRANSFORM IMAGE FUSION BASED ON CURVELET TRANSFORM AND FEATURE VOLUME PRODUCT

Based on the theory of curvelet transform and feature product, the PCA transform image fusion method based on curvelet transform and feature product is proposed, and the fusion step is as follows:

(1) The orthogonal component of the energy array, which is also called the main component of the image, is formed by applying PCA transform of the original multi-spectral image.

(2) Making histogram matching to the panchromatic image with the first principal component of multi-spectral image, thus it has the same mean and variance as the first principal components.

(3) The curvelet coefficients of different resolution can be obtained by applying curvelet transform to the multi-spectral image and matched panchromatic images, such as low frequency and high frequency coefficients. Then we use different approach to get the coefficients of low frequency and high frequency coefficient matrix. With the low frequency part, the weighted average method is selected. With the high frequency part, The feature weight Jide adaptive weighting algorithm is adopted.

(4) The low frequency and high frequency fusion coefficient are obtained by applying different fusion rules. Then the fusion image can be obtain by the curvelet inverse transform, thus the first principal component can be gotten.

(5) Finally, the main component and other components gotten by curvelet inverse transform are obtained by principal component inverse transform, and the final fusion image is obtained.

6. EXPERIMENTAL RESULTS

According to the method proposed in this paper, the given multi-spectral and panchromatic image of fusion are given by the fusion experiments. Multi-spectral image is shown as Figure 3. Panchromatic Image is shown as Figure 4. In this paper, the size is 256*256 pixels.

The images are PCA fusion, wavelet fusion, PCA-wavelet and the proposed method are used in this paper. The fusion results are shown in Figure 5, Figure 6, Figure 7 and Figure 8. From Figure 8, it is clear that the results of this method are not only clear texture, but also improve the performance of spatial details of the fusion image. Compared with other methods, the proposed method is more clear and less spectral distortion, the details are more prominent, and has a better visual effect.

Figure 3. Multi-spectral image Figure 4. Panchromatic image

Figure 5. PCA fusion Figure 6. Wavelet fusion
From the visual effect, the clear graphics of the objects under the same scene can be gotten by PCA fusion, wavelet fusion, PCA - wavelet fusion and the method proposed by this paper. From the pictures ,we can easily know the results obtained in this paper are clearer and the details are more prominent.

Also the ambiguity of the other two methods can be eliminated effectively by this method. Table 1 gives the objective evaluation index of the fusion images.

<table>
<thead>
<tr>
<th>Fusion algorithm</th>
<th>Variance</th>
<th>Information entropy</th>
<th>Definition index</th>
<th>Deviation index</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCA Fusion</td>
<td>53.0506</td>
<td>5.2607</td>
<td>22.1206</td>
<td>0.5251</td>
<td>0.7362</td>
</tr>
<tr>
<td>Wavelet fusion</td>
<td>49.8265</td>
<td>5.2114</td>
<td>9.3719</td>
<td>0.1029</td>
<td>0.9884</td>
</tr>
<tr>
<td>PCA - Wavelet fusion</td>
<td>54.6103</td>
<td>5.2897</td>
<td>23.4835</td>
<td>0.2211</td>
<td>0.9492</td>
</tr>
<tr>
<td>the method proposed by this paper</td>
<td>56.7432</td>
<td>5.31016</td>
<td>29.9712</td>
<td>0.2124</td>
<td>0.9671</td>
</tr>
</tbody>
</table>

From several evaluation indexes of table 1, we can see that the variance of the method proposed in this paper is the largest. In other words, the distribution of gray level is more dispersed, and the information is the largest. The information entropy is the largest, which means that the information content of the fusion image is better than that of other methods. And the method proposed by this paper is more significant than the other methods, and is more obvious than the other two methods. In short, from an objective evaluation of the perspective of the method in this paper can effectively improve the spatial resolution of the spectral information, and enhance the original multi-spectral image information, and highlight the edge details of the information.

REFERENCES

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