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Multi-Spectral and Panchromatic Image Fusion Based on Region Correlation Coefficient in Nonsubsampled Contourlet Transform Domain

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***Abstract*—Several widely used fusion methods may not be satisfactory to merge a high-resolution panchromatic image and low-resolution multi-spectral images because they can distort the spectral characteristics of the multi-spectral image or worsen the spatial resolution of the panchromatic image. In this paper, a fusion algorithm for multi-spectral and panchromatic images based on region correlation coefficient and the Nonsubsampled Contourlet Transform (NSCT) is proposed. According to the fusion idea of region division, the measurement named Region Correlation Coefficient (RCC) is presented to divide the multi-spectral image into the areas need to be spatially enhanced and need to preserve spectral characteristics. Then the NSCT is performed on the panchromatic image and the intensity component of the multi-spectral image at different scales and directions. The low-frequency subband coefficients and the high-frequency directional subband coefficients are fused with the different fusion strategy. Experimental results show that the algorithm proposed performs significantly better than the IHS transform, the redundant wavelet transform and the pixel-based NSCT.**

Keywords- image fusion; nonsubsampled contourlet transform; IHS transform; region correlation coefficient.

I. INTRODUCTION

It provides a lot of remote sensing images of spatial resolution, spectral resolution and phase resolution with the succeeded launches of all kinds of remote sense satellites. Panchromatic images supply high spatial resolution information but not spectrally, while multi-spectral images supply rich spectral information that can identify but not spatially. A fusion for multi-spectral and panchromatic images has not only the ability of showing the spatial detail but also remaining the spectral property of multi-spectral image to describe the earth object comprehensively. It has become a research focus in the field of remote sense image analysis [1~3].

Currently commonly used multi-spectral image fusion methods are IHS transform, principal component transform and wavelet transform. IHS transform and principal component transform produce spectral distortion. With wavelet-based method, the spectral distortion may be reduced to some extent, but the integration of the spectral and spatial feature usually does not appear smooth. The reason is that the discrete wavelet transform has sampling procedure during decomposition. It does not have shift-invariance property, which results in Gibbs effect[4] in the reconstructed image. On the backward of wavelet transform in the image processing, Da Cunha et. proposed contourlet transform of shift-invariant that is the Nonsubsampled Contourlet Transform (NSCT)[5]. Such transform provides a shift-invariant directional multiresolution image representation by means of iterated nonsubsampled filter banks, which can avoid the disadvantage of the discrete wavelet transform in the image processing.

The research [6] shows: the difference between multi-spectral and panchromatic image is the primary cause of spectral distortion of the fused image. The spatial intensity information of the multi-spectral image should be maintained to reduce spectral distortion in the region of large intensity difference. Meanwhile, injection of the intensity information of the panchromatic image will not result in excessive spectral distortion in the region of little intensity difference. The spatial resolution should be enhanced.

From above analysis, a fusion for multi-spectral and panchromatic images based on region correlation coefficient and the NSCT is proposed. Firstly, multi-level threshold segmentation is done for the multi-spectral image, then, notions about Region Correlation Coefficient (RCC) is presented to divide the multi-spectral image into the areas need to be spatially enhanced and need to preserve spectral characteristics, and the NSCT is performed on the panchromatic image and the intensity component of the multi-spectral image at different scales and directions. Finally, the fused coefficients are reconstructed to obtain the fused intensity component of the multi-spectral image.

II. THE NONSUBSAMPLED CONTOURLET TRANSFORM

NSCT is proposed based on Contourlet transform [7], the NSCT structure is consisted of the Nonsubsampled Pyramid (NSP) structure and the Nonsubsampled Directional Filter Banks (NSDFB) structure. The NSP structure is achieved by using two-channel nonsubsampled 2-D filter banks. The NSDFB is achieved by switching off the downsamplers/upsamplers in each two-channel filter bank in the DFB tree structure and upsampling the filters accordingly. As a result, NSCT is shift-invariant and leads to better frequency selectivity and regularity than contourlet

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transform. The scheme of NSCT structure is shown in Figure 1. The NSCT structure classify 2-D frequency domain into wedge-shaped directional subbands which is shown in Figure 2.

A. The Nonsubsampled Pyramid

The multi-scale property of the NSCT is obtained from a shift-invariant filtering structure that achieves subband decomposition similar to that of the Laplacian pyramid. Such expansion is similar to the 1-D nonsubsampled wavelet transform computed with the à trous algorithm and has a redundancy of J+1 when J is the number of decomposition stages. The ideal passband support of the lowpass filter at the j-th stage is the region $[-(\pi/2^j),(\pi/2^j)]^2$. Accordingly, the support of the high-pass filter is the complement of the low-pass support region on the $[(-\pi/2^{j-1}),(\pi/2^{j-1})]^2 \setminus [(-\pi/2^j),(\pi/2^j)]^2$ square. The filters for subsequent stages are obtained by upsampling the filters of the first stage. The decomposition process is shown in Figure 3.

In the process, x_{j+1} is the low frequency signal at scale J+1, y_{j+1} is the high frequency signal at scale J+1. H_j, G_j are the scale expansion of H_0, G_0 respectively at the 2^j-th stage.

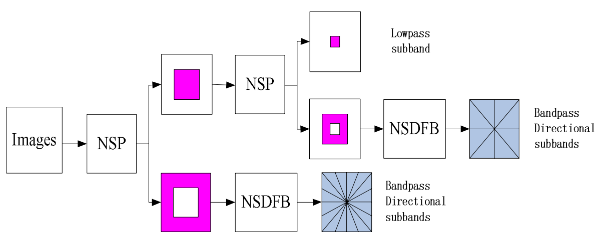

Figure 1. The structure of the NSCT

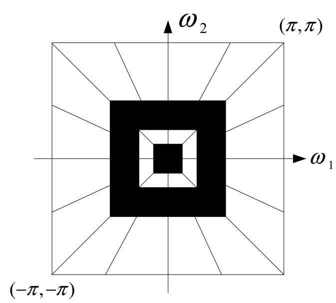

Figure 2. The idealized frequency partitioning obtained with the NSCT

B. The Nonsubsampled Directional Filter Banks

The NSDFB is constructed by combining critically-sampled two-channel fan filter banks which is proposed by Bamberger and Smith [8]. The result is a tree-structured filter bank that splits the 2-D frequency plane into directional wedges. A shift-invariant directional expansion is obtained with a NSDFB. The NSDFB is constructed by eliminating the downsamplers and upsamplers in the DFB. This is done by switching off the downsamplers/upsamplers in each two-channel filter bank in the DFB tree structure and upsampling the filters accordingly. This results in a tree composed of two-channel nonsubsampled filter banks. Figure 4. illustrates a four channel decomposition.

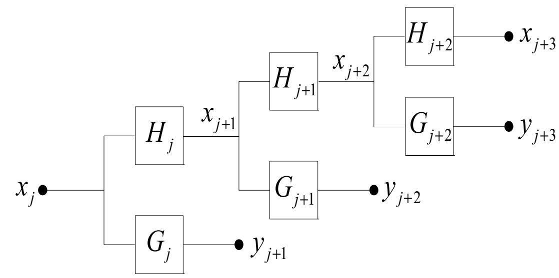

Figure 3. The NSP decomposition

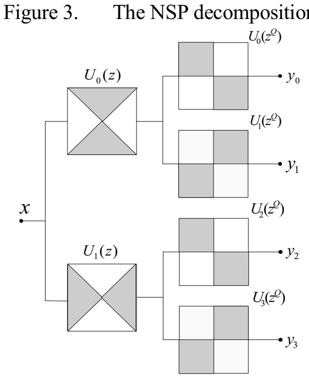

Figure 4. The NSDFB decomposition

III. FUSION ALGORITHM BASED ON REGION SEGMENTATION IN NSCT DOMAIN

At present, most fusion algorithm of multi-resolution analysis technology based on wavelet transform and NSCT belong to pixel-level fusion. Since local area characteristics of an image should be represented by pixels with strong correlation in stead of single pixel, Pixel-level fusion is one-sided. Feature-level fusion that based on region characteristics shows better visual effect and can restrain fusion trace effectively.

In this paper, a multi-spectral image is segmented through multi-level threshold segmentation and then classified into several regions by RCC. The regions serve as a unity to participate in the fusion process, which will not separate the physical meaning of the pixels.

A. Segmentation and Analysis of the multi-spectral image

In this paper, multi-level threshold segmentation based on Otsu[9]theory is used to segment the intensity component of the multi-spectral image. Otsu method is an adaptive thresholding method which is based on the image histogram and selects thresholds according to the rule of between-class maximum distance.

In the image fusion algorithm based on region segmentation, it is proposed that some measure operators can be used to represent the region characteristics. Operator such as region activity, match degree that proposed in paper [10, 11] has function on improving the fusion effect. In this paper, the purpose of region segmentation is to divide the multi-spectral image into the areas need to be spatially enhanced and need to preserve spectral characteristics. The above operators can not represent such regions effectively. The concept of Region Correlation Coefficient (RCC) is proposed in the paper and its definition is as followings:

$$RCC_{I,P}(R_i)=\frac{\sum_{(x,y)\in R_i}[I(x,y)-u_{R_i}^I]*[P(x,y)-u_{R_i}^P]}{\sqrt{\sum_{(x,y)\in R_i}[I(x,y)-u_{R_i}^I]^2\sum_{(x,y)\in R_i}[P(x,y)-u_{R_i}^P]^2}}\;. \quad (1)$$

In the formula,

$$u(R_i)=\frac{1}{N_{R_i}}\sum_{(x,y)\in R_i^{(k)}}L(x,y)\,. \quad (2)$$

N_{R_i} is the pixel number in region R_i. $L=I,P$ is the intensity component of the multi-spectral image and the panchromatic image respectively. $I(x,y)$ is the intensity component of the multi-spectral image and $P(x,y)$ is the gray value of the panchromatic image. $u(R_i)$ is the mean gray value in region R_i.

$RCC_{I,P}(R_i)$ represents the similarity between the intensity component of the multi-spectral image and the panchromatic image in region R_i. If the value of $RCC_{I,P}(R_i)$ is less, it means there is a larger difference between the multi-spectral image and the panchromatic image in the region which needs to keep the intensity component of the multi-spectral image to avoid spectral distortion. In contrary, if the difference between the multi-spectral image and the panchromatic image is less in the region, the spatial information of the panchromatic image should inject to increase the spatial resolution of the fused images.

$RCC_{I,P}(R_i)$ can represent the regions that need keeping spectral characteristics and enhancing spatial resolution in the multi-spectral image. It can be used as guideline in decision making during fusion process.

B. *Fusion algorithm*

The fusion algorithm of multi-spectral and panchromatic images based on region feature in NSCT domain has following steps (take two images as examples):

Step1. Make IHS transform for multi-spectral image T, obtain intensity component I, chrominance components H and saturation component S in IHS color space.

Step2. Make region segmentation on intensity component I and obtain segmentation map R, calculate the RCC value between I and panchromatic image P in every region of the map R.

Step3. Make multi-scale, multi-direction decomposition on I and P by NSCT and obtain NSCT coefficients $\left\{c_J^I, d_{l_j}^I\ (1\le j\le J, 1\le l\le l_j)\right\}$ and $\left\{c_J^P, d_{l_j}^P\ (1\le j\le J, 1\le l\le l_j)\right\}$. J is the scale decomposition number. l_j is the direction decomposition number in scale j. c_J is the low frequency subband coefficient. d_{l_j} is the bandpass directional subband coefficient.

Step4. Fuse the NSCT coefficients $\left\{c_J^I, d_{l_j}^I\right\}$ and $\left\{c_J^P, d_{l_j}^P\right\}$ by means of certain fusion rule to obtain fused NSCT coefficients $\left\{c_J^{I'}, d_{l_j}^{I'}\right\}$.

Step5. Make inverse NSCT on NSCT coefficients $\left\{c_J^{I'}, d_{l_j}^{I'}\right\}$ to obtain new intensity component I'.

Step6. Make inverse IHS transform on component I', H and S, and obtain fused high-resolution multi-spectral image F.

- Fusion strategy of the low frequency subbands

The fusion purpose of the multi-spectral and panchromatic images is to inject the spatial detail information of the panchromatic image and still keep the spectral characteristics of the multi-spectral image. Since spectral information mainly focus on the low-frequency subbands of the multi-spectral image while the low-frequency subbands of the panchromatic image contains limited spectral information, the low-frequency subband coefficients of the component I of the multi-spectral image can be regarded as that of the fused component I'. That is:

$$c_J^{I'}=c_J^I \quad (3)$$

- Fusion strategy of the high frequency directional subbands

The purpose of the high frequency component fusion is to obtain spatial detail information of the panchromatic image but still keep spectral information. According to the fusion idea of region division, $RCC_{I,P}(R_i)$ is served as measure operator to select the high frequency directional subband coefficient. If $RCC_{I,P}(R_i)$ is less than threshold T, the spatial characteristics deference between the multi-spectral image and the panchromatic image in region R_i is large. In order to avoid too much spectral distortion, the high frequency directional subband coefficient of the component I of the multi-spectral image in the region is selected as that of the fused component I'. In contrary, it means the spatial correlation between the multi-spectral image and the panchromatic image in regions R_i is high, injecting spatial detail information of the panchromatic image into fused image will not cause spectral distortion. The high frequency directional subband coefficient of the panchromatic image can be selected as that of the fused component I'. The fusion strategy is as followings:

$$d_{j,r}^{I'}(R_i)=\begin{cases} d_{j,r}^{I}(R_i), & if\ RCC_{I,P}(R_i)<T \\ d_{j,r}^{P}(R_i), & else \end{cases} . \quad (4)$$

Where $d_{j,r}(R_i)$ is the directional subband coefficient of the image at scale j, direction r ($r=1,2,\cdots 2^{l_j}$, l_j is the direction decomposition number in scale j) and region R_i. T is the RCC threshold which is 0.7~0.85 in general.

IV. EXPERIMENTAL RESULT AND ANALYSIS

A set of multi-spectral and panchromatic images have been used to evaluate of the image fusion algorithm proposed in this paper. We compare the results obtained by the image fusion methods based on the IHS transform, the redundant wavelet transform (RWT)[12] and the NSCT with simple fusion rule (NSCT_Simple)[13]. For the comparability among each fusion method, RWT and NSCT_Simple methods employ the same fusion rule, or the low frequency subband coefficients of the multi-spectral image are selected as that of the fused image and the high frequency directional subband coefficients of the panchromatic image are selected as that of the fused image. The RWT method with 3 decomposition depths is employed on the source images. Our algorithm and the NSCT_Simple method adopt 3 decomposition depths on the source images and 4,8,16 directions are used in the scales from coarser to finer respectively during the decomposition process. Figure 5 illustrates the corresponding fusion results.

It can be seen from Figure 5(d)-(g) that the fused image based on IHS method shows the most obvious spectral distortion. The problem is serious on the right vegetation area in the fused image. The fused image based on RWT and NSCT_Simple methods have slight color distortion. The fused image based on our algorithm hold the spectral information of the multi-spectral image best. For example, it inherits the spectral information of the multi-spectral image on the vegetation area. Conversely, the fused image based on IHS method has highest spatial resolution. The fused image based on NSCT_Simple method and our algorithm has higher spatial resolution than that based on RWT method. This is due to the perfect properties of the NSCT. Overall, the fused image based on our algorithm improves the spatial resolution of the multi-spectral image while holds the spectral information of the multi-spectral image best.

Another advantage of our algorithm is that the fused image can preserve some salience information that can be observed in the multi-spectral image while can not reflect in the panchromatic image. To explain this clearer, we extract some parts of the fused images Figure 5 (d)~(g) and put them into Figure 6 (a)~(d). In figure 5(a), we can observe there being a hole which is shown on the top right area of the multi-spectral image while can not reflect in the panchromatic image. In figure 6(a), the hole is very clear, but the other three algorithms can not reflect the salience information.

We also use two types of statistical parameters to evaluate the performances of the fusion methods. The first type of statistical parameters reflects the spatial detail information, such as variance, entropy and average gradient. The second type of statistical parameters indicates the capability of preserving the spectral characteristics, such as distortion degree, deviation index and correlation coefficient. They are computed by comparing the merged image to the original image. In this paper, we use entropy, average gradient, distortion degree and correlation coefficient [12] to evaluate the performances of the fusion methods.

Table 1 shows the statistical parameters of different methods. It shows that the entropy value based on our algorithm is highest and the average gradient value based on our algorithm is slightly lower than that based on IHS method. It suggests that our algorithm effectively improves the spatial detail as good as IHS method. As to spectral information, our scheme produces the minimal distortion degree and the maximum correlation coefficient. It indicates that the spectral information of our scheme is more similar to the original multi-spectral image. All the evaluation index suggest that the fusion effect of our scheme is best, which is consistent with the visual observation.

TABLE I. ASSESSMENT INDEX OF THE FUSION RESULTS

	Wave band	Entropy	Average Gradient	Correlation Coefficient	distortion degree
Original multi-spectral image	R	7.1689	11.6726	——	——
	G	7.1631	11.7762	——	——
	B	7.2756	11.8414	——	——
IHS transform	R	7.1628	16.8645	0.5108	29.2086
	G	7.2005	16.5902	0.5274	27.8626
	B	7.1160	16.4994	0.5905	28.2815
RWT	R	7.1258	16.0602	0.8246	8.7337
	G	7.1742	15.8748	0.8306	8.4078
	B	7.2450	15.8042	0.8589	8.3853
NSCT_Simple	R	7.1285	16.0666	0.8280	8.6578
	G	7.1763	15.8810	0.8340	8.3347
	B	7.2477	15.8123	0.8616	8.3111
Our algorithm	R	7.2272	16.4303	0.8803	8.5245
	G	7.2809	16.2056	0.8847	8.1853
	B	7.3405	16.2099	0.8998	8.1881

V. CONCLUSION

Aiming at the problem of spectral distortion in the fused remote sensing image, the fusion idea of region division is introduced and the measurement named region correlation coefficient is presented. The source images firstly are split into different regions with various spatial characteristics, and then different fusion rules are employed according to the degree of correlation between the multi-spectral image and the panchromatic image. From the experiment results, we have seen that the performances of our algorithm are better than the IHS, RWT and NSCT_Simple methods. We should conclude that the fused multi-spectral image based on our scheme can reduce the spectral distortion and improve the spatial detail information at the same time.

ACKNOWLEDGEMENTS

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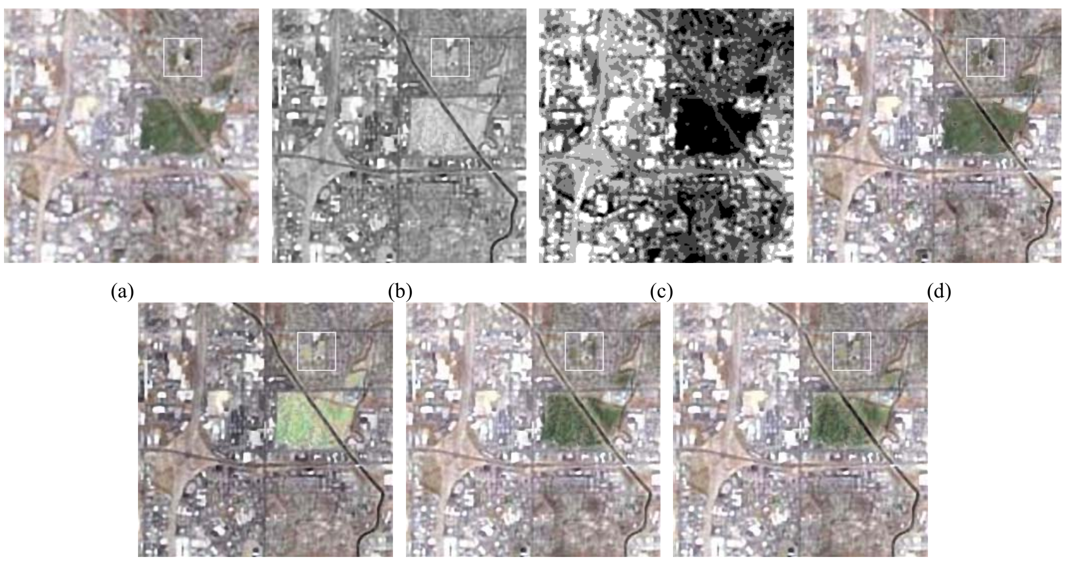
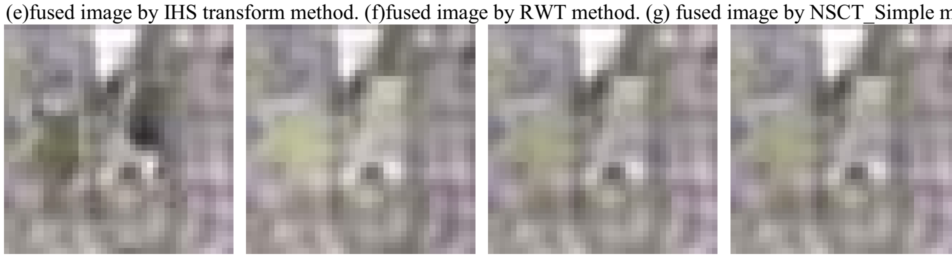


(a) (b) (c) (d)
(e) (f) (g)

Figure 5. Source images and fused results with different methods: (a) the multi-spectral image. (b) the panchromatic image. (c) the region map of the intensity component of the multi-spectral image. (d) fused image by our method. (e)fused image by IHS transform method. (f)fused image by RWT method. (g) fused image by NSCT_Simple method.



(a) (b) (c) (d)

Figure 6. Locally zoomed parts of the fused images: (a) taken from Fig.5(d). (b) taken from Fig.5(e). (c) taken from Fig.5(f). (d) taken from Fig.5(g).