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Remote Sensing Image Fusion Based on Enhancement of Edge Feature Information

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Abstract: A new image fusion algorithm of the multispectral image and the panchromatic image is proposed by using the non-subsampled contourlet transform and the lαβ color space. The non-subsampled contourlet transform is used to decompose an image into a low frequency approximate component and several high frequency detail components, and an edge enhancement method is employed to extract features from a high resolution image. For keeping the spectral little changing when image fusion, the lαβ color space, which is a new color space that simulates the visual perception of human, is adopted in this paper. Experimental results indicate that this proposed algorithm can obtain a fusion image which has more rich details.

Keywords: Remote sensing images, Non-subsampled contourlet transform, lαβ color space, Edge enhancement.

1. Introduction

Remote sensing platform often collect several kinds of data by using multiple sensors to the same location or target, which has the redundant information and complementary information compared with the one class data. By use of redundant information and complementary information in a particular way, multi-source image data fusion obtains the new image that has more reliable and accurate description of the information of the target. So image data fusion is one of the most important analysis methods in remote sensing image processing. Multispectral images and panchromatic images are two kinds of important remote sensing images. The multispectral image with the high spectral resolution has abundant spectral information, which plays an important part for the target recognition and interpretation. The panchromatic image with higher spatial resolution, can fully describe the details of the object characteristics and the spatial structure information. Due to the spatial resolution and spectral resolution of remote sensing optical systems are often unable to improve at the same time, so the information of multispectral images and panchromatic images fusion to obtain the abundant spectral information and high spatial resolution of the new image like a very meaningful thing.

An important requirement of this kind of data fusion is improve the spatial resolution of multispectral images through the details of the panchromatic image information, as much as possible keep the multispectral image spectrum information at the same time. Therefore, in this paper, on the one hand, the lαβ color space is used to obtain the brightness component of the multispectral image, as much as possible to reduce the influence of spectral information, on the other hand the non-sampling contourlet transform is used to obtain the panchromatic image multi-scale details characteristics, and information fusion through the edge character for both judging. Then the consistency of retention of spectral information and spatial information enhance are discussed. Comparative experiments prove that this method can improve the detail characteristics of multispectral image when the spectral information of multispectral image is little affected, and visual effect is good.

2. The Multiresolution Analysis

2.1. The Development of the Multiresolution Analysis

Human visual perception system has the characteristics of multiresolution, locality and directional. The multiresolution Analysis is based on function space theory, which is proposed in construction of the wavelet transform, and is formed by the tower algorithm, so it also called multi-scale Analysis [1]. In the past twenty years, the wavelet analysis has multiresolution and the locality. So the wavelet transform can well describe the image features and have a wide applications in the field of information fusion because of its good time-frequency local features. However, the two-dimensional wavelet transform is directly extension by the one dimensional wavelet transform with tensor product, in image said its support interval is square and which only have limited directions in horizontal, vertical and diagonal. The wavelet basis is limited to use square support interval describe profile, not with anisotropic [2]. Therefore, two-dimensional wavelet transform cannot optimal express high dimensional singular function that containing linesor surface, and is not able to realize the sparse expression of the two-dimensional geometric feature. So the information of the image boundary direction is very limited.

In recent years, there are many multi-scale analysis methods based on geometric features appeared after the wavelet transform and make up for some shortage of the wavelet multiresolution analysis, such as complex wavelet transform, curvelet transform [3, 4], contourlet transform [5, 6]. With the development of multiresolution analysis, these multi-scale analysis methods are effectively overcome the shortcomings of the wavelet about lacking of direction, so they can sparse express image geometric feature.

But for high order and regular singular edge, the curvelet transform is unable to achieve the optimal nonlinear approximation. In the same time, the curvelet transform has very high redundancy. Compared to the wavelet transform and the curvelet transform, the contourlet transform can sparsely express two-dimensional image better and have small redundancy [7].

2.2. The Non-subsampled Contourlet Transform

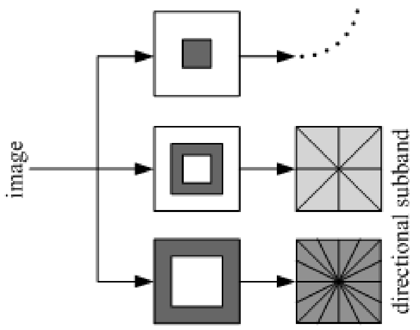
The contourlet transform have two parts about the subband decomposition and the direction transformation. By the pyramid directional filter bank (PDFB) of the contourlet transform, the image decomposed into band pass direction subbands in different scales. Firstly, the contourlet transform using the Laplacian pyramid transform (LP) for the multi-scale decomposition. By using the singular characteristic of point, the Laplacian Pyramid transform can obtain singular points from the image multi-scale decomposition. Then, by decomposing according to directions differently, the directions filterbank (DFB) synthesizes some discrete singular points as a factor, which distribute in the same direction. The contourlet transform get contain different direction subbands with the different direction detail at last. Compared with the wavelet transform, the contourlet transform have more effective support set and more sparse express of coefficients on account of the highly anisotropic in a small scale and a strong characteristic of the direction. However, the sampling operation exists in the Laplace pyramid and the directional filter can lead to the spectrum aliasing. The minor translation of the input image can lead to a larger transformation of the distribution of decomposition coefficients. If the decomposition coefficient be operated at this moment, ringing artifacts in edge of the final fusion result will appear due to a lack of the consistency of the coefficient distribution. So pseudo Gibbs distortion will appear in the result image edge. Although the contourlet base set have the ideal requirements by multiresolution transform, such as time domain local area, directivity, anisotropy, the contourlet transform also lack of the shift-invariance as the wavelet transform.

The non-subsampled contourlet transform (NSCT) is presented by [8]. It is constructed with the non-subsampled directional filterbank (NSDFB) and the non-subsampled pyramid (NSP) [8]. In the LP decomposition and DFB decomposition, the NSCT use àtrous algorithm constructs the non-sampling Laplacian transformation (NSLP), and use the non-subsampled directionalfilterbank implement directions of the subband division. The contourlet transform have the signal extraction that after the decomposition filter and the signal interpolation that before the integrated filter. The NSCT improvement them for the sampling to the corresponding filter and signal analysis, and do comprehensive filtering later. It effectively solves the problem of the shift variation. The condition of the signal can be completely reconstruction by avoiding the frequency aliasing that ensured by NSP and NDFB is filter meet as follows.

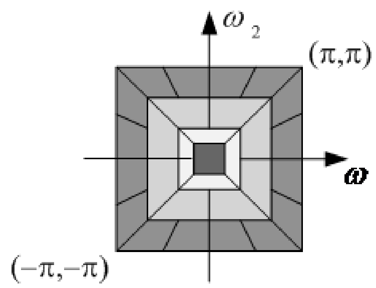
$$H_0(z)G_0(z) + H_1(z)G_1(z) = 1 , \tag{1}$$

where $H_0(z)$ and $H_1(z)$ denote decomposition filters, $G_0(z)$ and $G_1(z)$ denote reconstruction filters.

Fig. 1 is a schematic plot of the non-subsampled contourlet transform. Because of the NSCT remove the sampling process, all output coefficients of the image that are decomposed by each subband have the same size with the original image. It makes the NSCT having the shift-invariance. However, in the fusion process, it makes the large increase of the computational complexity and the storage space in the same time. As previously seen, the NSCT resolve the problem of translation variation is cost of the larger redundancy. The NSCT get multi-scale nature by the non-subsampled pyramid filter bank, and get multi-directional nature by the non-subsampled directional filterbank. So relative to the contourlet transform, the NSCT inherited the features of the multi-scale and the directivity from the contourlet transform, buthas the shift-invariance in difference. So the NSCT has better choice characteristics of frequency domain and it can more accurately express the two-dimensional image signal by effectively capture the geometry information of images.



(a) Non-subsampled pyramid filter



(b) Frequency decomposition

Fig. 1. A schematic plot of the non-subsampled contourlet transform.

2.3. The lαβ Space Model

As a new color space, the lαβ space simulates the visual perception of human [9-10]. In the lαβ space, the 'l' component is the signal channel about color brightness. The color channel 'α' is the yellow - blue opponent channel. The color channel 'β' is the red - green opponent channel. In the lαβ space, the relationship between three axes of the color space can minimize, then the influence of a channel change on other channels to the minimum. The type (2) - (4) can convert images from the RGB space to the lαβ space.

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 0.3811 & 0.5873 & 0.0402 \\ 0.1967 & 0.7244 & 0.0782 \\ 0.0241 & 0.1288 & 0.8444 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (2)$$

$$L^* = \log L,\ M^* = \log M,\ S^* = \log S \quad (3)$$

$$\begin{bmatrix} l \\ \alpha \\ \beta \end{bmatrix} = \begin{bmatrix} \frac{1}{\sqrt{3}} & 0 & 0 \\ 0 & \frac{1}{\sqrt{6}} & 0 \\ 0 & 0 & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & -2 \\ 1 & -1 & 0 \end{bmatrix} \begin{bmatrix} L^* \\ M^* \\ S^* \end{bmatrix} \quad (4)$$

The type (5) - (7) inverse transform images from the lαβ space to the RGB space.

$$\begin{bmatrix} L^* \\ M^* \\ S^* \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & -1 \\ 1 & -2 & 0 \end{bmatrix} \begin{bmatrix} \frac{\sqrt{3}}{3} & 0 & 0 \\ 0 & \frac{\sqrt{6}}{6} & 0 \\ 0 & 0 & \frac{\sqrt{2}}{2} \end{bmatrix} \begin{bmatrix} l \\ \alpha \\ \beta \end{bmatrix} \quad (5)$$

$$L = 10^{L^*},\ M = 10^{M^*},\ S = 10^{S^*} \quad (6)$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 4.4679 & -3.5873 & 0.1193 \\ -1.2186 & 2.3809 & -0.1624 \\ 0.0497 & -0.2439 & 1.2045 \end{bmatrix} \begin{bmatrix} L \\ M \\ S \end{bmatrix} \quad (7)$$

3. The Image Fusion Based on NSCT

3.1. The Edge Information Enhancement

Traditional image fusion methods often bring about the biggish spectral distortion in the fusion of the multispectral image and the panchromatic image. Through the image from RGB color space conversion to the lαβ color space, and the feature about each other small influence of each component in the lαβ color space, the influence on account of the information change of the multi-spectral image color in the fusion process is reduce. The small spectral change of multi-spectral images is beneficial to make full use of spectral information in the fusion image. At the same time, the excellent expression ability of the NSCT about the image geometric feature helps to better extracting the details of the texture feature from the panchromatic image. So the comprehensive performance of three aspects, which conclude keeping spectral information and improving spatial resolution and enhance detail texture information, can achieve a better balance in the image fusion. This paper proposes are mote sensing image fusion method that combined of edge information enhancement. It is combining with the characteristics of the lαβ color space and the NSCT, by strengthening the weak edge detail to provide more detail information for the fusion image, and the experiment about the fusion of the panchromatic image and the multispectral image is accomplishment.

3.2. Fusion Steps of NSCT

By the lαβtransform firstly, the multispectral image can get the luminance component MS-l, and get the MS-α, the MS-β component at the same time. The MS-l component histogram matching with the Pan image, then the luminance component MS-l' of the multispectral image and the panchromatic image are decomposed by NSCT respectively to obtain the respective NSCT coefficients $\{H_{j,k}^{MS-l}, L^{MS-l}\}$ and $\{H_{j,k}^{Pan}, L^{Pan}\}$. In expressions, j for multi-scale decomposition layer, k for the direction of each scale decomposition, L for the low frequency information of image, and H for the high frequency information of the image in the direction k and the scale j. Then the coefficients that obtained by the NSCT can deal with by the fusion rules. Finally, the low frequency information and the high frequency information refactor by the NSCT to get new fusion image. According to the characteristics of the multispectral image and the panchromatic image, the fusion method based on layered about the NSCT decomposition of the high frequency and the low frequency coefficients is used by different fusion rules. Rules include using the edge information of coarse scale coefficient as judging criteria of the low frequency, and using the function to enhance the weak edge detail scale coefficient in the high frequency. At last, the new brightness component is obtained by inverse transformation to MS-new and the final fusion results are obtained by replace the original brightness component with MS-new to the inverse lαβ transform.

3.3. Fusion of the Low Frequency Components

The main energy of the image focused on the low frequency component of the image that is reflect the overview and contour of the original image on the resolution. Most fusion methods are adopting the weighted average method or choose the biggest coefficient in the low-frequency component fusion. But with no consideration of characteristics such as the edge of the image, the contrast of the image is reduce by a certain extent, which makes the fusion result not clear. So in order to better keep the edge detail features from the original image, the options to determine the low frequency component of the fusion image is based on the edge features in this paper. Firstly, by the canny operator to detect the edge of the multispectral image L^{MS-l} and the panchromatic image L^{Pan-l}. Then the decision scheme is as follows.

The gray value of any pixel in the image set as *f (x, y)*. The modulus values of the pixel set as *M (x ,y)*. The x and y respectively indicate the pixel abscissa and ordinate in original images. The $M^2(x, y)$ is calculated as follow.

$$M^2(x,y) = \left(f(x+1,y) - f(x-1,y)\right)^2 + \\ + \left(f(x,y+1) - f(x,y-1)\right)^2, \quad (8)$$

1) If common edges of the multispectral image L^{MS-l} and the panchromatic image L^{Pan-l} are found, the low frequency component is calculated on the basis of the modulus value as the assigned.

$$L^{f-l} = \frac{M_L^{MS-l}}{M_L^{MS-l} + M_L^{Pan-l}} * L^{MS-l} + \\ + \frac{M_L^{Pan-l}}{M_L^{MS-l} + M_L^{Pan-l}} * L^{Pan-l}, \quad (9)$$

2) If the only one edge of the multispectral image L^{MS-l} and the panchromatic image L^{Pan-l} are found, the low frequency component is calculated as the assigned expression to eliminate the possible noise.

$$L^{f-l} = \begin{cases} w * L^{MS-l}, & edge \quad in \quad L^{MS-l} \\ w * L^{Pan-l}, & edge \quad in \quad L^{Pan-l} \end{cases} \quad (10)$$

$$w = \begin{vmatrix} \frac{1}{16} & \frac{1}{16} & \frac{1}{16} \\ \frac{1}{16} & \frac{1}{2} & \frac{1}{16} \\ \frac{1}{16} & \frac{1}{16} & \frac{1}{16} \end{vmatrix} \quad (11)$$

3) If it is not the source image edge, then the expression about the low frequency coefficients of the fusion image is calculated on the basis of the local modulus square proportion.

$$L^{f-l} = \frac{\left(M_L^{MS-l}\right)^2}{\left(M_L^{MS-l}\right)^2 + \left(M_L^{Pan-l}\right)^2} * L^{MS-l} + \\ + \frac{\left(M_L^{Pan-l}\right)^2}{\left(M_L^{MS-l}\right)^2 + \left(M_L^{Pan-l}\right)^2} * L^{Pan-l} \quad (12)$$

3.4. Fusion of the High Frequency Components

The edge is a remarkable feature of the image. It is directly affect the sharpness and the expression of the image information. Therefore, it is more conducive to the choice of the knowledge in the image fusion by enhance the characteristic of the image edge. In consideration of some value of panchromatic image edge are weak, the paper makes the weak edge of the image is amplified and reinforced by using the method of literature [11-12] to modify the coefficients of the NSCT. Thus spatial resolution of the fused image is improved.

$$y_k(x,\sigma)=\begin{cases}1 & x<k\sigma\\ \frac{x-k\sigma}{k\sigma}\left[\frac{m}{k\sigma}\right]^p+\frac{2k\sigma-x}{k\sigma} & k\sigma\le x<2k\sigma\\ \left[\frac{m}{x}\right]^p & 2k\sigma\le x<m\\ \left[\frac{m}{x}\right]^s & x\ge m\end{cases} \tag{13}$$

In the parameter value of the type, the σ is the image noise variance. The determines whether the strong edge and the weak edge strengthen or weaken. The value of k is used to ensure noise have been suppressed in the process of the weak edge enhancement. The adjustment factor m can take half as much as the mean or max value of decomposition coefficients, which is changing with the decomposition layer and the direction. In this experiment, parameters respectively adopt as p=0.5, s=0, k=3.

Later, the high frequency coefficient and the new MS-l component calculate as follows.

$$H_{j,k}^{Pan-f}=y_k(x,\sigma)*H_{j,k}^{Pan} \tag{14}$$

$$H_{j,k}^{f-l}=\max\left(H_{j,k}^{MS-l},H_{j,k}^{Pan-f}\right) \tag{15}$$

$$MS_l^{new}=INSCT\left\{H_{j,k}^{f-l},L^{f-l}\right\} \tag{16}$$

Finally, the reverse transformation about lαβ is used to obtain the fusion image. The new MS-l component together with the MS-α and MS-β components are converted from lαβ color space back to RGB color space.

4. Experimental Results and Analysis

On the one hand, Images fusion should keep the original spectrum. On the other hand, Images fusion should obtain the high resolution space information as much as possible. At the same time, Images fusion should not draw into other information that is not include in the panchromatic image or the multispectral image. So the paper try to adopt the lαβ color space to keep original spectra does not change in the fusion process, and try to adopt the edge enhancement method by NSCT to get more useful information in the fusion image. The fusion image by this paper with some experimental results in others fusion algorithm of the multispectral image and the high-resolution panchromatic image are given in Fig. 2.

As shown in the Fig. 2, by contrasting with the image (a), some fusion images have appeared larger spectral changes in results, such as the results of the method of (c) PCA and (d) IHS. At the same time, images of result (e) and result (f) are seemingly getting a good maintenance in the spectrum of fusion image, and the result (f) closer to the original multispectral image (a).

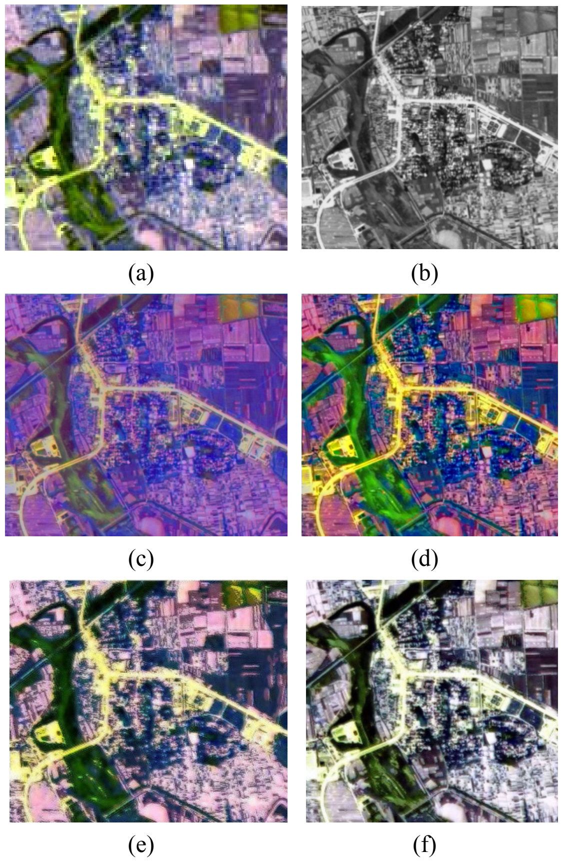


Fig. 2. The fusion results of the multispectral imageand the panchromatic image in different algorithms.
(a) multispectral image, (b) panchromatic image,
(c) PCA, (d) IHS, (e) IHS+NSCT,
(f) NSCT+ edge enhancement.

Due to the lack of the standard image, relative to other types of image fusion, the evaluation standard of fusion results of remote sensing images is difficult to master by contrast to other kinds of images fusion. The objective evaluation of fusion results has been a research direction in the digital image processing. The paper selects some typical standards that include of the standard deviation (std), entropy (ent), spectral distortion (dist) and correlation coefficient (cc).

$$std=\sqrt{\frac{\sum_{i=1}^{M}\sum_{j=1}^{N}[F(i,j)-\overline{\mu}]}{M\times N}} \tag{17}$$

$$ent=-\sum_{i=0}^{L-1}p_i\log_2 p_i \tag{18}$$

$$cc=\frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(F^k(i,j)-\mu(F^k))(A^k(i,j)-\mu(A^k))}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}(F^k(i,j)-\mu(F^k))^2(A^k(i,j)-\mu(A^k))^2}} \tag{19}$$

$$warp=\frac{1}{M\times N}\sum_{i=1}^{M}\sum_{j=1}^{N}\left|F^k(i,j)-A^k(i,j)\right| \tag{20}$$

The standard deviation (std) is an important symbol of the amount of image information. It is express the degree of dispersion between the average values with the pixel of the image and reflects the matching degree of the spectral information between the fusion image and the source image. So it can express the ability of transmitting details from the source high resolution image to the fusion image. The image information entropy (ent) is an indicator to measure the richness of the image information. The image, which contains more information, could have the greater value of the entropy. The correlation coefficient (cc) expresses the degree of correlation within the two images. That the value is closer to 1 means the better effect of the image fusion to achieved. The image spectral distortion degree (dist) directly reflects the light distortion of the multispectral image. The quality of the spectral is more serious when it is greater, and it is indicate that the spectral distortion is the worse, and vice versa better spectral quality.

The objective evaluation indexes of some different algorithms in Fig. 2 are gave as below of Table 1.

Table 1. The multi-index in different fusion results.

I	std			ent		
	R	*G*	*B*	*R*	*G*	*B*
c	41.8574	33.4078	31.7628	7.3788	6.9640	6.8942
d	74.7381	50.8954	45.9347	7.6475	7.5531	7.3980
e	88.5674	72.8905	71.3784	7.5906	7.9349	7.8845
f	70.3273	61.2226	59.5385	7.8123	7.7092	7.7200
I	cc			dist		
	R	*G*	*B*	*R*	*G*	*B*
c	0.7655	0.7649	0.8233	30.4037	45.9880	32.8654
d	0.8808	0.6384	0.7016	33.3496	44.6079	39.3130
e	0.8305	0.7723	0.7494	25.7207	24.3502	32.4341
f	0.9046	0.8816	0.7769	17.2651	17.2620	17.1932

As show on Table 1, the standard deviation of the image (c) and the entropy value of the image (d) are low. At the same time, the spectrum warping is on the high side of the image (c) and (d). These results of standards coincide with subjective visual results. The image (f) has bigger entropy value and correlation coefficient comparing with the image (e), and the spectrum warping of the image (f) is reduced at the same time. The experimental results show that the edge detail maintaining while improve the spatial resolution of the multispectral image, and the algorithm that based on lαβ and NSCT can reducing the spectral distortion. So the fusion requirements about the multispectral image with the panchromatic image are better reflects. In comprehensive consistency about the image resolution and spectrum, this algorithm is obviously superior to the front of a variety of algorithm in this paper.

5. Conclusions

A new fusion algorithm based on NSCT and lαβ is proposed in this paper. It combines the flexibility of NSCT for the image decomposition and the edge enhancement rule for feature representation. By experimental results indicate, the algorithm can keep the spectral little changing when fusion image get the rich space details. Comparing with some tradition algorithms of images fusion, the algorithm about the NSCT and the edge enhancement has better comprehensive visual perception. In future work, it has better application prospect in digital image process.

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