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Image Fusion Based on Spatial Weightage in Nonsubsampled Contourlet Transform Domain

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Abstract: Satellite imageries are categorized as both panchromatic and multispectral images. The panchromatic image has higher spatial resolution while the multispectral image has relatively lower spatial resolution but are rich in spectral information .The fusion of these two can produce a better imagery . Most of the fusion methods available to merge a high-resolution panchromatic image and low-resolution multi-spectral images may distort the spectral characteristics of the multi-spectral image or the spatial resolution of he panchromatic image may reduce. In this paper, a fusion algorithm for multi-spectral and panchromatic images based on spatial weightage called region correlation coefficient and in the Nonsubsampled Contourlet Transform (NSCT) Domain is proposed. The proposed fusion idea partitions both the source images into regions and Region Correlation Coefficient (RCC) is calculated between the corresponding regions of multispectral and panchromatic images .This RCC determines the regions of multispectral image with better spatial resolution and those with better spectral quality. The fusion is performed in NSCT domain. For that NSCT is performed on individual regions of panchromatic image and intensity component of multispectral image at different scales and directions. The obtained NSCT coefficients are fused taking into consideration the spatial weightage factor. Performance analysis show that the algorithm proposed is better than the IHS transform method and simple NSCT method.

Keywords: Satellite imagery, multispectral image, panchromatic image, Nonsubsampled Contourlet Transform, IHS transforms, Region Correlation Coefficient

I.INTRODUCTION

Image fusion is concerned with the integration or collection of multiple different images, derived from different sensors, into a unique image which inherits the qualities from source images to improve visual perception or quantitative and qualitative analysis. With the successful launching of the new generation of satellite imaging systems, very high resolution multispectral (MS) and Panchromatic (Pan) images are made available, to enhance the automation of vision tasks, and in some instances, act as replacements to the traditional aerial photographs [2]. The recent progress in Satellite imagery 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. The best use of both can be obtained through fusion.

A fusion of multi-spectral and panchromatic images can display the spatial characteristics as well as the spectral content of multi-spectral image. It has become a research focus in the field of remote sense image analysis [3].Some of the existing multi-spectral image fusion methods are IHS transform, principal component transform and wavelet transform. The disadvantage of IHS transform and principal component transform is the unavoidable spectral distortion. Wavelet-based method, reduce the spectral distortion to certain extent, but the fusion result cannot be smooth [1]. The sampling process adopted in wavelet based fusion during decomposition is shift invariant which results in Gibbs effect [4] in the reconstructed image. So to overcome the disadvantage of discrete wavelets, there arises a need of shift invariant directional multiresolution image representation. Such a transform is the Nonsubsampled Contourlet Transform (NSCT) [5] proposed by D Cunha et.NSCT uses iterated Nonsubsampled filter banks [1]

The difference between multispectral and panchromatic image is the major reason of spectral distortion of the fused image [6]. If the intensity difference between the two is more, the spatial intensity information of the multi-spectral image should be preserved in order to reduce spectral distortion .Otherwise if the intensity difference between the two is less even the introduction of spatial detail of panchromatic image will not result in excessive spectral distortion.

Keeping in view the above inferences, a fusion for multi-spectral and panchromatic images is proposed considering region correlation coefficient as spatial weightage to identify the region where spatial resolution has to be maintained and where spectral clarity is to be preserved. For achieving better quality fused result we are fusing the source images in NSCT domain. Firstly, the multi-spectral image and panchromatic images are divided into regions of equal sizes called subimages and notions about Region Correlation Coefficient(RCC) is presented to analyse whether the area need to be spatially enhanced or to preserve spectral detail. NSCT is performed on every region of both panchromatic image and the intensity component of the multi-spectral image at different scales and directions. Finally, the obtained fused coefficients are reconstructed to get the fused intensity component of the multi-spectral image.

The following section II discusses the basic structure of NSCT and concept of nonsubsampled directional filter banks of NSCT. Section III describes the proposed method for fusion. Section IV shows how the proposed method gives better results than some existing methods through experimental approach and quantitative analysis using statistical parameters. Finally, Section V concludes the proposed method wholly.

II.THE NONSUBSAMPLED CONTOURLET TRANSFORM

NSCT is proposed basing 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 down samplers / up samplers in each two-channel filter bank in the DFB tree structure and up sampling the filters accordingly. As a result, NSCT is shift-invariant and leads to better frequency selectivity and regularity than contourlet transform. The scheme of NSCT structure is shown in Figure 1. The NSCT structure classify 2-D frequency domain into wedge-shaped directional subband as 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 $[(\frac{\pi}{2^j}),(\frac{\pi}{2^j})]^2$. Accordingly, the support of the high-pass filter is the complement of the low-pass support region on the $[(\frac{\pi}{2^{j-1}}),(\frac{\pi}{2^{j-1}})]^2$ / $[(\frac{\pi}{2^j}),(\frac{\pi}{2^j})]^2$ square. The filters for subsequent stages are obtained by up sampling 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 is the scale expansion of H0, G0 respectively at the 2^j -th stage.

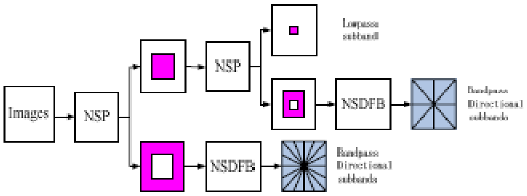


Figure 1. The structure of the NSCT

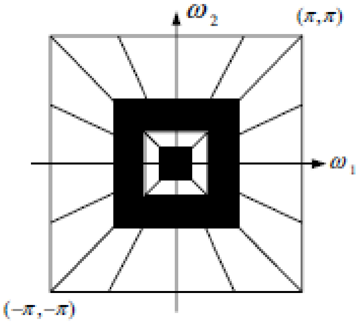


Figure 2. The idealized frequency partitioning obtained with the NSCT

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 down samplers and up samplers in the DFB. This is done by switching off the downsamplers/upsamplers in each two channel two channel filter bank in the DFB tree structure and up sampling the filters accordingly. This results in a tree composed of two-channel Nonsubsampled filter banks. Figure 4. Illustrates four channel decomposition.

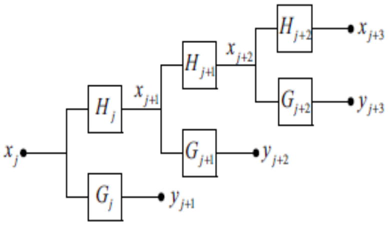


Figure 3. The NSP decomposition

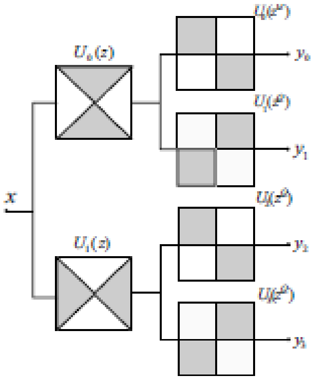


Figure 4. The NSDFB decomposition

III. PROPOSED FUSION ALGORITHM

The actual fusion process can take place at different levels of information representation [8]. A common method is to distinguish between pixel, feature and symbol level. Image fusion at pixel-level means fusion at the lowest processing level referring to the merging of measured physical parameters. Fusion at feature-level requires first the extraction (e.g., by segmentation procedures) of the features can be identified by characteristics such as size, shape, contrast and texture. The fusion is thus based on those extracted features and enables the detection of useful features with higher confidence [9]. Fusion at symbol level allows the information to be effectively combined at the highest level of abstraction[9]. The choice of the appropriate level depends on many different factors such as data sources, application and available tools. Most image fusion applications employ pixel-based methods. The advantage of pixel fusion is that the images used contain the original information. Furthermore, the algorithms are rather easy to implement and time efficient. The existing fusion methods based on pixel-level are very sensitive to misregistration, thus the accuracy of image registration is demanded in sub-pixel level. The region-based approach have some advantages that the fusion process becomes more robust and avoids some of the well-known problems in pixel-level fusion such as blurring effects and high sensitivity to noise and misregistration.

A. Image analysis basing on Spatial weightage RCC

In this paper, the intensity component of the multi-spectral image and the panchromatic image are divided into subimages. The regions of multispectral image are distinguished as those needed to be spatially enhanced and those whose spectral characteristics are to be preserved using some metric. Operators such as region activity, match degree that proposed in paper [10, 11] has function on improving the fusion effect. The purpose of region division is to divide the multi-spectral image into the areas need to be spatially enhanced and need to preserve spectral characteristics [1]. The above operators can not represent such regions effectively. The concept of Region Correlation Coefficient (RCC) can be defined as follows [1]

$$RCC_{I,P}(R_i)=\frac{\sum\limits_{(x,y)\in Ri}[I(x,y)-u_{Ri}^{I}]*\ [P(x,y)-u_{Ri}^{P}]}{\sqrt{\sum\limits_{(x,y)\in Ri}[I(x,y)-u_{Ri}^{I}]^2\ \sum\limits_{(x,y)\in Ri}[P(x,y)-u_{Ri}^{P}]^2}}$$

(1)

In the formula,

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

N represents number of pixels in the region *Ri*. *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*.

$RCC_{I,P}(R_i)$ is used as a spatial weightage to measure similarity between the intensity component of the multi-spectral image and the panchromatic image in region R_i [1]. 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 multispectral 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 spatial weightage i.e. RCC in NSCT domain can be summarized in following steps (take a multispectral image and a panchromatic image as source images):

Step1: Compute IHS transforms for multi-spectral image M Obtain intensity component I, chrominance component *H* and saturation component *S* in IHS color space.

Step2: Make partition on intensity component I and panchromatic image P to obtain equal blocks (or) regions R1, R2….Rn corresponding to both images. Calculate the *RCC* value between I and panchromatic image *P* in every region.

Step3:Perform multi-scale, multi-direction decomposition on I and *P* using NSCT for every region and obtain NSCT Coefficients $\{ c^{I}_{J}, d^{I}_{lj}\ (1 \le j \le J, 1 \le l \le l_j)\}$ and $\{ c^{P}_{J}, d^{P}_{lj}\ (1 \le j \le J, 1 \le l \le l_j)\}$ corresponding to a region ,say R1 . *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_{lj} is the bandpass directional subband coefficient.

Step4: Fuse the NSCT coefficients $\{ c^{I}_{J}, d^{I}_{lj} \}$ and $\{ c^{P}_{J}, d^{P}_{lj} \}$ using equations (3)and (4) for low frequency subbands and high frequency directional subbands respectively to obtain fused NSCT coefficients $\{ c^{I'}_{J}, d^{I'}_{lj} \}$

Step5: Apply inverse NSCT on NSCT coefficients $\{ c^{I'}_{J}, d^{I'}_{lj} \}$ to obtain new intensity component *I''* corresponding to region R1

Step6: Repeat step 3 to step 5 for all regions R2, R3…..Rn and get individual intensity components say I_2'', I3''…In''.

Step6: Merge the intensity components I1'', I2''…In'' corresponding to regions R1, R2, R3…..Rn to get fused Intensity component I'.

Step7: Apply inverse IHS transform on component *I'*, *H* and *S*, and obtain fused high-resolution multispectral image *F*.

- *Fusion approach of the low frequency subbands*

The criteria of fusion of the multi-spectral and panchromatic images are to introduce the spatial detail information of the panchromatic image without distorting the spectral characteristics of the multi-spectral image. The low-frequency subbands of the multi-spectral image have rich spectral information compared to that of the lowfrequency subbands of the panchromatic image .Then the low-frequency subband coefficients of fused image is considered as equal to the low frequency subband coefficient of multispectral image .

$$c^{I'}_{J} = c^{I}_{J} \tag{3}$$

- *Fusion approach of the high frequency directional subbands*

The importance of the high frequency component fusion is to introduce spatial detail information of the panchromatic image without effecting the spectral information. The proposed fusion idea uses spatial weightage, $RCC_{I,P}(\ R_i)$ as measure operator to choose the high frequency directional subband coefficient. If *RCCI, P (Ri)* is less than threshold T , the spatial characteristics correlation between the multispectral image and the panchromatic image in region *Ri* is small. So, if we introduce spatial detail of panchromatic in such regions it will deteorate the spectral features of multispectral image. Hence 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'*. Otherwise if $RCC_{I,P}(\ R_i)$ is greater than threshold *T* ,it means the multi-spectral image and the panchromatic image in regions are highly correlated and the introduction of spatial detail information of the panchromatic image into fused image don't effect the spectral distortion. Thus in such regions high frequency directional subband coefficient of the panchromatic image is selected as that of the fused component *I'*. The fusion approach is given by eq.(4)[1]:

$$d^{I'}_{lj} = \begin{cases} d^{I}_{lj} & \text{if} \quad RCC_{I,P}(Ri) < T \\ d^{P}_{lj} & \text{else} \end{cases} \tag{4}$$

where $d_{j,r}(\ R_i)$ is the directional subband coefficient of the image at scale j , direction r (1,2,… $2^{l\ j}$, 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 RESULTS AND ANALYSIS

Various multi-spectral and panchromatic images have been used to evaluate the performance of the proposed fusion algorithm. The obtained results of the proposed image fusion method is compared with the fusion method based on the IHS transform, [11] and the NSCT with simple fusion rule (NSCT_Simple)[12].In the simple NSCT fusion rule, 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 proposed algorithm and the NSCT_Simple method assume 2 decomposition depths on the source images and 4,8 directions are used in the scales from coarser to finer respectively during the decomposition process. Figure 4 illustrates the corresponding fusion results. From figure 4(c) fusion based on IHS method shows the most obvious spectral distortion figure 4 (d). The fused image based on NSCT_Simple method have slight color distortion. The fused images based on proposed algorithm shown in figure 4 (e) holds the spectral information of the multi-spectral image in the best way. The proposed method thus has the ability to preserve some finest information of the multi-spectral image even after fusion with panchromatic spatial details.

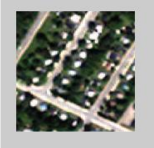
The paper makes use of two types of statistical parameters to analyse the performance of the fusion methods. The parameters which reflect the spatial detail information are entropy and average gradient [12] whereas those selected to describe about spectral characteristics is correlation coefficient [12]. The metrics are evaluated between the fused image and the input image. Table 1 analysis the performance of different fusion methods. From the table the entropy value based on proposed algorithm is highest and the average gradient value based on proposed algorithm is comparatively lower than IHS and simple NSCT methods. Thus proposed algorithm effectively improves the spatial characteristics. Also from the table, proposed method results in highest correlation coefficient compared to the rest of two methods. Thus proposed algorithm preserves most of the spectral information of original multi-spectral image. The performance analysis shows the proposed method is the best, the same can be observed through visual perception of images shown in Figure 4

V. CONCLUSION

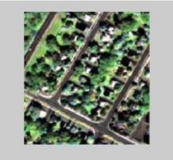
The problem of introduction of spectral distortion observed in the fusion process of remote sensing images can be overcome with the proposed fusion idea of region division and the spatial weightage region correlation coefficient. The source images firstly are split into different regions with equal sizes .These regions are transformed into low frequency and high frequency subband coefficients and then different fusion approaches are adopted in transformation domain i.e.NSCT basing on the computed spatial weightage of regions of multi-spectral image and the panchromatic image. After performance evaluation, proposed algorithm shows better results in terms of entropy, average gradient and correlation coefficient compared to the IHS and NSCT_Simple methods. Thus proposed method works best to enhance spatial resolution as well as can preserve spectral content.

TABLE I PERFORMANCE ANALYSIS OF VARIOUS FUSION METHODS

Method	Wave band	Entropy	Average Gradient	Correlation coefficient
Original multispectral image	R	7.6728	15.3721	------
	G	7.7798	14.4119	------
	B	7.6097	13.4847	-----
IHS transform	R	7.7336	14.1883	0.8356
	G	7.8575	14.9951	0.8491
	B	7.5722	13.0352	0.8194
NSCT_simple	R	7.6804	11.4534	0.8567
	G	7.7929	11.5080	0.8488
	B	7.6557	10.5240	0.8503
Proposed method	R	**7.6810**	**9.4330**	**0.8686**
	G	**7.7846**	**8.8714**	**0.8557**
	B	**7.6157**	**8.3736**	**0.8697**


(a)


(b)


(c)


(d)


(e)

Figure 4. Source images and fused results with different methods:(a)The multispectral image.(b)The panchromatic image.(c)The fused image by HIS Transform.(d)Fused image by NSCT simple method.(e)Fused image by proposed method

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