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## A Novel Remote Sensing Image Enhancement Method Based on NSCT

<sup>1</sup>Qian Li, <sup>1</sup>Zhenhong Jia, <sup>1</sup>Xizhong Qin, <sup>2</sup>Yingjie Hu and <sup>3</sup>Jie Yang

<sup>1</sup>College of Information Science and Engineering, Xinjiang University, Urumqi, 830046, P.R. China

<sup>2</sup>Knowledge Engineering and Research Discovery Institute,  
Auckland University of Technology, Auckland, New Zealand

<sup>3</sup>The Institute of Image Processing and Pattern Recognition, Shanghai Jiao Tong University,  
Shanghai, 200240, P.R. China

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**Abstract:** Image enhancement has developed for decades and remote sensing image enhancement is one important section of it. A novel remote sensing image enhancement method based on the Nonsubsampled Contourlet Transform (NSCT) is proposed in this study which can remove noise in image and enhance the contrast and details at the same time. For the classical Histogram Equalization (HE) can quickly and effectively improve the contrast of image globally. The HE is utilized to enhance the contrast of remote sensing image at first. Then the remote sensing image after HE is decomposed into the NSCT domain with a low-frequency sub-band and several high-frequency sub-bands. An adaptive threshold de-noising method is used to remove noise in the high-frequency and to further enhance the contrast of image locally, the fuzzy contrast enhancement are applied at the high-frequency sub-bands after de-noising. The low-frequency part stays without being processed to prevent over-enhanced. At last the remote sensing image is transformed into frequency domain and a Laplacian filter is utilized to enhance the edges. The experiment results have demonstrated that the proposed method has significant improvement in remote sensing image enhancement.

**Key words:** Image enhancement, NSCT, histogram equalization, fuzzy contrast, laplacian filter

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### INTRODUCTION

Remote sensing satellite and its images appeared during the cold war which have been being widely used in many fields, such as meteorology, geology, agriculture, education, etc. (Lee *et al.*, 2013; Wu *et al.*, 2011). In the process of reception and transmission of remote sensing image, the picture is contaminated or damaged inevitably due to the impact of atmospheric radiation, sensor performance and external noise. The main purpose of remote sensing image enhancement is to make the damaged or contaminated image enhanced for human recognition or computer processing. And the de-noising, contrast enhancement, edge and detail enhancement are the main contents of image enhancement.

The purpose of de-noising is to remove the noise contained in the signal and retaining the important signal features as much as possible at the same time (Chang *et al.*, 2000). Traditionally, this is achieved by spatial filters, such as Median filtering, Wiener filtering, Morphological filtering and so on. In recent years, multi-resolution analysis has been widely used in image de-noising, since it can better preserve the details while

de-noising. Transform domain-based image de-noising includes wavelet (Chang *et al.*, 2000; Shui, 2005), Curvelet (Starck *et al.*, 2002), Contourlet (Eslami and Radha, 2003), etc. The smoothness along edges in image is commonly, but the traditional wavelet transform is blind to it and on the other hand, the traditional wavelet transform can only capture the limited direction information. (Eslami and Radha, 2003). Curvelet transform and Contourlet transform were developed in an attempt to overcome the inherent limitation of wavelet. However, Curvelet transform has high redundancy but, the Curvelet transform is complex due to its high redundancy and images after Contourlet transform will produce pseudo-Gibbs phenomena around singularities for it lacks of shift-invariance. To solve these problems, Da Cunha *et al.* (2006) put forward the NSCT which has shift invariance, anisotropy and rich directions. In this article, an adaptive threshold de-noising based on NSCT was adopted.

Histogram equalization is a traditional method for image contrast enhancement and the improved algorithms based on HE have been widely used. HE can enhance the contrast of images from the global, however, globally-based methods often do not take into account the

relationship among neighborhoods and leads to noise amplification and poor improvement in local information (Men *et al.*, 2010). Li *et al.* (2004) put forward a novel image fuzzy contrast enhancement algorithm based on fuzzy theory which can enhance the image contrast locally and has good robustness to noise. Fuzzy contrast in NSCT domain can achieve a better result in image enhancement for it combines the merits of NSCT and the fuzzy contrast (Men *et al.*, 2010). To enhance the contrast of remote sensing images locally and globally, both HE and fuzzy contrast in NSCT domain are utilized in this study.

## METHODS

**Nonsubsampled contourlet transform:** Contourlet transform overcomes the shortcoming of Wavelet-based methods which can only capture the limited direction information in horizon and diagonal. However, it is a difficult task to design good filters for the Contourlet transform. Moreover, the Contourlet transform lacks of shift-invariant due to downsamplers and upsamplers present in both the Laplacian pyramid and the Directional Filter Banks (DFB) (Li *et al.*, 2010). To overcome the drawbacks of Da Cunha *et al.* (2006) developed the NSCT and studied its applications by Da Cunha *et al.* (2006). NSCT inherits the merits of Contourlet transform and satisfies perfect reconstruction conduction and has shift invariance. So transforming image to NSCT domain can keep more details of image and get better noise reduction. NSCT is consisted of two parts: Nonsubsampled Pyramid (NSP) and Nonsubsampled Directional Filter Bank (NSDFB). NSP decomposes an image into a number of radial sub-bands while NSDFB is used to decompose

band-pass images into several directional sub-band images to capture the directional information. The scheme can be iterated repeatedly on the coarse image. For more details about NSCT, this study refer readers to Da Cunha *et al.* (2006). The structure of NSDFB and the idealized NSCT frequency decomposition is shown in Fig. 1.

**Self-adaptive thresholding de-noising method:** NSCT can transform an image into a low-frequency image and:

$$\sum_{l=1}^j 2^l$$

( $l$  denotes the number of decomposition level) high-frequency images. Those images have the same size as the original image. High-frequency sub-band containing the image noise which can be separated from the image by selecting an appropriate threshold. The non-orthogonal of NSCT results in different noise variance in each sub-band. In order to retain more details when removing noise, the correlation among sub-bands is considered, an adaptive thresholding is selected in this study for denoising. The Bayes Shrink threshold is computed as:

$$T_B = c \frac{\sigma^2}{\sigma_x^2} \quad (1)$$

where,  $c$  is a constant between 0 and 1.  $\sigma^2$  is the noise variance,  $\sigma_x^2$  is the signal variance.

$$\sigma = \frac{\text{median} |d_{i,j}|}{0.6745} \quad (2)$$

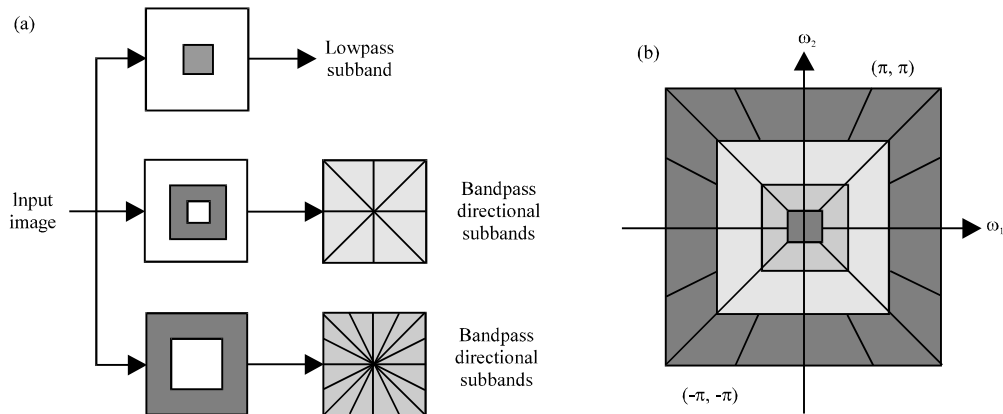


Fig. 1(a-b): Nonsubsampled contourlet transform (a) NSCT (Nonsubsampled contourlet transform) structure and its decomposition process and (b) Idealized schematic diagram of frequency resolution

$$\sigma_x = \sqrt{\max\left(\frac{1}{mn} \sum_{i=1}^m \sum_{j=1}^n d_{i,j}^2(1,k) - \sigma^2, 0\right)} \quad (3)$$

The average of coefficients in  $l$ th levels and  $k$ th direction is shown in Eq. 4.

$$S_{l,k} = \frac{1}{m \cdot n} \sum_{i=1}^m \sum_{j=1}^n d_{i,j} \quad (4)$$

when the decomposition level is 1,  $2^1$  sub-band coefficient matrices are obtained. The average is:

$$S_l = (\sum_{k=1}^n S_{l,k}) / n(n=2^l) \quad (5)$$

The weighted factors in different directions are computed by Eq. 6:

$$\lambda = S_{l,k} / S_l \quad (6)$$

Adaptive thresholding in this study is calculated as follows:

$$T = \lambda T_0 \quad (7)$$

$$d'_{i,j} = \begin{cases} d_{i,j}, & d_{i,j} > T \\ 0, & d_{i,j} \leq T \end{cases} \quad (8)$$

where,  $m$  represents the number of rows of sub-band coefficients matrix,  $n$  represents the number of columns of sub-band coefficients matrix,  $d_{i,j}$  is the coefficient at  $(i,j)$  and  $d'_{i,j}$  is the coefficient after de-noising.

**Fuzzy contrast enhancement in NSCT domain:** The fuzzy theory was applied to image enhancement by Pal and King (1981). With the concept of fuzzy set, an image  $X$  of  $M \times N$  dimension and  $L$  levels can be mapped as an array of  $M \times N$  in fuzzy domain:

$$X = \bigcup \{\mu(x_{mn})\} = \{\mu_{mn} / x_{mn}\} \quad (9)$$

$m = 1, 2, \dots, M; n = 1, 2, \dots, N$

where,  $x_{mn}$  denotes the color intensity at the  $(m, n)$ ,  $\mu_{mn}/x_{mn}$  represents the membership or grade of some property  $\mu_{mn}$  of  $x_{mn}$ .

The normalized fuzzy contrast is defined as Eq. 10 Li *et al.* (2004):

$$F_c = \frac{|\mu_{mn} - \overline{\mu_{mn}}|}{|\mu_{mn} + \overline{\mu_{mn}}|} \quad (10)$$

The fuzzy contrast enhancement in NSCT domain is described as following:

- Coefficients are transformed from NSCT domain to fuzzy domain by a membership function given Eq. 11:

$$\mu_{ij} = \frac{d_{ij} - d_{\min}}{d_{\max} - d_{\min}} \quad (11)$$

where,  $d_{ij}$  represents the high-frequency sub-band coefficient at  $(i, j)$ ,  $d_{\max}$  and  $d_{\min}$  represent the maximum and minimum in sub-band, respectively.

- Calculate the fuzzy contrast of each sub-band by Eq. 10
- Transforming  $F_c$  using nonlinear function below

$$F'_c = \Phi(F_c) \quad (12)$$

$$\Phi(x) = 4x - 6x^2 + 4x^3 - x^4 \quad (13)$$

- The changed membership is shown in Eq. 14

$$\mu'_{mn} = \begin{cases} \frac{\overline{\mu_{mn}}(1 - F'_c)}{1 + F'_c} & \mu_{mn} \leq \overline{\mu_{mn}} \\ 1 - \frac{(1 - \mu_{mn})(1 - F'_c)}{1 + F'_c} & \mu_{mn} > \overline{\mu_{mn}} \end{cases} \quad (14)$$

- Transforming the membership function from fuzzy domain to NSCT domain

$$d'_{ij} = \mu'_{mn}(d_{\max} - d_{\min}) + d_{\min} \quad (15)$$

The detailed procedure to perform the proposed algorithm is described as follows:

- **Step 1:** Improve the contrast of the input remote sensing image using the histogram equalization globally
- **Step 2:** Decompose the histogram equalized image using NSCT

Get De-noising of the high-frequency coefficients using Eq. 8.

Adjust local contrast using the fuzzy contrast enhancement.

- **Step 3:** Transform image from NSCT domain to spatial domain

- **Step 4:** Enhance the image details using a Laplacian filter

Laplacian filter is an isotropic filter which has been commonly used as an enhancement operator. For the response of the isotropic filter can regardless of sudden changes direction in processed image and easy to be designed, it is widely used in image enhancement. The Laplacian filter selected in this study is  $\begin{bmatrix} 1 & 1 & 1 \\ 1 & -8 & 1 \\ 1 & 1 & 1 \end{bmatrix}$  (Polesel *et al.*, 2000).

## RESULTS AND DISCUSSION

Two remote sensing images namely City and Harbour are selected for testing. In order to test the performance of the proposed method, results of experiments were analyzed from both objective and subjective. The subjective evaluation depends mainly on human eyes which can evaluate the effect on the enhancements intuitively and quickly. The proposed method is compared with HE method, Multi-scale Retinex (MSR) (Zhao *et al.*, 2008), Contourlet Transform (CT) (Nezhadarya and Shamsollahi, 2006) and fuzzy contrast enhancement based on NSCT (NSCT-FC) (Men *et al.*, 2010). To facilitate

subjective analysis, the original images and the enhanced result images are shown in Fig. 2 and 3.

It is obvious to see that the proposed method performs better than other methods on contrast enhancement, noise suppression and detail direction preservation. To further illustrate the result from objective, this study select the following objective evaluation criteria for remote sensing image enhancement effects assessment: definition, information entropy, the peak signal to noise ratio (PSNR). Table 1 and 2, respectively correspond to the data in Fig. 2 and 3.

Table 1 and 2 shows the definition, entropy and PSNR of the proposed method and the comparative methods. By comparing of the data in the tables, it is can be seen that the definition of the enhanced remote sensing image by NSCT-FC is close to the proposed method, but the information entropy and PSNR value in this algorithm are far below the result from the proposed method, especially the information entropy. For the first remote sensing image, the information entropy value of NSCT-FC is lower by 99.08% than the proposed method, in the second remote sensing image, the information entropy of enhanced image by the proposed method increased by 97.77%. The definition, information entropy

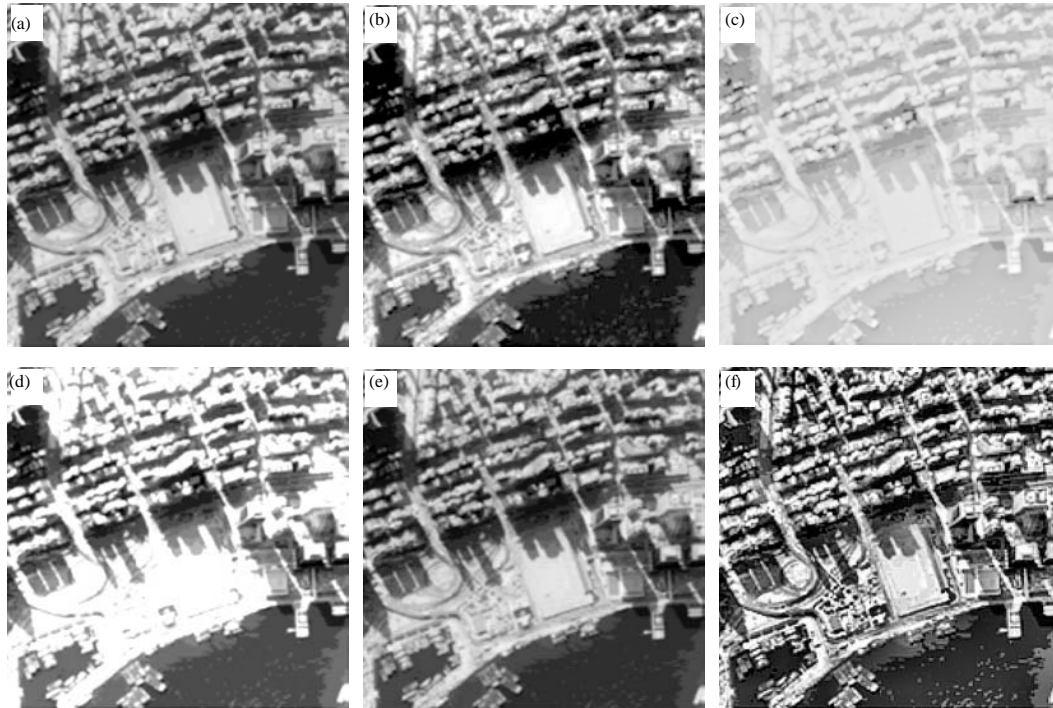


Fig. 2(a-f): The 'City.bmp' and its enhanced images, (a) Original image, (b) Enhanced image after HE, (c) Enhanced image based on MSR, (d) Enhanced image based on CT, (e) Enhanced image based on NSCT-FC and (f) Enhanced image using the proposed method

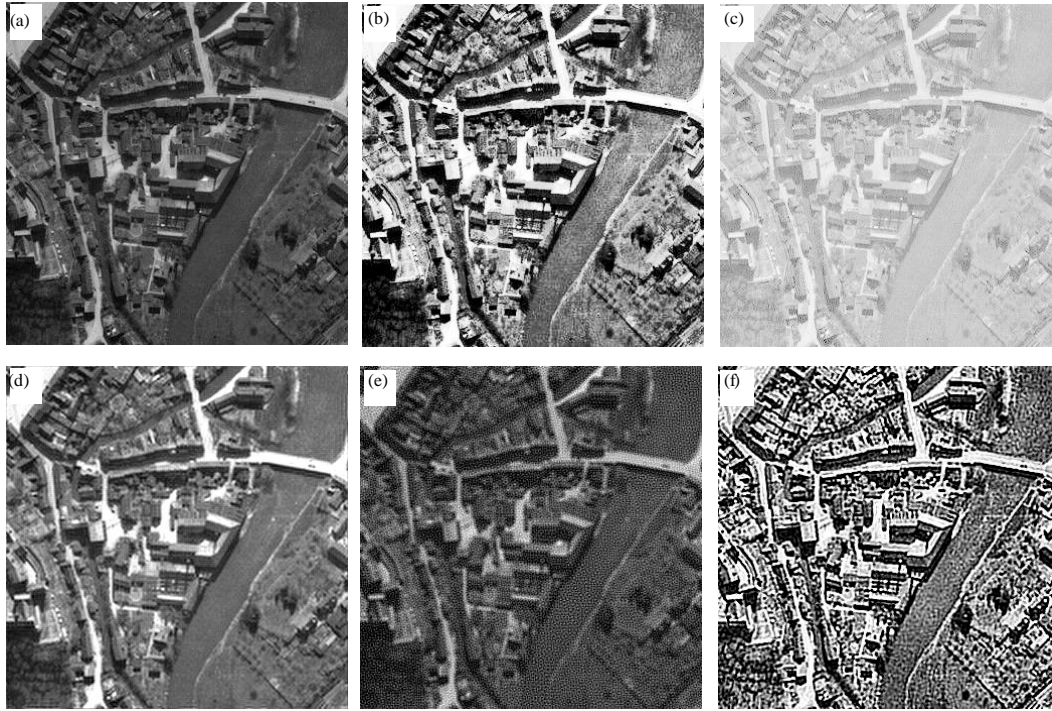


Fig. 3(a-f): The ‘Harbour.bmp’ and its enhanced images, (a) Original image, (b) Enhanced image after HE, (c) Enhanced image based on MSR, (d) Enhanced image based on CT, (e) Enhanced image based on NSCT-FC and (f) Enhanced image using the proposed method

Table 1: Definition, entropy and PSNR of images in Fig. 2

Evaluation	HE	MSR	CT	NSCT-FC	Proposed method
Definition	4.68	3.79	14.82	15.94	17.56
Entropy	5.81	0.000064	0.0024	0.02	7.57
PSNR	27.73	24.32	11.29	24.02	28.36

\*Abbreviation in Table 1: PSNR-Peak signal to noise ratio; HE: Histogram equalization; MSR: Multi-scale Retinex; CT: Contourlet transform; NSCT-FC-Fuzzy contrast enhancement based on nonsubsampling contourlet transform

Table 2: Definition, entropy and PSNR of images in Fig. 3

Evaluation	HE	MSR	CT	NSCT-FC	Proposed method
Definition	16.47	10.22	18.02	32.50	32.86
Entropy	5.93	0.000158	0.000158	0.15	6.72
PSNR	25.39	24.06	15.32	18.09	26.07

\*Abbreviation in Table 2: PSNR-Peak signal to noise ratio; HE: Histogram equalization; MSR: Multi-scale Retinex; CT: Contourlet transform; NSCT-FC-Fuzzy contrast enhancement based on nonsubsampling contourlet transform

and the PSNR (Nezhadarya and Shamsollahi, 2006) are not high enough. The Enhancement based on multi-scale Retinex algorithm also has low definition and information entropy, it is also can be seen from Fig. 2c and 3c that the visual effects for enhanced remote sensing image is not satisfied and therefore those two methods are not suitable to enhance the images selected in this experiment. The PSNR of enhanced image using HE is close to the proposed method, however, the information entropy and

definition are lower the proposed method, respectively by 1.275 and 14.635 on the average. Overall, the definition, the information entropy and PSNR values of the proposed method are the highest of all methods, indicating that the proposed method got better performance in remote sensing image enhancement than other four methods.

## CONCLUSION

According to the characteristics of remote sensing images and demands for remote sensing image enhancement, this study presents a novel remote sensing image enhancement method based on NSCT which fully integrates the merits of histogram equalization, NSCT and the Fuzzy contrast and achieved a significant improvement in de-noising and enhancing the contrast and details of remote sensing images. The experimental results show that the proposed method has certain advantages in the remote sensing image enhancement.

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