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AIRBORNE SAR IMAGE BRIGHTNESS COMPENSATION ENHANCEMENT PROCESSING BASED ON NSCT TRANSFORM

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ABSTRACT:

Image brightness compensation processing is one of the important aspects to decide whether the image can be further used for remote sensing quantitative applications. In this paper, a brightness compensation enhancement processing method based on nonsubsampled contourlet transform (NSCT) is used to address the widely used problems of synthetic aperture radar (SAR) images with unbalanced internal brightness and blurred detailed texture features and severe image SAR. Firstly, the image is decomposed using the NSCT transform and the sub-band coefficients are adjusted after calculating the improvement coefficients for the statistical radiation change curve of its low-frequency sub-bands to achieve brightness compensation; for each high-frequency sub-band image, a hard threshold function is used to enhance the contour texture information of the image and suppress noise; finally, all sub-bands are combined using NSCT inverse reconstruction to obtain the resultant image. Aiming at the problem of radiation discrepancies arising from SAR images due to its side-view observation method and antenna directional map, this method is more applicable to SAR images and has better improvement effects than the traditional image equalization algorithm, increasing the average gradient and structural similarity, better preserving the detail features, significantly improving the brightness non-uniformity problem, enhancing the visual effect and providing some support for the subsequent monitoring of various disasters.

1. INTRODUCTION

Synthetic aperture radar (SAR) is a radar capable of all-weather observation and has the unique advantage of penetrating some ground features, playing a pivotal role in urban management, planetary exploration, resource surveys and disaster monitoring (Gishkori et al,2019;Oliver et al,1991). The brightness information of SAR images reflects the backscattering intensity of ground targets to radar waves, which depends on factors such as the polarization mode of the radar, the side angle of the radar, and the wavelength of the radar. The actual complex characteristics of the ground make the SAR amplitude images have a large dynamic range (Han Yutao et al., 2014), which makes the SAR images show different degrees of brightness differences within the SAR image, especially in the distance direction, which is mainly dark on both sides and bright in the middle in the distance direction. This difference directly affects the interpretation of the SAR resultant images and the visual effect of subsequent processing. Therefore, the brightness compensation of SAR images is one of the key technologies for generating SAR orthophoto products, which is directly related to the visual effect of digital orthophoto images and plays a pivotal role in their image quality.This paper adopts a SAR image brightness compensation method based on Nonsubsampled Contourlet Transform (NSCT) to correct the brightness of the original SAR image, so as to effectively solve the problem of uneven image brightness distribution while preserving the detail information of the image.

At present, most of the studies on the internal brightness compensation processing of single-view images are proposed based on optical images, mainly statistical information methods, mathematical modeling methods and frequency domain filtering methods. Statistical information method is to use the statistical information of the image (such as histogram, mean and variance, etc.) for brightness compensation, and the main methods are histogram equalization method ((LI Shuo et al,2018; Khan, Mohammad Farhan et al,2020), and Wallis transform (Li Shuo et al,2019). The mathematical modeling method uses a mathematical model to estimate the light variation trend of the image and then compensates for different parts of the image. Mostly polynomial models are used to fit the grayscale or light distribution (JIN Shuying etal,2000). The frequency domain filtering method is a light leveling method that uses frequency domain filters to simulate the brightness distribution within the image. Wavelet transform (XIA Kaijian et al,2019), Gaussian low-pass filter, and curvilinear transform (XIAO Ding et al,2011) are frequency domain enhancement methods, which are generally applied to MASK leveling method(YUAN Xiuxiao et al,2014;ZHANG Zhen,2010;ZHU Shulong et al,2011) and Retinex leveling method (Hussein Ruaa Riyadh etal,2019;A.S.Parihar et al,2018;Hassan, Najmul et al,2021) to eliminate the brightness differences within the image.

The research on the equalization of optical images at home and abroad has been quite mature, but the brightness variation law of SAR images is very different from the existence of optical images, and the adoption of the equalization method of optical images to directly carry out the processing of SAR images cannot get satisfactory results. For the brightness equalization of SAR images, when considering the distance-oriented brightness difference of SAR images, the main reason is the antenna orientation map, SAR active oblique distance projection system and other factors, which make the tones of SAR images dark at the near and far ends and bright at the distance-oriented center. Based on this, Yanqin et al (YAN Qin et al,2013)proposed a SAR image enhancement algorithm, which uses azimuthal intensity integration to find the enhancement coefficients and integrates the intensity values of SAR images at each distance in azimuthal direction, and the image data are converted to the frequency domain by Fourier transform and then the enhancement coefficients are found by low-pass filtering to

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reduce the brightness difference of the SAR images. However, the intercepted information may contain not only noise but also real useful information.

The NSCT transform is a frequency domain enhancement method, which is mostly used for image fusion and image denoising. Ma Qixing et al (Ma Qixing et al,2022) used the NSCT decomposition to process sonar images, with fuzzy set enhancement for the low-frequency components and variable Bayesian threshold denoising enhancement for the high-frequency components to complete the sonar image denoising. To enhance the low contrast,Cao ting and Wang Weixing (CAO Ting,WANG Weixing,2020) used the NSCT transform, with the low-frequency component enhanced using adaptive scaling Retinex and scaling parameters adjusted by local mean and standard deviation. The high-frequency components are computed by a non-local mean operator to preserve texture detail. To address the problem that fused image details are not well preserved and feature target information is incomplete, Wu Chunming et al (WU Chunming et al,2020) proposed a new method for fusing infrared and visible images - a dual fusion method of infrared and visible light. Combining the non-downsampled contour wave transform and pulse-coupled neural network, the method makes full use of the flexible multi-resolution, multi-directional nature of NSCT as well as the global coupling and pulse-synchronous excitation properties of PCNN to effectively combine the features of IR images with the texture details of VI images. As the information at different scales and directions has different properties and characteristics, processing the low and high frequency sub-bands of the NSCT decomposition separately can achieve improved image quality, suppress noise, and obtain useful information, which is supportive for image brightness compensation. Since the information at different scales and in different directions has different properties and characteristics, the processing of the low-frequency and high-frequency sub-bands after NSCT decomposition can achieve improved image quality, suppress noise, and can obtain useful information, which has a certain support role for image brightness compensation.

2. METHOD

2.1 Basic Ideas

The purpose of SAR image brightness compensation is to correct the brightness difference on the original SAR image and produce an image that satisfies a high degree of balance with moderate contrast. By analyzing the causes of the radiation inhomogeneity phenomenon of SAR images, the low-frequency and high-frequency subband information of the NSCT transform is used for radiation compensation processing of images. In this paper, the NSCT transform is applied to the luminance compensation of SAR images for the purpose of image luminance equalization and improvement of visual effects. Firstly, the NSCT transform is adopted to decompose a SAR image data into a low-frequency subband and multiple high-frequency subbands.From the analysis of the SAR image spectrum features, it is known that the SAR image radiation errors caused by factors such as side view patterns and antenna orientation maps are contained in the low frequency information(CHEN Nannan et al,2018). The flow chart is shown in Figure 1.

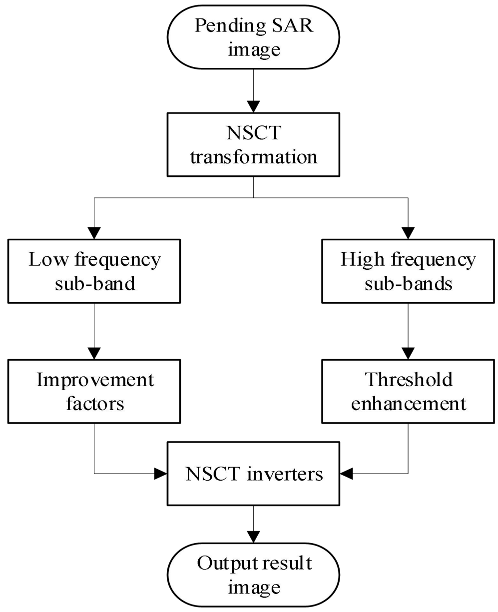


Figure 1. Flow chart of NSCT-based SAR image brightness compensation method

2.2 NSCT Transformation

The NSCT transformation consists of two parts: the Nonsubsampled Pyramid (NSP) and the Nonsubsampled Directional Filter Bank (NSDFB). The NSCT not only has multi-scale, local characteristics and multi-directionality, but also ensures that the detail information of each high frequency sub-band is retained after the NSCT processing, and the low frequency part avoids frequency confusion and has stronger directionality. First, the original image is multi-scale decomposed using NSP to obtain a low-frequency subband and multiple bandpass subbands.

2.3 Low frequency subband processing

The low-frequency sub-band obtained after image decomposition by NSCT concentrates on the basic information of the original image and contains a large amount of background information of the original image. Therefore, the brightness equalization can be achieved by processing the low-frequency sub-bands.

In order to compensate for the radiation brightness difference that appears in the distance-up direction of conventional SAR, the average value of coefficients in the distance direction of low-frequency sub-bands is counted, $data_m$ and the low-frequency background curve $data_m$ representing the radiation difference.

$$data = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{pmatrix} \qquad data_m = (A_1 \quad A_2 \quad \cdots \quad A_n) \tag{1}$$

where $data$ = the coefficient of low-frequency subband after NSCT decomposition
m = the number of samples in the azimuthal direction of low-frequency subband
n = the number of samples in the distance direction of low-frequency subband
a_{ij} = the coefficient of the i-th row of the azimuthal direction and j-th column of the distance direction of

low-frequency subband where, i = 1, 2, ..., m; j = 1, 2, ..., n

$$A_n = \frac{\sum_{i=1}^{m} a_{ij}}{m}$$

Because the radiation brightness difference is a smooth curve, the radiation difference curve obtained by this method contains prominent noise, so it is necessary to use window filtering to further process the low-frequency background information to obtain filtered data $D(x)$.

$$D(x) = smooth(data_m) \tag{2}$$

To improve the image brightness, the ratio of the maximum value of the low-frequency background information $D(x)$ to $D(x)$ is used to obtain a compensation factor $r(x)$ in the distance direction, as in the following equation.

$$r(x) = \max D(x) / D(x) \tag{3}$$

Then the compensation factor $r(x)$ is used to compensate the coefficients of the whole low-frequency subband to correct the SAR image radiation inhomogeneity problem and achieve brightness equalization.

2.4 High frequency subband processing

After the image is processed by the NSCT transform, the edges, details and noise are mainly concentrated in the high-frequency sub-bands, and the high-frequency sub-band coefficients are adjusted using the Bayesian shrinkage method of estimating thresholds (HAN Jing,2018) to improve edge detail information and suppress noise. The expression of the Bayesian shrinkage method to estimate the threshold is

$$T = \sigma^2(l,m) / \sigma_x(l,m) \tag{4}$$

Where $\sigma^2(l,m)$ =the noise standard deviation of the lth scale and mth direction high frequency sub-band

$\sigma_x(l,m)$ = the signal standard deviation of the lth scale and mth direction high frequency sub-band

The subband coefficients obtained from the noisy image transformed by NSCT are non-independent between and within scales, and the noise intensity of the decomposed subband image is different at each scale.

In this paper, the noise standard deviation is obtained using robust median estimation:

$$\sigma(l,m) = median(\left|g_m^l(i,j)\right|) / 0.6745 \tag{5}$$

where $g_m^l(i,j)$ = the coefficient of the lth scale, mth direction high frequency sub-band

The standard deviation of the signal in this subband is obtained according to the maximum likelihood estimation method:

$$\sigma_x = \sqrt{\max(\sigma_x^2(l,m) - \sigma^2(l,m))} \tag{6}$$

where $\sigma_x^2(l,m) = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N} g_m^l(i,j)$

$\sigma_x^2(l,m)$ = the variance of the corresponding high frequency sub-band coefficients

In the above equation (4), the threshold T only considers the correlation between the coefficient scales of the subbands in the NSCT domain, while ignoring the relationship between the subbands in each direction at the same scale. Therefore, the following equation was used to improve the threshold (WANG Sheng et al., 2020).

$$T_m^l = (1 - \frac{L}{4} \times \frac{s_m^l}{\sum_{l=1}^{L} s_m^l})T \tag{7}$$

where L= the number of directions at the lth scale

s_m^l = the energy of the mth directional subband at the lth scale, which is equal to the sum of the squares of all coefficients in that directional subband

$\sum_{l=1}^{L} s_m^l$ = the energy of all directions at the lth scale

The specific steps of the proposed method in this paper are.

(1) NSCT transformation of the SAR image.
(2) Performing radiation brightness compensation for the low-frequency sub-band images based on the compensation factor obtained from equation (3).
(3) calculating the energy of the sub-bands in the high-frequency direction with the total energy of each layer decomposition and, according to equation (7), finding the threshold value of the high-frequency sub-bands and performing hard thresholding on the corresponding high-frequency sub-bands

The new low-frequency sub-band coefficients and high-frequency sub-band coefficients derived from steps (2) and (3) are inverted by NSCT to obtain the reconstructed image.

3. EXPERIMENT AND ANALYSIS

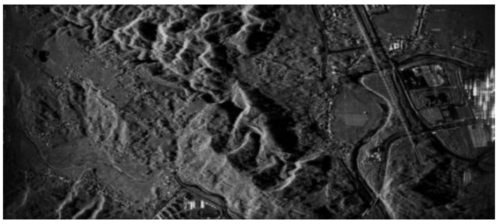
The SAR images were processed by the low-pass equalization method, JHE (adaptive histogram equalization) method (LIU Shuaiqi et al,2014) and the method of this paper, and then their experimental results were compared and analyzed to evaluate the quality of the image results from both subjective evaluation and objective quantitative evaluation.

The airborne C-band SAR images acquired in Ya'an area and the airborne C-band SAR images acquired in Genhe area were used as the experimental samples. The relevant parameters are shown in Table 1.

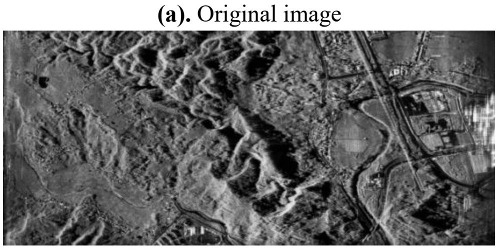
Parameter Types	Parameter Value		
	Figure 2(a)	Figure 3(a)	Figure 4(a)
Number of azimuthal pixels	5000		8192
Number of distance pixels	11482		19456
Polarization Type	HH	HV	VV
Bands	C		C
Navigation height	5393.696		5810.502
Resolution	0.6		1

Table 1 SAR Data Related Parameters

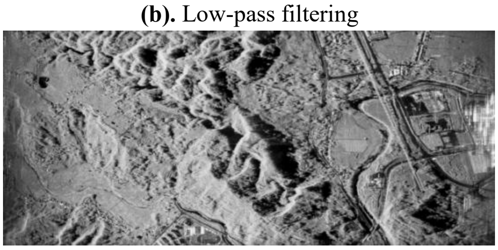
The decomposition directions of the NSCT transform are 4 and 8 respectively. the images after processing by three methods are shown in Figure 2-4. (c) is the JHE method, i.e., adaptive histogram equalization, which is widely used in optical image equalization, but from the results it can be seen that it does not take into account the distance-oriented radiation difference of SAR, and the problem of brightness in the middle and darkness at both ends still exists after equalization. (d) is the method adopted in this paper. From the processing results, it can be seen that the brightness compensation method adopted in this paper can effectively improve the brightness unevenness of SAR images, and the overall image brightness is moderate, and the visual effect is better than (b) and (c), and the detail information can be effectively maintained.



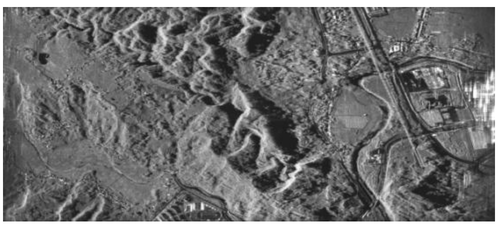
(a). Original image



(b). Low-pass filtering

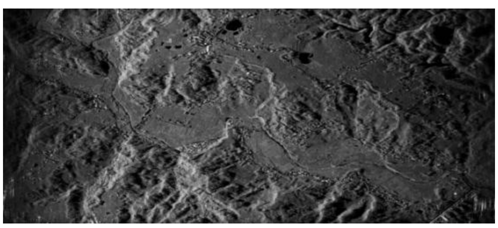


(c). JHE

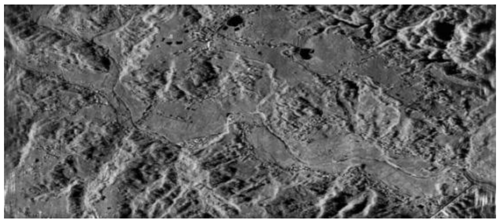


(d). Methodology of this paper

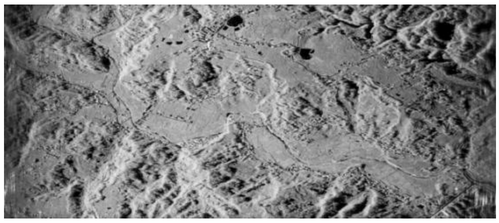
Figure 2. HH-polarized SAR images of the Ya'an area



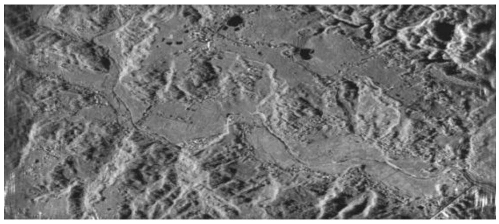
(a). Original image



(b). Low-pass filtering



(c). JHE



(d). Methodology of this paper

Figure 3. HV-polarized SAR images of the Ya'an area

(a). Original image

(b). Low-pass filtering

(c). JHE

(d). Methodology of this paper

Figure 4. VV-polarized SAR images of the Genhe area

3.1 Quantitative evaluation

In order to objectively evaluate the SAR image equalisation results, four evaluation metrics - luminance mean, standard deviation, mean gradient and structural similarity - are used to evaluate the image luminance compensation results.

According to Table 2, although the JHE method is overall higher than the other two methods in terms of luminance mean and information entropy, some of the details are over-enhanced leading to exposure, which masks the detailed texture information, so the average gradient enhancement is the lowest. Compared with methods (b) and (c), method (d) in this paper performs moderately in the luminance mean index and standard deviation, and the image information entropy is slightly reduced, which is due to the noise filtered by setting the threshold. However, the excellent performance of the average gradient indicates that the method in this paper maintains the image texture edges while equalizing the image brightness, highlighting the target details, and the most useful information can be obtaine.

images	brightness mean	standard deviation	Information entropy	Average gradient
Figure 2 (a)	54.0283	55.6348	6.9854	28.8919
Figure 2 (b)	96.6984	74.5859	7.5446	48.6016
Figure 2 (c)	125.0570	73.5566	7.9727	44.6111
Figure 2 (d)	119.4982	75.4071	7.3977	52.2873
Figure 3 (a)	62.5777	57.7235	7.2547	32.8550
Figure 3 (b)	96.6984	74.5859	7.5446	48.6016
Figure 3 (c)	125.0570	73.5566	7.9727	44.6111
Figure 3 (d)	119.4982	75.4071	7.3977	52.2873
Figure 4 (a)	69.0118	55.8558	5.2307	24.2681
Figure 4 (b)	126.6012	76.8164	7.5577	37.2133
Figure 4 (c)	121.2470	73.3624	7.8197	31.5705
Figure 4 (d)	112.1170	76.9716	7.5501	38.8907

Table 2 Comparison of quantitative evaluation indicators for images

4. CONCLUSION

In this paper, the NSCT transform is used to decompose the image, and the mean value of the distance-to-coefficient of the decomposed low-frequency sub-bands is counted, and the compensation factor is obtained after optimisation to enhance the low-frequency sub-bands and improve the brightness difference of the low-frequency image; the threshold value is calculated for the decomposed high-frequency sub-bands, and then the coefficients are adjusted using the soft threshold function to enhance the contour texture information and weaken the noise.

The technical methods and experimental analysis show that the method proposed in this paper can provide good improvements in the compensation of radiation differences caused by SAR incidence angle differences, overall image visual enhancement and detail highlighting. This method combines the advantages of other methods and is superior to other methods in terms of the overall visual effect and the degree of preservation of the original image information. Since this method does not require the knowledge of antenna directional map information and does not require external radiometric calibration, it is theoretically suitable for a wide range of SAR image equalisation and enhancement. Based on the method in this paper, it is necessary to test SAR images of different bands, platforms and polarization modes, and further improve the method based on the test, so that it can be applied to different types of SAR images with good results, which is the work to be carried out in the future.

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