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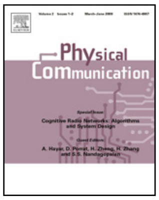

Full length article

Synthetic Aperture Radar image nonlinear enhancement algorithm based on NSCT transform

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ABSTRACT

Due to the imaging mechanism, Synthetic Aperture Radar (SAR) images are susceptible to speckle noise, which affects radar image interpretation. So image denoising and enhancement are important topics of improving SAR image performance. A nonlinear image enhancement algorithm based on nonsubsampled contourlet transform (NSCT) is proposed in this paper. The image is decomposed into coefficients of different scales and directions through nonsubsampled contourlet transform. It is denoised by the threshold method of the multi-scale product of NSCT coefficients. Then thresholds of the nonlinear enhancement function are determined according to the coefficients of each scale. The two parameters of the function, among which one is used to control the range of enhancement and the other can determine the strength of enhancement, are obtained by solving nonlinear equations. The coefficients processed by the enhancement function are used to reconstruct the image. The simulation results on the Matlab platform show that the algorithm has a good effect of enhancing details of images and suppressing noise signals meanwhile.

1. Introduction

SAR images play an important role in military and commercial fields, since they have the advantages of all-weather imaging, high resolution and strong penetration, etc. They are the expressions of radar scattering characteristics of objects on the ground. As the signals emitted by imaging radar are pure coherent waves, the interference of random scattering signals of targets and the radar signals will generate speckle noise. So the fine structure of SAR images may be blurred and the image interpretation becomes difficult. Fortunately, image denoising and enhancement as common image pre-processing techniques are effective ways to improve the effects of SAR images.

Image enhancement technologies are broadly divided into two types. One is based on the spatial domain and the other is based on the transform domain. Since the former enhances the image information and the noise signals at the same time, the enhancement effect is often unsatisfactory. The latter can effectively suppress noise signals during the process of enhancement, so it has been more widely used.

Enhancement algorithms based on the transform domain are more common in wavelet transform, contourlet transform and so on. But these algorithms lack the shift invariance property. They are able to cause pseudo-Gibbs phenomena at the edges of the processed image. Nonsubsampled contourlet transform which has the translation-invariant feature was proposed by Arthur L. Cunha et al. on the foundation of contourlet transform [1]. The algorithm has shown good performance in image denoising and enhancement. In this paper, we propose an adaptive nonlinear enhancement algorithm based on NSCT transform. The parameters of enhancement function are

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determined according to the characteristics of the transform coefficients in each scale, so the enhancement model is established adaptively. The experiments show that the algorithm has good effect of enhancement and denoising. The image quality has been significantly improved.

2. Introduction to NSCT

2.1. Contourlet transform

Contourlet transform is a two-dimensional representation of an image proposed by M.N. Do and M. Vetterli et al. in 2005 [2]. It not only has the multi-resolution feature of wavelet transform, but also has the superiority of anisotropy, which means that the algorithm has a good grasp of the geometry of the image. The process of contourlet transform has two steps. First, decompose the image into coefficients of different scales by Laplacian pyramid transform in order to capture singular points. Second, use a directional filter bank to apply directional filtering to the high frequency components, and connect the points of the same direction into a line structure in order to describe the outline of the image. However contourlet transform itself is not shift-invariant due to the downsamplers and upsamplers, so it tends to show the problem of the pseudo-Gibbs distortion, which affects the image processing effects.

2.2. Nonsubsampled contourlet transform

The basic idea of NSCT is to use the nonsubsampled pyramid decomposition to decompose the image into multiple scales. And then through the nonsubsampled directional filter bank, the signals of each scale are decomposed into different directional sub-bands. The number of subbands in each scale can be any power of 2. NSCT has no down-sampling process in the two-step decomposition, so it has the feature of translation invariant [1].

3. Multi-scale product denoising

Based on the cross-scale feature of signal edges, Rosenfeld proposed a multi-scale product image edge detection theory [3]. The theory makes full use of the relevance between wavelet decomposition coefficients of different scales. That is, if the coefficient in the parent scale is large, the coefficient of its offspring scale is generally large, and vice versa. In general, the power of noise signals is limited to small scale, so they do not have the cross-scale feature, while edge signals and detail signals are present in different scales. As the decomposition scales become more sophisticated, the multi-scale coefficients of noise signals decay rapidly, while the coefficients of image detail signals are stable. That is the coefficients of image signals are strong relevant, while the noise coefficients are weak relevant or irrelevant. Therefore, if the signal's product of coefficients of adjacent scales is smaller than a threshold, it can be considered as the noise signal, which should be suppressed. While, if the product is larger than the threshold, it should be retained as the image signal.

We extend the theory of multi-scale product to NSCT transform. Multi-scale products of adjacent scales are calculated in each directional sub-band of high-frequency scales. When the product is smaller than a pre-set threshold, it is considered to be a noise signal, and coefficient will be set to zero, so as to achieve the purpose of denoising. Experiments and theoretical analyses prove that multi-scale product denoising is effective to suppress Gaussian noise. In order to denoise SAR images, we converted speckle noise to Gaussian-like noise by homomorphic filtering before multi-scale product denoising.

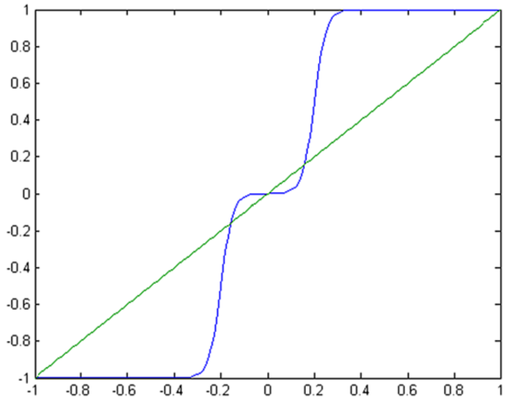

Fig. 1. $f(x)$ for $b = 0.25$ and $c = 40$.

4. Nonlinear enhancement model

4.1. Nonlinear function

The information contained in an image can be divided into several types: edges and details, approximate trends and noise signals. And the edges of image can be subdivided into strong edges and fuzzy edges. In the process of image enhancement, these types of information need to be treated differently. That is, the strong edges should be preserved; the fuzzy edges need to be enhanced, while the noise signals must be suppressed. Thus, using a nonlinear function as an enhancement model is a better choice. The selected enhancement function herein is presented in 1994 by A.F. Laine [4]. Since then, many scholars have achieved good results in applying it to image enhancement [5–7]. The function is as follows:

$$f(x) = a[sigm(c(x-b)) - sigm(-c(x+b))] \tag{1}$$

where a is defined as $a = \frac{1}{sigm(c(1-b)) - sigm(-c(1+b))}$, $sigm$ is defined as $sigm(x) = \frac{1}{1+e^{-x}}$.

There are b and c two parameters in this function, where b is used to control the scope of enhancement; its value is in the range of (0, 1). And c is used to control the enhancement strength. It is usually used as a fixed value taken between 20 and 50. The blue curve in Fig. 1 shows the image of $f(x)$; in this picture, b is set to be 0.25, while c is 40.

In order to see the feature of the function clearly, Fig. 2 illustrates the first-order derivative of the function shown in Fig. 1.

It can be seen from the two figures above that after processed by $f(x)$, within the range of $(-b, b)$, the original