Optik 127 (2016) 634–637

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

A novel thresholding technique in the curvelet domain for improved speckle removal in SAR images

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ARTICLE INFO

Article history:
Received 24 December 2014
Accepted 11 October 2015

Keywords:
Speckle
Curvelet
Improved thresholding

ABSTRACT

Speckle noise is the grainy salt-and-pepper pattern present in radar imagery caused by the interaction of out-of-phase waves with a target. Speckle degrade the spatial resolution, contrast of the image, decreases object detectability and causes inconvenience to the SAR (Synthetic Aperture Radar) image interpreter. Reduction of speckle can be carried out for proper interpretation and object detection. In this work, an improved thresholding technique in the curvelet domain is proposed to reduce the speckle in SAR images and preserve the details of the image. The results of denoised images are compared visually and statistically. The performance of the proposed technique is better compared with improved thresholding technique in the wavelet domain, curvelet denoising and curvelet cycle spin technique.

1. Introduction

The SAR is an active microwave remote sensor and it provides the middle or high-resolution remote sensing images irrespective of the weather conditions. The images captured by SAR generally contain a more speckle. This results in a change in the characteristics of objects and there is difficulty in target identification [1].

To remove speckle in an image, the filters used to operate in the spatial and frequency domain. The spatial filters will remove noise to a certain extent while blurring some details of the image such as smoothening the edges [4]. The filters operating in the frequency domain are the Fourier transform, Wavelet transforms and Curvelet transform based. Despeckling in the frequency domain is done by applying the transform to the image and then applying the threshold to modify the coefficients and obtain the inverse transform. The regular thresholding used for removing noise are hard and soft thresholding proposed by Donoho and Johnstone [12]. These techniques have some limitations. In hard thresholding because of the discontinuity, the reconstructed image may contain residual noise [2]. The soft thresholding is continuous and a constant deviation exists between the true and estimated coefficients, which may lead to errors in the reconstruction of the image [2]. In this paper, an improved thresholding technique in the curvelet domain is proposed to overcome such limitations of the hard and soft thresholding techniques.

The results of the proposed technique are compared with improved thresholding technique in the wavelet domain [2], curvelet denoising technique [3] and the curvelet cycle spin technique [11]. For performance analysis, the assessment parameters used are NMV (noise mean value), MSD (mean square difference), ENL (equal number of looks) and NSD (noise standard deviation), and it has been shown that the proposed method gives better result.

2. Description of SAR experimental data

The SAR data used for experimental work is RISAT-1, C-band (5.35 GHz) of coarse, medium and fine resolution images. The area of the image taken is of Ahmedabad, the capital of Gujarat state, India. For the experimental purpose the part of the image is taken of size 512×512, of 8 bit depth. The details of the images shown in Table 1.

3. Methodology

Fig. 1 shows the process of speckle removal for the given image. Because of the multiplicative nature of speckle noise, denoising process cannot be directly applied to the noisy image. First, it has to be converted into additive noise and then the denoising process has to be applied. Conversion from multiplicative noise to additive noise is done by applying the logarithm to the given image [10]. Next, the curvelet transform is applied. The noise coefficients are filtered out by applying the threshold for all coefficients and we

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http://dx.doi.org/10.1016/j.ijleo.2015.10.057
0030-4026/

Table 1
SAR image details.

Satellite	Resolution	Polarization	Depth	Location centered
RISAT-1, C-band (5.35 GHz)	Coarse—50 m	HH	16 bit	23°45′N, 71°42′E
	Fine—6 m	RH	16 bit	23°14′N,72°38′E
	Medium—25 m	HH	16 bit	23°39′N, 73°4′E

obtain the inverse transform. The final step is applying the antilogarithm (exponential) to the inverse transformed image to obtain the denoised image.

4. Noise model

The speckle noise has a standard deviation which is linearly related to the mean and is often modeled as a multiplicative process. This indicates that the higher signal strength, the higher is the noise. As a result, more speckle noise is commonly present near brighter pixel areas. The curvelet denoising is based on additive Gaussian noise. The speckle noise converted to the additive noise with the help of homomorphic transform by applying the logarithmic operator.

The model of the noisy image is given as:

$$I_{\mathrm{n}} = I_{\mathrm{s}}\eta \tag{1}$$

The multiple nature of speckle noise can be converted into additive by applying the logarithm to both sides of Eq. (1)

$$\log(I_{\mathrm{n}}) = \log(I_{\mathrm{s}}) + \log(\eta) \tag{2}$$

where, I_{n} is noisy image, I_{s} is unknown original image, η is noise.

5. Curvelet transform and Curvelet transform via wrapping technique

5.1. Curvelet transform

Curvelet transform is a multiscale geometric transform. It is developed to overcome the limitations of the Wavelet transform [3]. The transform was designed to represent the edges and other singularities along the curves much more efficiently than Wavelet transform [6] [7]. The curvelet transform is a multiscale pyramid with many directions and positions of each scale, and with needle-shaped elements at fine scales [7,8]. It decomposes the signal into several subbands at each scale with different orientations and positions in the frequency domain [7].

In Cartesian coordinates, taking $f[t_1, t_2]$, $0 \le t_1$, and $t_2 < n$, as input, the digital curvelet transform $c^D(j, k, l)$ is obtained as:

$$c^D(j, k, l) = \sum\nolimits_{0 \le t_1,\ t_2 < n} f[t_1 t_2] \quad \overline{\varphi^D_{j,l,k}[t_1 t_2]} \tag{3}$$

where, $\overline{\varphi^D_{j,l,k}[t_1 t_2]}$ is the digital curvelet waveform.

5.2. Curvelet transform via wrapping technique

The curvelet transform used in this work is a fast discrete curvelet transformed via the wrapping technique. This new discrete curvelet transforms is simpler, faster and less redundant compared to the first generation version [7].

The steps for fast discrete curvelet transform via the wrapping technique are as follows:

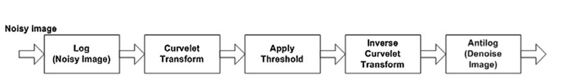

Fig. 1. Block diagram of the despeckling process.

(1) For a given two-dimensional function which is defined in Cartesian coordinate, a 2D FFT is applied to obtain $\hat{f}[n_1, n_2]$, $\frac{-n}{2} \le n_1, n_2 \le \frac{n}{2}$
(2) For each scale j and angle l in the frequency domain, $\hat{f}[n_1 n_2]$, is re-sampled to obtain $\hat{f}(n_1 n_2), \hat{f}\left(n_1 n_2 - n_1 \tan\theta_l\right) \quad (n_1 n_2) \in P_j$
(3) The sampled value is multiplied by the window function $\tilde{U}_j$ to obtain $\hat{f}(n_1 n_2) = \hat{f}[n_1 n_2 - n_1 \tan\theta_l]\tilde{U}_j[n_1 n_2]$
(4) $\hat{f}[n_1 n_2]$ is wrapped around the origin to obtain $\hat{f}[n_1 n_2] = W\left(\tilde{U}_{j,l}\hat{f}\right)[n_1 n_2]$, here the ranges of n_1 and n_2 are now $0 \le n_1 < L1, j$ and $0 \le n_2 < L2, j$, and range of θ is $-\frac{\pi}{4} < \theta < \frac{\pi}{4}$.
(5) The inverse 2D FFT is applied to each $f_{j,l}$, after obtaining the discrete curvelet transform coefficients, $c^D(j, k, l)$.

The denoising in the curvelet domain is obtained by taking curvelet transform to noisy image, and using threshold to change the detail and fine coefficients. Then the inverse curvelet transform is applied to obtain the denoised image.

6. Proposed threshold function

The despeckling of the SAR image done with the hard thresholding will have distortion and it contains residual noise. In case of soft thresholding if the curvelet coefficients greater than the threshold, the estimated coefficient will have a constant deviation compared to the input coefficient. This may result in a blurred image and it reduces the quality of the reconstructed image [2].

To overcome the limitations of the hard and soft thresholding, the improved thresholding function is proposed. Improve thresholding technique has better continuity for coefficients when coefficients are less than the threshold. This resolves the limitations of hard thresholding. When the coefficients are greater than the threshold, the deviation between the true and the estimated coefficient will be very small. This will overcome the limitations of soft thresholding.

The improved threshold function is given as:

$$f(x) = \begin{cases} \varepsilon x + (1-\varepsilon)(\mathrm{sign}(x))\left(x - \dfrac{\beta\ \mathrm{th}}{\beta + |x| - \mathrm{th}}\right), & |x| > \mathrm{th} \\ \dfrac{|x|^5}{\mathrm{th}^4}, & |x| \le \mathrm{th} \end{cases} \tag{4}$$

where, ε is given as

$\varepsilon = 1 - \exp\left(-\mu\sqrt{|x| - \mathrm{th}}\right)$, $0 < \varepsilon < 1$, $\beta > 0$, μ is a positive number, ε adjustment parameter, and th threshold, it is given as:

$$\mathrm{th} = \sigma_{\mathrm{w}} k \sigma_{\mathrm{n}} \tag{5}$$

σ_{n} is the standard deviation of noise and it is obtained with the help of the robust median estimator from the finest wavelet coefficients [9] as shown in Eq. (6). To estimate the noise variance, σ^2_{w} of each curvelet index, the Monte-Carlo simulation method is used. Few standard white noise images, with zero mean and variance one, i.e., $N(0, 1)$ were discrete curvelet transformed and the variance, σ^2_{w} is estimated. k is a scale-dependent value the last scale, it is 4. For other scales, it is 3 [2].

$$\sigma_n = \frac{\mathrm{median}\left|w_{i,j}\right|}{0.6745} \tag{6}$$