Signal Processing 93 (2013) 1056–1063

Contents lists available at SciVerse ScienceDirect

Signal Processing

journal homepage: www.elsevier.com/locate/sigpro

Directionlet-based denoising of SAR images using a Cauchy model

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A R T I C L E   I N F O

Article history:
Received 16 December 2011
Received in revised form
24 November 2012
Accepted 30 November 2012
Available online 7 December 2012

Keywords:
Synthetic aperture radar (SAR) image
Cauchy distribution
Stationary directionlet transform
Speckle noise

A B S T R A C T

A new denoising algorithm based on directionlet transform using a Cauchy probability density function (PDF) is proposed to remove speckle noise. First, an anisotropic directionlet transform is taken on the logarithmically transformed SAR images. The directionlet transform coefficients of reflectance image are modeled as a zero-location Cauchy PDF, while the distribution of speckle noise is modeled as an additive Gaussian distribution with zero-mean. Then a maximum a posteriori (MAP) estimator is designed using the assumed priori models. And a regression-based method is proposed to estimate the parameters from the noisy observations. Finally, the performance of the proposed algorithm is compared with those of existing despeckling methods applied on both synthetic speckled images and actual SAR images. Experimental results show that the proposed scheme efficiently removes speckle noise from SAR images.

1. Introduction

Synthetic aperture radar (SAR) images provide useful information for many applications, such as remote sensing for mapping, surface surveillance, automatic target recognition, and mine detection. Unfortunately, since the imaging sensor is not able to resolve the microscale of the objects' roughness of the order of a wavelength, the speckle noise [1] occurs in SAR images. The presence of such speckle noise visually degrades the appearance of images and severely diminishes the performances of automatic scene segmentation. Therefore, speckle removing is a critical preprocessing step in tasks, such as segmentation, detection, and classification in SAR images processing.

A number of spatial-domain adaptive despeckling algorithms [2–6] have been proposed in the past few years. The multiplicative speckle noise and the reflectance are modeled as certain distributions, respectively, and then the despeckling filters or estimators are constructed according to some optimal criterions. Finally, the noise-free image is recovered from the observations. These classical filters can usually provide a good performance for removing speckle noise, however, the performances of these filters are mainly dependent on the size and orientation of the mask used in the method.

In recent years, the multiscale wavelet transform has been widely applied in the field of image processing [7–11]. In the wavelet domain, we not only simplify the statistics of many natural images but also convert the multiplicative speckle noise into additive noise by taking the logarithmic transform on the SAR image. Wavelet denoising methods usually either recover the noise-free image based on considering the wavelet coefficients as some models, or apply thresholding [12] to the detail wavelet coefficients of the noisy images. The discrete wavelet transform (DWT) can provide a better reduction of the speckle noise than that of the spatial-domain filters. However, two drawbacks relating to wavelet-based methods must be noted, one is the DWT itself and the other is the model. DWT is an isotropic transform, which filtering and subsampling operations are iterated with the same number of steps along both the horizontal and vertical directions at each scale, that is, it cannot capture edges

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0165-1684/$ - see front matter
http://dx.doi.org/10.1016/j.sigpro.2012.11.028

and contours properly. Most models used in the literatures encounter some difficulties in practice, such as the lack of a closed-form expression [13] and the difficulty in parameter estimation [14].

In this paper, despeckling is tackled as a MAP estimation problem based on directionlet transform. This anisotropic transform can capture the edges and contours of the images more effectively compared with the general DWT. To recover the noise-free image using MAP estimator from the observation, Cauchy PDF is utilized to model the directionlet coefficients of the log-transformed reflectance. A regression analysis method with low computational complexity is also proposed to estimate all the parameters simultaneously.

This paper is organized as follows. Section 2 briefly overviews the directionlet transform, the statistical properties of SAR images, and a statistical model of directionlet coefficients. In Section 3, we present the design of MAP estimator and the estimation method of the parameters. In Section 4, the performance of the proposed algorithm is evaluated and compared with the existing despeckling methods. Finally, Section 5 concludes the paper.

2. Stationary directionlet transform and statistical modeling of SAR image

2.1. Stationary directionlet transform

The standard 2-D WT is an isotropic transform, which filtering and subsampling operations (1-D transform) are iterated with the same number of steps along both the horizontal and vertical directions at each scale (see Fig. 1(a)). On the contrary, in anisotropic WT (AWT), the 1-D transform along one out of two directions (horizontal and vertical) is performed more than along the other (see Fig. 1(b)). Apparently, the AWT represents the edges and contours of the objects more efficiently than the DWT.

However, the AWT filtering and subsampling only along the horizontal and vertical directions, and this, to some extent, limit the capability of representation of images, especially the edges and contours. To overcome the drawback, Velisavljevic [15] proposed a novel anisotropic wavelet transform called directionlet transform denoted by S-AWT (M_Λ,n_1,n_2) to decompose the image. The transform makes use of two concepts: anisotropy and directionality. Anisotropy is achieved by an unequal iteration of 1-D transform steps along two directions like the AWT; Directionality is obtained by implementation of the sampling using lattice which partitions the image into a series of cosets. Due to the use of separable filter, the computational complexity of directionlets is $O(LN^2)$ (where L is the length of the filter used in the transform and $N \times N$ is the size of input image), which is lower than the complexity of other similar approaches.

The attractiveness of the stationary wavelet transform (SWT) is its time-invariance property [16], which can reduce the Gibbs phenomena in the neighborhood of discontinuities. For this reason, the despeckling algorithm in this paper is based on the stationary version of directionlets transform (SDT). SDT is also an anisotropic transform based on lattice, but the filtering operations in coset are changed. Instead of using the subsamplers in decomposition filters and upsamplers in reconstruction filters, we put 2^{j-1} zeros between each coefficients of $H_j(G_j)$ at scale j to form the next scale filter $H_{j+1}(G_{j+1})$. Therefore, all the subbands have the same number of coefficients as the original image.

2.2. Statistics of speckle noise

Let $y(t,p)$ be the observed image, $x(t,p)$ be the noise-free image, and $\eta(t,p)$ be the speckle noise. If we assume that the speckle noise is fully developed, the corresponding model of SAR image can be expressed as [17]

$$y(t,p) = x(t,p)\eta(t,p). \tag{1}$$

The statistical properties of the speckle have been first studied by Goodman [1], and several speckle noise models [13,18–20] have been proposed in the past. To transform

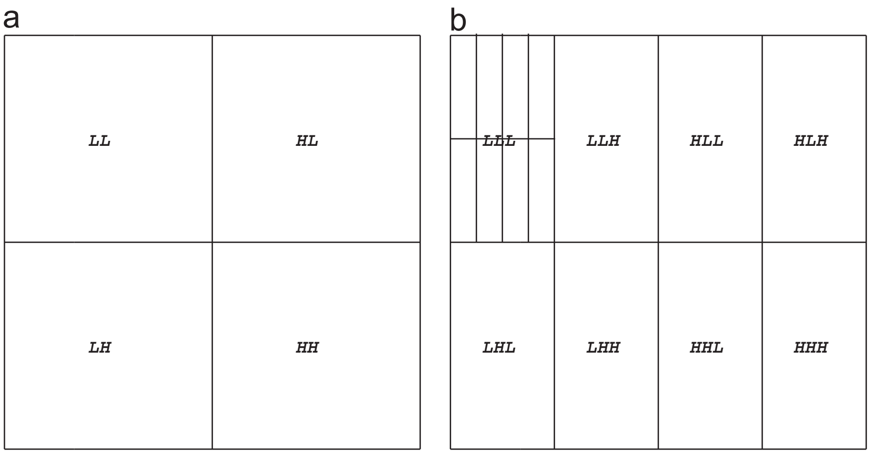

Fig. 1. Frequency decomposition of the standard 2-D DWT and the anisotropic wavelet transform (AWT). (a) The frequency decomposition of the standard 2-D DWT, where one decomposition scale is used. 1-D wavelet transform steps along two directions (horizontal and vertical) are equal at each scale. (b) The frequency decomposition of AWT, where two decomposition scales are used. 1-D wavelet transform steps along two directions (horizontal and vertical) are not equal at each scale.