INVESTIGATING THE SUPRESSION OF REMANENT SPECKLE NOISE IN SAR IMAGES USING A WAVELET APPROACH

FÁTIMA N. S. MEDEIROS[1], NELSON D. A. MASCARENHAS[2] , LUCIANO DA F. COSTA[3]

[1]*Departamento de Engenharia de Teleinformática*
Universidade Federal do Ceará
Campus do PICI Bloco 705, CEP 60455-760, Fortaleza, Ce, Brasil
E-mail: fsombra@dee.ufc.br

[2]*Departamento de Computação*
Universidade Federal de São Carlos
Via Washington Luiz Km 235, Cx. Postal 676, CEP 13565-905, São Carlos, SP, Brasil
E-mail: nelson@dc.ufscar.br

[3]*Departamento de Física e Informática*
Instituto de Física de São Carlos - USP
Caixa Postal, 369, SP, 13560-970, Brasil
E-mail: luciano@if.sc.usp.br

Resumo — Este artigo apresenta um novo algoritmo para suprimir o ruído *speckle* remanescente em imagens de radar de abertura sintética (SAR) usando um algoritmo que combina a abordagem *maximum a posteriori* (MAP) e *wavelets*. Primeiramente a imagem ruidosa é filtrada com filtro MAP, e para suprimir o ruído remanescente, um segundo algoritmo baseado em *wavelets* é aplicado à imagem. Alguns parâmetros são utilizados para avaliação quantitativa desta nova abordagem com respeito à distorção radiométrica e borramento de bordas. Experimentos têm sido realizados em imagens SAR reais.

Abstract — This paper presents a new algorithm to suppress the remanent speckle noise in SAR images using an algorithm based on the maximum a posteriori (MAP) approach combined to wavelets. The noisy image is first MAP filtered and to suppress the remanent noise a second algorithm based on wavelets is applied to the image. Some parameters are used in order to obtain quantitative evaluation of the new approach with respect to radiometric distortion and to edge blurring. Experiments have been carried out in real synthetic aperture SAR images.

Keywords — Map filter; speckle; noise; SAR image; wavelets.

1 Introduction

Synthetic aperture radar (SAR) is an active coherent all-weather imaging system that operates in the microwave region of the spectrum. Because of its high resolution ratio and all-weather characteristics, SAR is widely applied in many fields, such as earth remote sensing, the mapping of mesoscale ocean features, coastal monitoring, natural resources monitoring, disasters and weather forecasting and intelligence scout. Speckle phenomena results from the coherent radiation which appears as a granular signal-dependent noise, whose effect is to degrade the performance of image segmentation and classification algorithms (Aiazzi *et al*, 1998). In order to overcome this serious drawback in SAR images it is essential to reduce speckle before procedures such as automatic target detection and recognition.

A variety of techniques is usually employed to reduce speckle and a good reconstruction filter demonstrates the following properties: speckle reduction in extended uniform regions, feature preservation, absence of artifacts and radiometric preservation (Oliver and Quegan, 1998). This means that a good filter should smooth homogeneous areas while preserving edges and targets. The multilook technique is applied during the radar signal processing by averaging uncorrelated images from nonoverlapping spectra to improve the radiometric accuracy at the price of spatial resolution. Another category of speckle filtering techniques is based on statistical models and in the literature there are several sophisticated spatial filtering techniques that are quite effective in supressing speckle (Lee, 1981). Algorithms like the mean filter is often used for reducing speckle in radar images, even though it is not effective in preserving boundaries and point targets. Kuan and collaborators (Kuan *et al.*, 1987) were the first to propose an adaptive non-linear punctual filter based on the MAP approach for SAR image filtering by assuming the multiplicative model for the speckle noise, as well as one-look, quadratic detection and Gaussian a priori density.

Sant'Anna (Sant'anna, 1995) proposed speckle noise MAP filters for linear and quadratic detection SAR images using different a priori densities. Using a similar approach, Medeiros and collaborators (Medeiros *et al.*, 1998a) proposed a nonlinear adaptive filter based on the maximum a posteriori technique to reduce speckle in one-look, linear detected SAR images, that was combined with the k-means clustering algorithm. The k-means over Changle Li's coefficient (Li, 1988) in this proposed filter is used to classify the noisy image in regions of homogeneous statistics, which are used as a guide for choosing the best window size for parameter estimation. Medeiros *et al.* in (Medeiros *et al.*, 1999a) investigate the improvement that can be achieved by adopting adaptive neighborhoods within the MAP approach aiming to find a better subset around each pixel (with variable shape and size) whose respective statistical information is more suitable to perform the filtering.

During the last decade several methods for noise filtering based on wavelets were also proposed in the literature. Guo *et al.* (Guo *et al.*, 1994) proposed a computationally efficient wavelet shrinkage of the logarithmically transformed image to reduce speckle in SAR images while preserving the resolution of original image. The basic idea is to compute the wavelet decomposition of the noisy signal or image and to reduce the amplitude of the insignificant details coeficients in wavelet subspaces using hard and soft thresholding. One of the advantages of this approach over the traditional methods is the fact that the wavelet algorithm achieves the denoising in multiple scales. Aiazzi and collaborators present in (Aiazzi *et al.*, 1998) a multiresolution scheme relying on laplacian pyramid to deal with multiplicative noise. Local statistics filtering was applied to the layers of the image pyramid and the results have demonstrated that a superior filtering scheme can be achieved by using local statistics and geometric features.

This work proposes a new speckle noise filtering algorithm that combines the MAP and wavelet approach. The noisy SAR image is filtered using the MAP approach and It is assumed that the a priori density follows a Gaussian distribution and the conditional probability density function of the speckle follows a Rayleigh (for amplitude and one-look image) and square root of gamma (for amplitude and multilook image) distribution (Medeiros, 1999b). As a second step, an algorithm based on wavelets and proposed by Fukuda and Hirosawa (Fukuda and Hirosawa, 1998) is applied to filter remanent speckle. The new overall filtering algorithm performance is evaluated according to some qualitative and quantitative assessment techniques such as the radiometric distortion, dispersion along straight borders and lines, better class discrimination and visual assessment.

This paper is organized as follows: Section 2 introduces a fundamental background on SAR image MAP and wavelet filtering including a brief review of the multiplicative model and the distributions that models the speckle noise and the wavelet shrinkage methods for denoising data. Also, in this section the new algorithm is described. In the section 3 there is a description of the quality measures used to determine if the reconstruction departs from the expected speckle statistics, the effects on straight lines and edges and radiometric distortion. Section 4 proceeds with the simulations results and section 5 with concluding remarks.

2 Overview of the Filtering Algorithms

2.1 Maximum a Posteriori Approach

The model used for the noisy signal is given by Eq. (1), where $z_{i,j}$ describes the amplitude of the noisy observed pixel in linear detection, $x_{i,j}$ is the original signal and $n_{i,j}$ is the noise with unitary mean. The random variables x and n are assumed to be independent. The indexes i and j indicate the spatial position over the image.

$$z_{i,j} = x_{i,j}.n_{i,j} \tag{1}$$

The MAP estimator of x is obtained by maximizing the a posteriori probability density function $f(x|z)$, which can be related to the a priori distribution $f(x)$ through Eq. (2). The conditional distribution $f(z|x)$ which describes the speckle model is a Rayleigh or a square root of gamma distribution, depending on the type of detection:

$$f(x \mid z) = \frac{f(z \mid x).f(x)}{f(z)} \tag{2}$$

Using the Gaussian a priori density the MAP equation is obtained combining in Eq. (2) the Gaussian a priori knowledge and the conditional probability density function of the speckle (Rayleigh type). The MAP estimator is given by the solution of

$$2x^4 - 2\mu_x x^3 + 4\sigma_x^2 x^2 - \sigma_x^2 \pi z^2 = 0 \tag{3}$$

The μ_x and σ_x^2 parameters are estimated by the sample mean and the sample variance. The real and positive root of Eq. (3) whose value is between the mean and the observed pixel is taken as the filtered pixel value. Following the same procedure as above but using the conditional probability density function of the speckle following a square root of gamma distribution, the MAP estimator is given by the solution of (Medeiros *et al.*, 1998b):

$$\begin{aligned} &x^4\Gamma^2(N) - x^3\Gamma^2(N)\mu_x + x^2\Gamma^2(N)2N\sigma_x^2 \\ &-\sigma_x^2 2z^2\Gamma^2(N+1/2) = 0 \end{aligned} \tag{4}$$

whose value is between the mean and the observed pixel is taken as the filtered pixel value, N is the number of looks and $\Gamma(N)$ is the value of the gamma function.

2.2 Wavelet Transformation

A wavelet is defined by a set of functions given by

$$\psi^{a,b} = \frac{1}{\sqrt{|a|}}\psi\left(\frac{t-b}{a}\right), \; \left(a, b \in \Re, \; a \neq 0\right) \tag{5}$$

which are translated and scaled versions of a mother wavelet $\psi(t)$. An integral transformation using the functions in Eq. (5) as basis is called a wavelet transformation is defined as follows:

$$U(b,a) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} u(t)\psi(\frac{t-b}{a})dt \qquad (6)$$

When the admissibility condition concerning the basis is satisfied, the inverse transformation reconstructs the original signal. Daubechies (1990) found compactly supported orthonormal bases and these are named D2, D4, D6 and so on. When the Daubechies wavelets are implemented as a digital filter, the larger the index i of D_i is, the larger the number of filter coefficients are non-zero, that is to say, the longer tap the filter has (Fukuda and Hirosawa, 1998). Mallat (1989) developed the multiresolution analysis theory using the orthonormal wavelet basis. The multiresolution analysis expresses the space that a scaling function generates as a sequence of closed subspaces, where each space has a different spatial resolution. The multiresolution analysis is extended to two-dimension by transforming the rows and columns directions, separately. A wavelet transform of an image consists of four sub-images with a quarter area. The sub-image composed of the low frequency parts in both row and column direction is iteratively decomposed into four sub-images level by level.

In this paper the proposed post-filtering algorithm uses the Fukuda and Hirosawa scheme to reduce the remanent speckle noise by thresholding the amplitude of detail coeficients in wavelet subspaces. In (Fukuda and Hirosawa, 1998) the filter reduces speckle while edges are retained by releasing the amplitude around them, where the information on edges, contained in the detail images themselves, is utilized. This is done by using windows for detecting information on edged in detail images. The SAR images were decomposed into the wavelet subspaces with a pyramidal structure setting the subspaces level (M) to be 5 as suggested by the authors. The Daubechies bases D2 and D6 presented the best results.

3 Evaluation Methodology

To assess the improvement brought by the proposed algorithm the filtered images are evaluated according to some aspects as radiometric distortion, edge/straight lines preservation, better class dicrimination and how the overall visual aspect of the image is improved. The quantitative measures that are presented in the following were used to investigate the filtering performance.

a) The first one is presented in (Oliver and Quegan, 1998) and consists of the ratio of the noisy pixel, $z_{i,j}$, to the estimated one, $\hat{x}_{i,j}$, represented by the expressions:

$$r_k = \frac{z_{i,j}}{\hat{x}_{i,j}}$$

$$MEAN\_ratio = \frac{1}{Q}\sum_{k=1}^{Q} r_k \qquad (7)$$

$$VAR\_ratio = \frac{1}{Q}\sum_{k=1}^{Q} (r_k - 1)^2$$

where Q is the number of pixels in the image. The ratio, r_k, should correspond to the statistics of pure speckle noise (speckle fluctuations) with unit mean (*MEAN_ratio*). When the observed mean value differs significantly from one, it is an indication of radiometric distortion. If the reconstruction follows the original image too closely, the standard deviation (*VAR_ratio*) would be expected to have a lower value than predicted (e.g. when the original image has 2.2 effective looks, the expected standard deviation for the intensity ratio image is 0.674) (Oliver and Quegan, 1998).

b) The Hough Transform is used in this work to extract information about the dispersion along straight borders in the filtered images. It is proposed in (Medeiros *et al.*, 1998c) the implementation of this technique to describe a straight line is as follows:

$$x\cos\theta + y\sin\theta = \rho \qquad (8)$$

where x, y indicate the spatial position of the pixel over the image. The parameters (ρ,θ) represent the normal distance from the line to the image origin and its orientation, respectively. A straight line passing through the point (x,y) represents a sinusoidal curve in the Hough space. Hence, a set of collinear points on the binary image space corresponds to intersections of multiple sinusoids on the parameter space. To find a straight line in the binary image we can set up a two-dimensional array in the Hough space (ρ,θ) and for each point (x_i,y_i) in the binary image, we increment all the cells in the ρ,θ space that correspond to the sinusoidal curve for that point. A maximum count in a (ρ,θ) bin corresponds to a line segment passing through a maximum number of pixels. After doing that for all points, we apply a threshold (backmapping) to the accumulator array in order to eliminate spurious information. The surroundings of the peaks obtained in the final Hough Transform (backmapping) are analysed in order to quantify the distortions (dispersion) in straight features known to exist in the original image (e.g. images including man-made structures such as buildings, etc.). The average value of the areas of the regions surrounding the peaks were obtained and used as a measure of straight edge preservation (Medeiros *et al.*, 1999a). The measure used to evaluate the results is given by

$$S = \frac{\sum_{i=1}^{N} C_i}{N} \qquad (9)$$

where C_i is the area around the peak and N is the number of peaks.

To evaluate the visual improvement and the better discrimination of classes of the real filtered SAR images the histograms and the respective images are shown in the following sections.

4 Experimental Results Applied to Real SAR Images

The real images used to test the proposed algorithm are shown in Fig. 1 and Fig. 3.

a) In Fig. 1 an airbone SAR image over the region of Freiburg, Germany, It is shown an amplitude and single look image, being fraction of 512x512 pixels of the SAR580 original image.

b) Fig. 3 presents a 481x481 pixels image of the National Forest of Tapajós, Pará, Brazil, taken on June 26, 1993, by the JERS-1 satellite. It is a three looks, amplitude detected image.

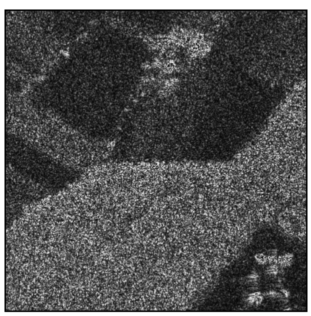

Figure 1. SAR580 noisy image.

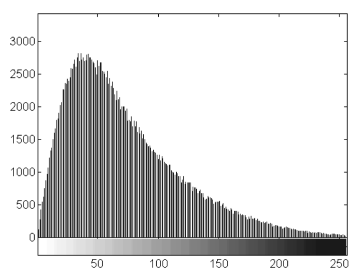

Figure 2. Histogram of the SAR580 noisy image.

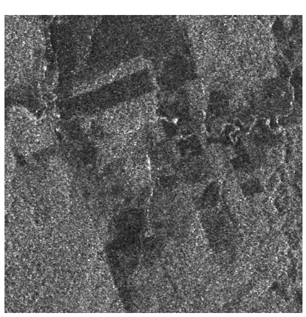

Figure 3. JERS481 noisy image.

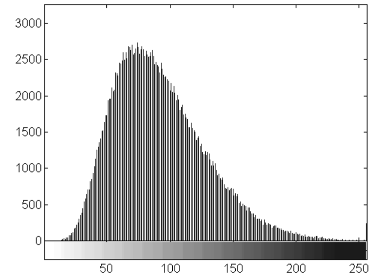

Figure 4. Histogram of the JERS481 noisy image.

The graphs in Figs. 5, 6 and 7 illustrate the performance of the proposed filtering algorithm over the SAR580 and JERS images using the MAP and the Kuan filters combined to the wavelet approach. Radiometric distortions over the SAR580 filtered image are investigated knowing that the theoretical mean value and variance of the speckle fluctuations are expected to be about 1 and 0.2732, respectively for the Rayleigh model. The theoretical mean value and variance of the speckle fluctuations for square root of gamma model (JERS481 image) are expected to be 1 and 0.0865, respectively. As the first step of the speckle filtering the Gaussian MAP filter and the Kuan filter (Kuan, 1987) were applied. The algorithms did not preserve overall radiometric accuracy because the mean values depart significantly from the unitary mean. These results also suggest that the Kuan filter introduces more radiometric distortion than the MAP approach, when combined with the wavelet denoising procedure.

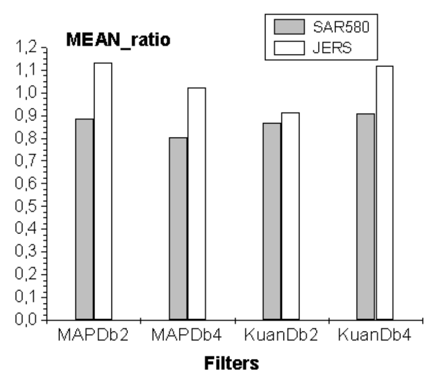

Figure 5. Mean value of the speckle fluctuations.

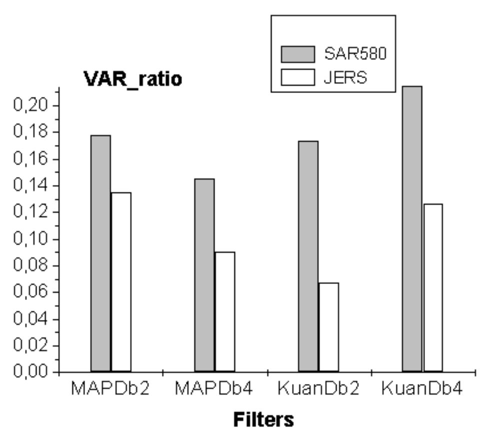

Figure 6 - Variance of the speckle fluctuations.

In Fig. 7 the results from *S* measure show that the dispersion along the straight lines caused by the Kuan-wavelet filter is greater than the MAP-wavelet scheme.

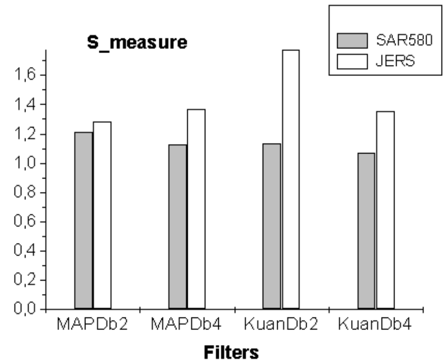

Figure 7. S measure

The proposed filtering scheme was applied to the SAR580 and JERS481 image and improved the discrimination of predominant classes (regeneration and forest) shown by the histograms. The original speckled image has a very broad histogram while the filtered one tends to have valleys in its histograms, resulting in a better discrimination of classes. It is visually noticed from the images in Figs. 8, 9, 10 and 11 that the speckle fluctuations were reduced.

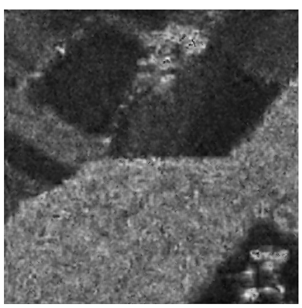

Figure 8. SAR580 Gaussian MAP-wavelet filtered image.

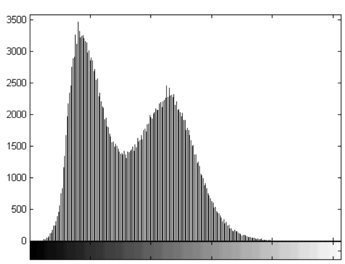

Figure 9. Histogram of the SAR580 Gaussian MAP-wavelet filtered image.

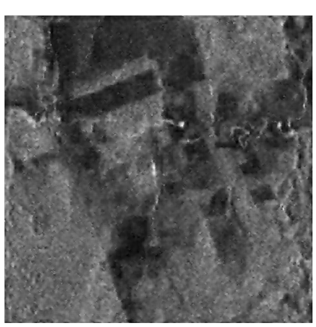

Figure 10. JERS481Gaussian MAP-wavelet filtered image.

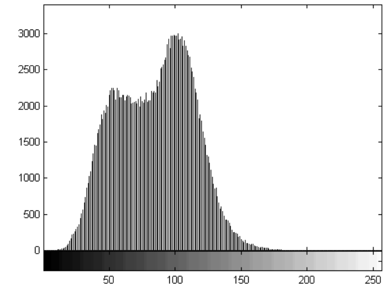

Figure 11. Histogram of the JERS481Gaussian MAP-wavelet filtered image.

5 Concluding Remarks

The contribution of this work is to investigate the performance of a new speckle filtering algorithm and from the results we can conclude that the proposed algorithm performance is satisfactory with respect to the parameters investigated on these test images, but there are more aspects to evaluate as the SNR, the best level to stop decomposing the image, the more effective wavelet bases to use and so on. This new approach can be further studied and improved considering these relevant aspects.

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