Evaluating an Adaptive Windowing Scheme in Speckle Noise MAP Filtering

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Abstract. Synthetic aperture radar (SAR) images are corrupted by speckle noise, which degrades the quality and interpretation of the images. Speckle removal provides a better interpretability of SAR images if the technique performs the filtering without loss of spatial resolution and preserves fine details and edges. This work aims to redefine the neighborhood areas around the noisy pixel and in this area the local mean and variance are computed to estimate the Maximum a Posteriori (MAP) filter parameters. The proposed modified MAP algorithm improves the ability to filter the speckle noise without blurring edges and targets by applying the MAP estimator in the current adaptive window that is controlled by a measure of homogeneity in the area around the noisy pixel. This adaptive windowing was also incorporated to the classical Kuan [3] and Frost [13] filters in order to evaluate the performance of the proposed scheme. The effectiveness in reducing speckle by the modified MAP filter is evaluated in terms of qualitative and quantitative aspects such as line and edge preservation and the improvement of the signal to noise ratio. The tests were performed in real SAR images.

1. Introduction

The radar wave coherence produces in SAR imagery a grainy texture pattern that complicates image analysis and interpretation in remote sensing tasks. This random pattern called speckle degrades the image quality and speckle filtering is a common requirement in some SAR image applications. Up to now, speckle reduction remains a major issue in SAR imagery processing. Usual filtering techniques designed for additive noise as the Wiener filter, fail due to the multiplicative nature of speckle [11].

During the last decade several methods for noise filtering based on wavelets were also proposed in the literature and these methods have been successful in reducing the speckle noise in SAR images. Medeiros et al. [5] presented an algorithm to suppress the remanent speckle noise in SAR images using the MAP approach combined to wavelets. The noisy image was first MAP filtered and to suppress the remanent noise a second algorithm based on wavelets was applied to the image. Foucher et al. [11] combined image multiscale analysis and classical techniques of adaptive filtering as the classical Gamma MAP filter proposed by Lopes et al. [2]. In this approach the wavelet coefficients of the ground backscatter are estimated with a Bayesian model, maximizing the *a posteriori* probability density function and the different probability density function are modelled with the Pearson family of distributions [11].

Sant'Anna [12] proposed speckle noise MAP filters for linear and quadratic detection SAR images using different a priori densities. Using a similar approach, Medeiros et al. [6] proposed a nonlinear adaptive filter based on the maximum a posteriori technique to reduce speckle in one-look, linear detected SAR images. Baraldi et al. [1] modified the Refined Gamma MAP (RGMAP) speckle filter proposed by Lopes et al. [2] enhancing its ability in exploiting shape adaptive windowing near image contours, where speckle is not fully developed. The Modified Refined Gamma Map (MRGMAP) speckle filter detects image regions by means of the combination of non-connected contours with region growing techniques and applies the GMAP filter on local areas that are localized within segment boundaries.

In Park et al. [8] an adaptive windowing algorithm was proposed to reduce speckle where the window size is automatically adjusted depending on the local statistics such as mean and standard deviation. The adaptive windowing proposed by Park et al. [8] was also used by Medeiros et al. [4] by combining it with the wavelet approach. As the noise is spread out over the details coefficients this filtering scheme consisted in looking for the most homogeneous areas around the noisy coefficient to truncate it without blurring edges and targets [4].

In this paper we describe a new filtering algorithm that investigates the use of an adaptive windowing procedure that runs over the noisy SAR image looking for local statistically homogeneous area near the pixel. The statistics used to replace the central pixel by the MAP estimator is computed in this homogeneous areas. In the same direction we modified the Frost and Kuan filters incorporating to them the adaptive windowing. These classical filters are used to compare and assess the adaptive windowing MAP filtering performance.

In section 2 we review the MAP estimator formulation and the adaptive windowing scheme is described. The experimental results are presented in section 3. Quantitative and qualitative comparisons of the experimental results are discussed in section 4.

2. The FilteringAlgorithm

There is a drawback that many papers report on the subject of speckle filtering in SAR images that is the conflict between preserving edges and reducing the strength of the speckle noise. Although the well-known Lee [9] filter can preserve edges, the use of too large windows produces a loss of fine details in the image. Attempting to overcome this kind of problem, a class of adaptive filters that use a running window whose size is automatically adjusted to the local statistics has been wide spread in SAR images filtering. We proposed an adaptive windowing MAP filtering algorithm inspired in the Park et al. [8] scheme and we extended the adaptive approach to the classical Frost and Kuan filters.

2.1 The MAP Estimator

The multiplicative 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.

$$z_{i,j} = x_{i,j}.n_{i,j} \quad (1)$$

The MAP estimate of x is obtained by maximizing the "a posteriori" probability density function $f(x/z)$, which can be related to the *a priori* distribution through Equation (2).

$$f(x/z) = \frac{f(z/x)f(x)}{f(z)} \quad (2)$$

Since we assume one-look, linear detected images, the speckle noise is distributed according to the Rayleigh distribution. Supposing that the non-noisy image follows a Gamma distribution given by:

$$f(x) = \frac{\sigma_x}{\Gamma(\lambda)}(\sigma_x x)^{\lambda-1} e^{-\sigma_x x} \quad (3)$$

The Gamma MAP estimator is obtained by the solution of the following equation [6]:

$$2\sigma_x x^3 + x^2(6-2\lambda) - \pi z^2 = 0 \quad (4)$$

where the parameters σ_x and λ are estimated by the sample mean $(\hat{\mu}_x)$ and the variance $(\hat{s}^2)$ through the method of moments, using the multiplicative model as shows Equation 5.

$$\hat{\lambda}_x = \frac{\hat{\mu}_x^2}{\hat{s}^2} \qquad \hat{\sigma}_x = \frac{\hat{\mu}_x}{\hat{s}^2} \quad (5)$$

2.2 Frost and Kuan Filters

In order to evaluate the performance of the proposed algorithm we applied Frost's and Kuan's filters using a 5x5 window size and a scanning adaptive window to the set of test images.

Frost et al. [13] proposed a spatial domain adaptive Wiener filter that is based on the multiplicative noise model and uses the local statistics. The recorded radar image $z(i,j)$ is modeled by Frost et al.[13] as,

$$z_{i,j} = [x_{i,j}.n_{i,j}] * h_{i,j} \quad (6)$$

where $h_{i,j}$ is the system impulse response and * denotes convolution [13]. The minimum mean square filter has the form,

$$\hat{x}(t) = z(t) * m(t) \quad (7)$$

where $t = (i,j)$ is the spatial coordinate. The $m(t)$ function is an isotropic impulse response of the spatial filter chosen to minimize

$$J = E\left[(\hat{x}(t) - x(t))^2\right] \quad (8)$$

It is given by an exponential expression:

$$m(t) = K_1 \alpha \exp(-\alpha|t|) \quad (9)$$

K_1 is a normalizing constant and α is the decay constant given by:

$$\alpha^2 = \left(2a / \sigma_n^2\right)\left[\sigma_x^2 / (\sigma_x^2 + \bar{z}^2)\right] + a \quad (10)$$

where a is the correlation coefficient between adjacent pixels of the original image $x(t)$. and $|t|$ corresponds to the distance between pixels in the spatial domain.

Kuan et al. [3] proposed a local linear minimum square error filter based on the multiplicative model. To perform the adaptive speckle noise pointwise filtering, the local statistics are computed using a fixed neighborhood. The noisy pixel is updated by the expression: $\hat{x} = \mu_x + K(z - \mu_x)$, where $\hat{x}$ is the minimum mean square estimate of x, μ_x (or $\bar{x}$) is obtained from the local mean of the noisy pixel computed in the fixed neighborhood, z is the noisy pixel and K is given by:

$$K = \frac{\sigma_x^2}{\mu_z{}^2\sigma_n^2 + (1+\sigma_n^2)\sigma_x^2} \quad (11)$$

In the absence of a precise model for the signal x, the noisy image is used to estimate the a priori mean and variance of the signal from the local mean $\bar{z}$, and local variance σ_z^2 in a 5x5 window [10] as shown in Equation (12).

$$\bar{z} = \bar{x}.\bar{n}$$
$$\sigma_x^2 = \frac{\sigma_z^2 - \sigma_n^2\bar{z}^2}{1+\sigma_n^2} \quad (12)$$

where σ_n^2 represents the noise variance and σ_x^2 is the variance of the original image and $\bar{n}$ is the unitary mean of the speckle noise.

2.3 Adaptive Windowing

The adaptive windowing algorithm reduces speckle where the window size is automatically adjusted depending on the local statistics such as mean and standard deviation. The algorithm uses a measure of homogeneity (σ_x) or coefficient of variation estimated in the current window, in terms of the standard deviation to mean ratio over homogeneous areas. Among the elements in the current window w_{ij}, only the samples in the boundary of this window are used for the decision of the next window size to save the computational load [8]. The decision is done by comparing this estimated value with a standard one (C). The standard value (C) is adjusted to test images according to parameters such as the number of looks and the type of detection (linear or quadratic). The scheme proposed by Park et al. [8] suggested that if the running window met fine details such as edges and point targets the window size must be decreased down to the minimum window size (3x3 pixels). It means that if the calculated standard deviation to mean ratio value was above C the class of terrain reflectivity corresponded to a heterogeneous one and must be preserved. If it was below C it denoted a homogenous area and the next window size must be increased unless it was greater than the maximum value. In case of amplitude detection and single look image the C value is suggested to be the standard deviation of the speckle noise, σ_n [5]. For linear detected and single look images C is established to be 0.5227 and for multi-look images it is given by $0.5227/\sqrt{N}$.

Medeiros et al. [4] used this neighborhood scheme starting from the maximum window size that is 7 by 7 pixels and testing its homogeneity threshold using only the pixels in the boundary, as it is shown in the dashed areas in Figure 1. In case that the calculated threshold is below the C value the window size stops growing, otherwise the window size must be decreased down to the minimum dimension (3x3 pixels) in order to preserve edge and fine details. After stop growing or decreasing the window size, this area is used to compute the local mean and variance to estimate the filtering parameters.

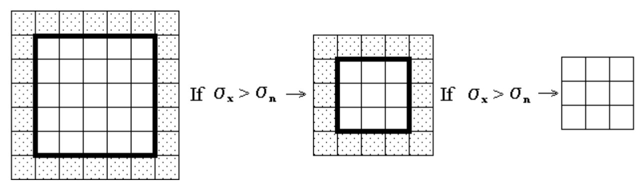

Figure 1. Adaptive windowing

2.4 Measures of the Filters Performance

To assess the improvement brought by the proposed algorithm, the filtered images are evaluated according to some aspects as edge and straight lines preservation, class discrimination and the amount of the speckle reduction over the homogeneous areas. The quantitative measures that are presented in the following were used to investigate the filtering performance.

a) To measure the amount of speckle reduction in the homogeneous areas the speckle index β is calculated in terms of the ratio of the standard deviation to the mean and it is defined as [10]:

$$\beta = \frac{\sigma_{\hat{x}}}{\mu_{\hat{x}}} \quad (13)$$

b) To evaluate the edge-preserving ability of the filters we used the S measure proposed by Medeiros et al. [7]. It is based on the Hough transform and using a simple edge detection algorithm we generated a boundary image and the Hough transform is applied to it. This measure is given by

$$S = \frac{\sum_{i=1}^{N} C_i}{N} \qquad (14)$$

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

3. Evaluating the Experimental Results

The real SAR images used to test the proposed algorithm are shown in Fig. 2 and Fig. 3.

a) The original image in Figure 2 is a 512x512 pixels image of a desert area (Kirtland Crater, New Mexico) obtained from the Airbone Multisensor Pod System. It is a single look and amplitude detected image of one-foot resolution and HH polarization. For the sake of improving the printing quality the brightness and contrast of the image were adjusted.

b) In Fig. 3 an airbone SAR image over the region of Freiburg, Germany is displayed. It is an amplitude detected and single look image, being a fraction of 512x512 pixels of the SAR580 original image obtained on the L band and HH polarization.

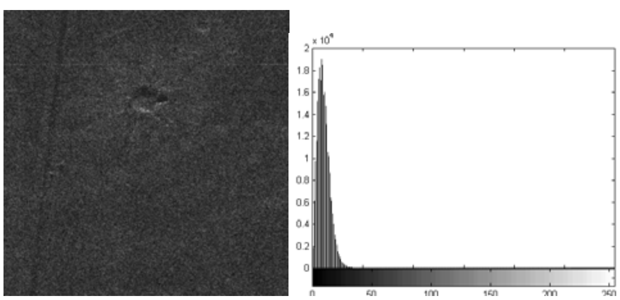

Figure 2. Original Craters image and its histogram

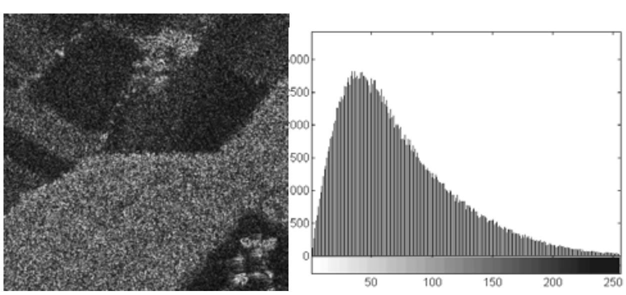

Figure 3. Original SAR 580 image and its histogram

In the following a set of figures is presented to observe the speckle noise filtering effects over the test images.

The original noisy image in Figure 2 exhibits a broad histogram compared to the filtered ones in Figures 4 to 8, that tend to be narrower. The Craters image is almost homogeneous so there was no class discrimination.

The filtered image in Figure 4 resulted from the application of the Gamma MAP filtering algorithm using a fixed-size 5x5 window and in Figure 5 is the modified version using the adaptive windowing scheme. The other speckle filters applied to the test images and presented in the following figures are the Frost and Kuan filters

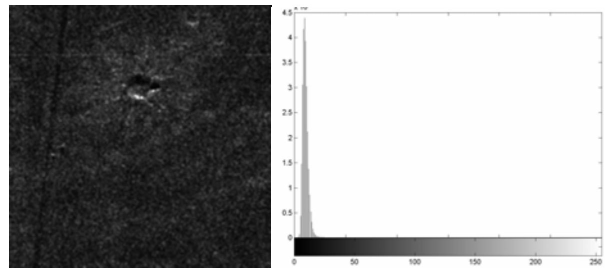

Figure 4. Gamma MAP filtered image and its histogram (5x5 window)

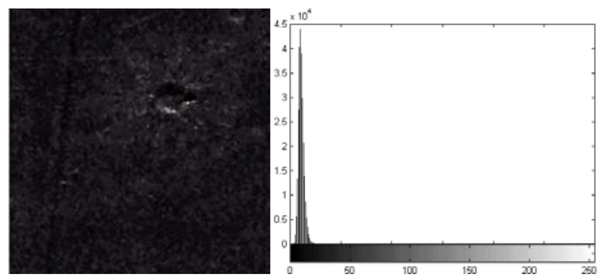

Figure 5. Gamma MAP filtered image and its histogram (adaptive window)

The filtered images in Figure 6 and 8 resulted from the application of the Frost and Kuan filtering algorithms respectively, using a fixed-size 5x5 window and in Figures 7 and 9 are the modified versions using the adaptive windowing scheme.

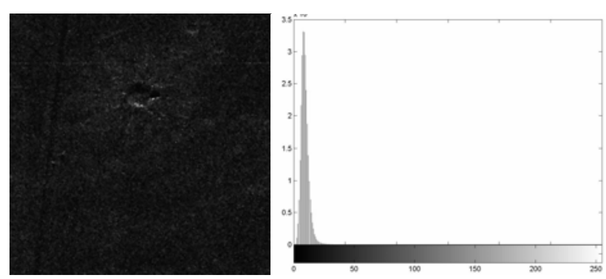

Figure 6. Frost filtered image and its histogram (5x5 window)

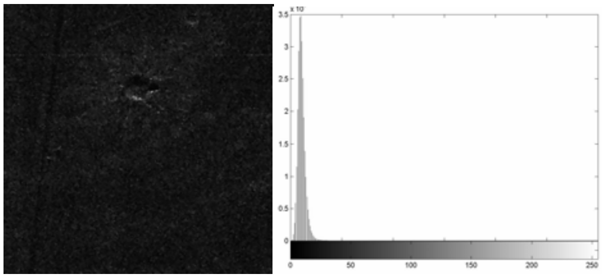

Figure 7. Frost filtered image and its histogram (adaptive windowing)

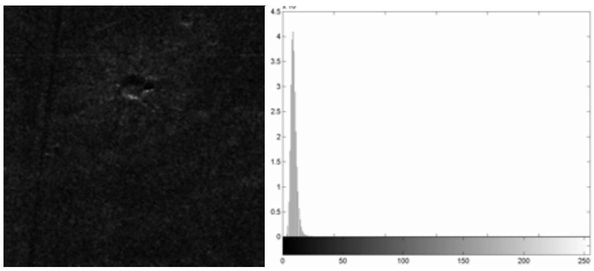

Figure 8. Kuan filtered image and its histogram (5x5 window)

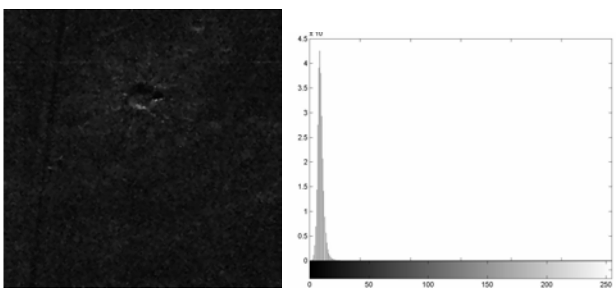

Figure 9. Kuan filtered image and its histogram (adaptive windowing)

By inspecting the original noisy images in Figure 3 we noticed that it has a very broad histogram, while the filtered ones in the following Figures 10 to 15 tend to be narrower. Subjective evaluation of these filtering results is employed to qualitatively compare them. The SAR580 filtered images in Figures 10 to 15 were visually improved showing a better contrast and discrimination of classes.

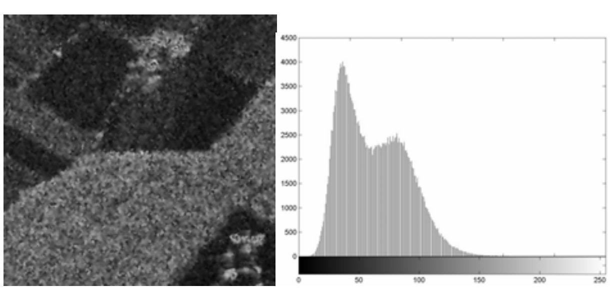

Figure 10. Gamma MAP filtered image and its histogram (5x5 window)

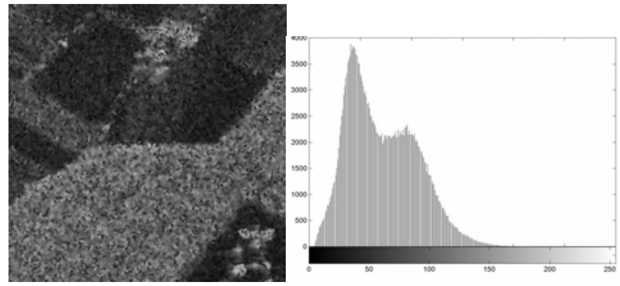

Figure 11. Gamma MAP filtered image and its histogram (adaptive windowing)

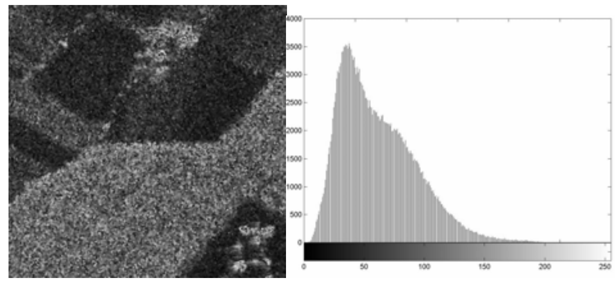

Figure 12. Frost filtered image and its histogram (5x5 window)

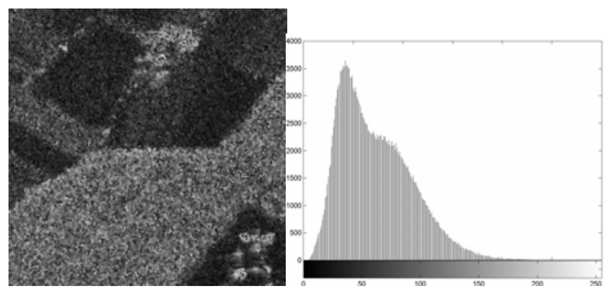

Figure 13. Frost filtered image and its histogram (adaptive windowing)

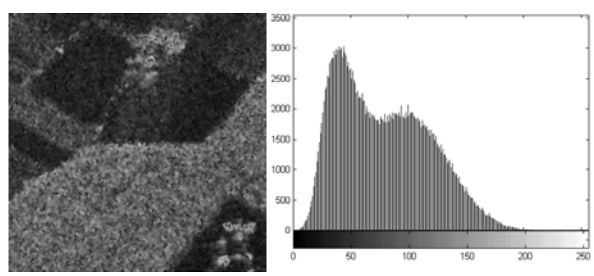

Figure 14. Kuan filtered image and its histogram (5x5 window)

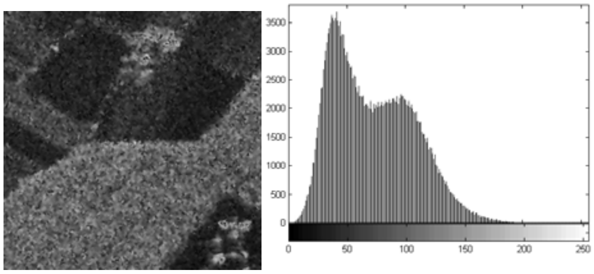

Figure 15. Kuan filtered image and its histogram (adaptive windowing)

Figures 16 and 18 show the calculated indexes (β) used to evaluate the speckle strength reduction. These indexes were calculated over a homogeneous area and resulted from a least squares fitting for some pixels, the best straight line adjusted to their mean versus standard deviation. The β index theoretical value for amplitude, linear detected image is 0.5227. Over the original SAR580 image the practical value was 0.5244. When the speckle is smoothed this value tends to become lower, indicating how well the filter performs.

In Figure 16 we can observe that although presenting the smallest β index of speckle reduction, the adaptive windowing was not effective when incorporated to the Gamma MAP filtering approach as it was in the Frost and Kuan filters. Even reducing speckle more than Kuan and Gamma MAP filters, Frost's filter blurs edge and straight lines less using the adaptive windowing scheme than the others as shows Figure 17.

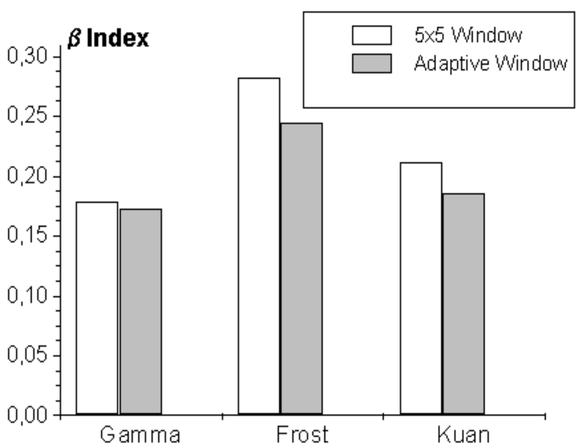

Figure 16. β index calculated over Craters filtered image

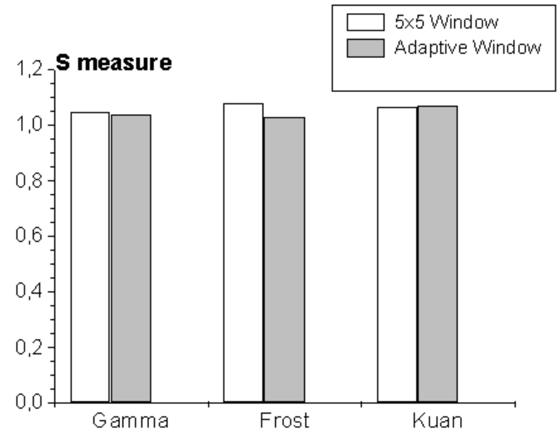

Figure 17. S measure calculated over Craters filtered image

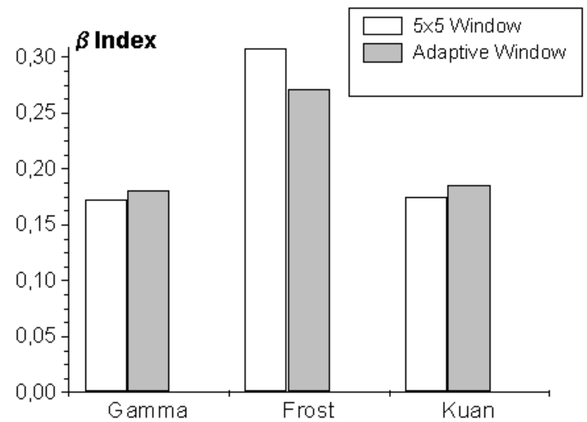

Figure 18. β index calculated over SAR580 filtered image

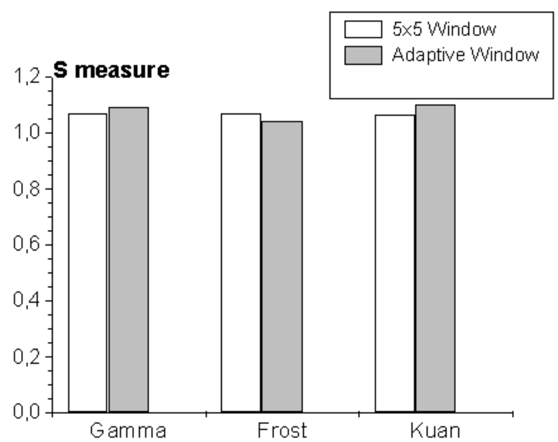

Figure 19. S measure calculated over SAR580 filtered image

4. Concluding Remarks

This paper presents a new method of speckle smoothing by using an adaptive windowing scheme incorporated to speckle noise filtering algorithms. Experimental results applied to real images showed that the speckle reduction ability of the modified Frost's filter was improved in comparison with the conventional one, that uses a fixed 5x5 window size. Although the modified MAP filter did not perform as well as Frost's filter, it still smooths speckle more than the other filters when applied to the Craters image. The visual interpretation of the results shows that the proposed algorithm did not introduce artifacts in the filtered images providing quite satisfactory performance. As we expected, the strategy of looking for a local statistically homogeneous area near the pixel to compute the local statistics tends to improve the adaptive filtering.

Acknowledgements

This work was supported by the CNPq grant #68.0082/01-8 (CNPq-ProTem) and by FUNCAP. Nelson D. A. Mascarenhas is also grateful to FAPESP for financial help.

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