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Speckle Noise Reduction in SAR Image: A Survey

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***Abstract:** It is very difficult to detect small targets when the scattering intensity of background clutter is as strong as the targets and the speckle noise is serious in synthetic aperture radar (SAR) images. Because the scattering of manmade objects lasts for a longer time than that of back ground clutter in azimuth matching scope, it is much easier for manmade objects to produce strong coherence than ground objects. As the essence of SAR imaging is coherent imaging, the contrast between targets and background clutter can be enhanced via coherent processing of SAR images. This paper produces the outcome of two methods which are very effective in their research area. One method proposes a novel method to reduce speckle noise for SAR images and to improve the detected ratio for SAR ship targets from the SAR imaging mechanism. This new method includes the coherence reduction speckle noise (CRSN) algorithm and the coherence constant false-alarm ratio (CCFAR) detection algorithm. Real SAR image data is used to test the presented algorithm sand the experimental results verify that they are feasible and effective. In another method Depending on the weighting coefficients, the class of the WVDFs can be designed to perform a number of smoothing operations with different properties, which can be applied for specific filtering scenarios. In order to adapt the weighting coefficients to varying noise and image statistics, the paper presents a methodology, which achieves an optimal trade-off between smoothing and detail preserving characteristics. The proposed angular optimization algorithms take advantage of adaptive stack filters design and weighted median filtering framework. The optimized WVDFs are able to remove image noise, while maintaining excellent signal-detail preservation capabilities and sufficient robustness for a variety of signal and noise statistics.*

***Keywords:** Directional Smoothing Filter (DSF), Artificial Intelligence (AI), Electromagnetic (EM), Synthetic Aperture Radar (SAR), Shuttle Imaging Radar (SIR)*

I. INTRODUCTION

Among the remote sensing technologies, Polarimetric Synthetic Aperture Radar (PolSAR) has achieved a prominent position. PolSAR Imaging is a well-developed coherent microwave remote sensing technique for providing large-scale two-dimensional (2-D) high spatial resolution images of the Earth's surface dielectric properties. In SAR systems, the value at each pixel is a complex number: the amplitude and phase information of the returned signal. Full PolSAR data is comprised of four complex channels which result from the combination of the horizontal and vertical transmission modes, and horizontal and vertical reception modes. The speckle phenomenonin SAR data hinders the interpretation these data and reduces the accuracy of segmentation, classification and analysis of objects contained within the image. Therefore, reducing the noise effect is an important task, and multi look processing is often used for this purpose in single and full-channel data. In the latter, such processing yields a covariance matrix in each pixel, but further noise reduction is frequently needed. According to Lee and Pottier [21], Polarimetric SAR image smoothing requires preserving the target polarimetric signature. Each element of the image should be filtered in a similar way to multilook processing by averaging the covariance matrix of neighboring pixels; and homogeneous regions in the neighborhood should be adaptively selected to preserve resolution, edges and the image quality. The second requirement, i.e. selecting homogeneous are as given similarity criterion, is a common problem in pattern recognition. It boils down to identifying observations from different stationary stochastic processes. Usually, the Boxcar filter is the standard choice because of its simple design. However, it has poor performance since it does not discriminate different targets. Lee et al. [18, 19] propose techniques for speckle reduction based on the multiplicative noise model using the minimum mean square error (MMSE) criterion. Lee et al. [20] proposed a methodology for selecting neighboring pixels with similar scattering characteristics, known as Refined Lee filter. Other techniques use the local linear minimum mean squared error (LLMMSE) criterion proposed by Vasile et al. [37], in a similar adaptive technique, but the decision to select homogeneous areas is based on the intensity information of the polarimetric coherency matrices, namely intensity driven adaptive-neighborhood (IDAN). Çetin and Karl [4] presented a technique for image formation based on regularized image reconstruction. This approach employs a tomographic model which allows the incorporation of prior information about, among other features, the sensor. The resulting images have many desirable properties, reduced speckled among them. Osher et al. [26] presented a novel iterative regularization method for inverse problems based on the use of Bregman distances using a total variation denoising technique tailored to additive noise. The authors also propose a generalization for multiplicative noise, but no results with this kind of contamination are shown. The main contributions were the rigorous convergence results and effective stopping criteria for the general procedure, that provides information on how to obtain an approximation of the noise-free image intensity. Goldstein and Osher [16] presented an improvement of this work using the class of L1-regularizedoptimization problems, that originated in functional analys is for finding extrema of convex functionals. The authors apply this technique to the Rudin–Osher–Fatemi model for image denoising and to a compressed sensing problem that arises in magnetic resonance imaging. Soccorsi et al. [29] presented a despeckling technique for single-look complex SAR image using non-quadratic regularization. They use an image model, a gradient, and a prior model, to compute the objective function. We employ the full polarimetric information provided by the multi look scaled complex Wishart distribution. Chambolle [5] proposed a total variation approach for a number of problems in image restoration (denoising, zooming and mean curvature motion), but under the Gaussian additive noise assumption. Li et al. [22] propose the use of a particle swarm optimization algorithm and an extension of the curvelet transform for speckle reduction. They employ the homomorphic transformation, so their technique can be used either in amplitude or intensity data, but not in complex-valued imagery. Wongand Fieguth [41] presented a novel approach for performing blind decorrelation of SAR data. They use a similarity technique between patches of the point spread function using a Bayesian least squares estimation approach based on a Fisher Tippett log-scatter model. In a similar way, Solbo and Eltoft [30] assume a Gamma distribution in a wavelet based speckle reduction procedure, and they estimate all the parameters locally without imposing a fixed number of looks (which they call "degree of heterogeneity") for the whole image. Buades et al. [3] proposed a methodology, termed Nonlocal Means (NL-means), which consists of using similarities between patches as the weights of a mean filter; it is known to be well suited for combating additive Gaussian noise. Deledalle et al. [11] applied this methodology to PolSAR data using the Kullback Leibler distance between two zero mean complex circular Gaussian laws. Following the same strategy, Chenetal. [6] used the test for equality between two complex Wishart matrices proposed by Conradsen et al. [8].

Torres et al. [4] presents a technique for reducing speckle in Polarimetric Synthetic Aperture Radar (PolSAR) imagery using non-local means and a statistical test based on stochastic divergences. The main objective was to select homogeneous pixels in the filtering area through statistical tests between distributions. This proposal uses the complex Wishart model to describe PolSAR data, but the technique can be extended to other models. The weights of the location variant linear filter are function of the p-values of tests which verify the hypothesis that two samples come from the same distribution and, therefore, can be used to compute a local mean. The test stems from the family of (h–ϕ) divergences which originated in Information Theory. This novel technique was compared with the Boxcar, Refined Lee and IDAN filters. Image quality assessment methods on simulated and real data are employed to validate the performance of this approach. We show that the proposed filter also enhances the polarimetric entropy and preserves the scattering information of the targets.

Bhateja et al. [28] due to backscattering of microwave signals, SAR images get contaminated with speckle noise. Author proposes an improved local statistics filter for filtering the speckle noise from the SAR images. The proposed filter is a combination of mean and hybrid median filters, employing a novel 7x7 filtering template. The performance of the proposed filter is tested against the standard Hybrid Median filters for which the evaluated values show better performs in terms of PSNR (in dB) and SSI.

Huang et al. [5] informs that it is very difficult to detect small targets when the scattering intensity of background clutter is as strong as the targets and the speckle noise is serious in synthetic aperture radar (SAR) images. Because the scattering of manmade objects lasts for a longer time than that of back ground clutter in azimuth matching scope, it is much easier for manmade objects to produce strong coherence than ground objects. As the essence of SAR imaging is coherent imaging, the contrast between targets and background clutter can be enhanced via coherent processing of SAR images. This paper proposes a novel method to reduce speckle noise for SAR images and to improve the detected ratio for SAR ship targets from the SAR imaging mechanism. This new method includes the coherence reduction speckle noise (CRSN) algorithm and the coherence constant false-alarm ratio (CCFAR) detection algorithm. Real SAR image data is used to test the presented algorithm sand the experimental results verify that they are feasible and effective.

Lukac et al. [6] presents a class of weighted vector directional filters (WVDFs) based on the selection of the output sample from the multichannel input set is analyzed and optimized. The WVDF output minimizes the sum of weighted angular distances to other input samples from the filtering window. Dependent on the weighting coefficients, the class of the WVDFs can be designed to perform a number of smoothing operations with different properties, which can be applied for specific filtering scenarios. In order to adapt the weighting coefficients to varying noise and image statistics, we introduce a methodology, which achieves an optimal trade-off between smoothing and detail preserving characteristics. The proposed angular optimization algorithms take advantage of adaptive stack filters design and weighted median filtering framework. The optimized WVDFs are able to remove image noise, while maintaining excellent signal-detail preservation capabilities and sufficient robustness for a variety of signal and noise statistics

II. PROBLEM AND SOLUTIONS

In order to attain good noiseless output images for SAR images, SAR image data characteristics must be taken into account. This dissertation will address the effects of two key characteristics of SAR images, namely their speckle noise and their wide dynamic range. Speckle noise contamination of SAR images is an important data characteristic that needs to be considered in SAR image compression. Speckle is an inherent phenomenon in coherent imaging systems. Speckle noise not only obscures image scene contents. But it reduces image's visual performance by weakening or breaking the inter-pixel correlation. Consequently, in order to compress SAR images more efficiently. It is desirable to reduce speckle noise improve for better image. Another consideration in designing SAR image denoising algorithms is that SAR images are usually of large size; as such these different regions may exhibit a variety of information content which are of differing levels of interest for different users.

III. PROPOSED METHOD

If the image information interferes with impulsive noise [26], filters based on the robust order-statistic theory provide an efficient solution. Note that the direct extension of the order-statistic theory to colour images is impossible due to their vectorial nature [38]. Therefore, the observed samples are ordered according to specially developed distance functions. Reducing speckle noise is an important content for SAR image interpretations. There are many methods to smooth speckle noise, such as multilook processing technique and filtering processing algorithms. Multilook processing decreases image spatial resolution at the cost of increasing radiation resolution. Mean and median filters can preferably restrain speckle noise. But both of the mare non-adaptive filters [25] and speckle noise is multiplicative [26], so the saving textures are not satisfactory. Then a lot of locally adaptive statistics filters based on multiplicative speckle noise were developed.

A filter that can be used to match elliptically-shaped regions that are aligned with the co-ordinate axes is given by:

$$f(x,y) = \begin{cases} 1 \text{ if } \frac{x^2}{a^2}+\frac{y^2}{b^2}\leq 1 \text{ and} \\ 0 \quad \text{otherwise} \end{cases} \quad (1)$$

Where 'a' and 'b' are the axes lengths. The values of 'a' and 'b' define the scale of the filter and their ratio defines the aspect ratio or the elongatedness of the ellipses. To match elongated regions at an arbitrary orientation θ with the x-axis, it can use the matrix of rotation to transform each of the points inside the ellipse. This yields:

$$f(x,y) = \begin{cases} 1 \text{ if } \frac{(x\sin\theta - y\cos\theta)^2}{a^2}+\frac{(x\sin\theta + y\cos\theta)^2}{b^2}\leq 1 \text{ and} \\ 0 \text{ otherwise.} \end{cases} \quad (2)$$

It is easy enough to see that the filter described in Equation (1) cannot be written in the form $f_1(x)$ and $f_2(y)$ and is therefore not separable. Consequently, the filtering cannot be divided into two stages of row-wise filtering and column wise filtering. Any oriented smoothing filter, f, is such that

$$f(x,y)\neq f(-x,y)$$
$$f(x,y)\neq f(x,-y) \quad (3)$$
$$f(x,y)=f(-x,-y)$$

The two inequalities are a result of the meaning of "oriented", since the orientation we mean is with respect to the coordinate axes. The symmetry constraint is imposed by the low-pass nature of the filters. Suppose a low-pass filter, $f(x,y)$exists that is both oriented and separable. Then, we can write: $f(x,y)=g_1(x)\times g_2(y)$ This, along with the inequalities of Equation (3) yields:

$$g_1(x)\times g_2(y) \neq g_1(x)\times g_2(-y) \quad (4)$$
$$g_1(x)\times g_2(y) \neq g_1(-x)\times g_2(y) \quad (5)$$

For any value of (x,y) where $f(x,y) \neq 0$ (so that neither $g_1(x)$ nor $g_2(y)$ is zero) So this yields,

$$g_1(x) \neq g_1(-x) g_2(y) \neq g_2(-y) \quad (6)$$

This implies that within the region of support of the filter functions $h_1(x)$ and $h_2(y)$ can be defined such that:

$$g_1(x) = h_1(x)\times g_1(-x)$$
$$g_2(y) = h_2(y)\times g_2(-y) \quad (7)$$

This, along with the symmetry constraint of Equation (2) yields $h_1(x) = h_2(y)$-1 which would lead us to the absurd conclusion that the filter values in the x and y directions are dependent, unless the functions $h_1(x)$ and $h_2(y)$ are constant. Hence, there exists no low-pass filter, f(x, y), that is both oriented and separable.

A. FLOW CHART

As shown in the flow chart below the input siganl is taken first and then it is converted to the gray scale image as to apply filtering the input argument to the function needs the image to be in gray scale format. Then speckle noise is added to the image so as to model the actual scenario. This noisy image is assumed to be obtained from the radar and the proposed algorithm is applied for filtering the noise from the image. After the application of proposed method i.e. DSF filter the image quality parameter is calculated in terms of

MSE and PSNR. Then the result obtained is discussed in the subsequent section of the paper.

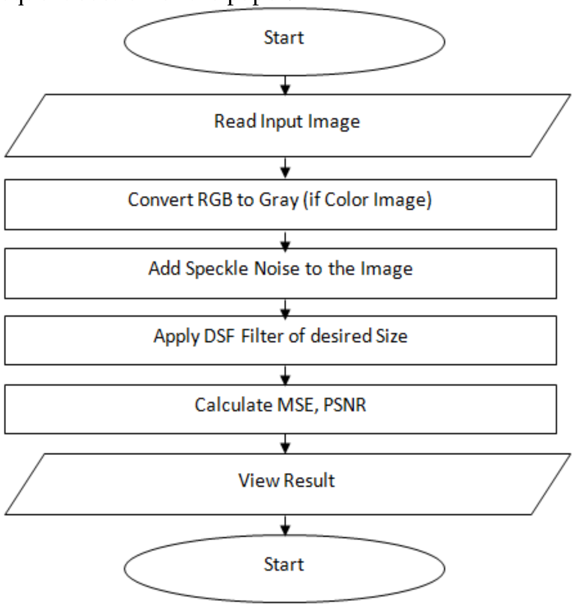

Figure 2: Flow Chart

IV. RESULT

The quantitative parameters which can be used to compare the image quality are the PSNR value and the MSE Value.

$$PSNRindB = 10\ Log_{10}\left(\frac{255^2}{MSE}\right) \quad (8)$$

$$MSE = \frac{\sum_i \sum_j \{Y(i,j) - \hat{Y}(i,j)\}^2}{M \times N} \quad (9)$$

Where PSNR stands Peak Signal to Noise Ratio, MSE stands for Mean Square Error, MxN is size of the image, Y represents the original image, $\tilde{y}$ denotes the denoised image. A Higher PSNR indicates the reconstruction is of higher quality when the two images are identical. The results obtained on some of the images are as shown below.

V. CONCLUSION

A deep survey of the various techniques that can be used for noise removal in SAR image has been done and presented in the paper. As the researches proceeded and improvements done new and better techniques evolved and has proved to be the better noise removal technique in the SAR images. This paper presents all the methods that has been applied previously and utilized for excellent results. Also the paper presents a new method for SAR image denoising. A primary requirement of the method is that it should take into account the characteristics of SAR images which are different from optical images. Therefore it needs to adopt approaches specifically for SAR images to achieve the goal of SAR denoising. The problem of SAR speckle reduction has been related and studied simultaneously. In addition to its role in image denoising the proposed speckle smoothing method makes use of the so-called hierarchical correlation to identify edges from noise.

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