An Improved Kuan Algorithm for Despeckling of SAR Images

Aditi Sharma, Vikrant Bhateja and Abhishek Tripathi

Abstract Synthetic Aperture Radar (SAR) is an acquisition tool for coherent imagery used for meteorological and astronomical purposes. The speckle noise diminishes the information and image quality which evokes the necessity of pre-processing of SAR images. Kuan filter is a popular despeckling algorithm among the various local statistics filters. Kuan filter works efficiently within the homogenous regions of the SAR images while penalty is imposed by the edges. This paper presents an improved Kuan filter which combines the concept of gradient and conduction function for despeckling of SAR images. In this, the image is processed by classifying it into three regions i.e., homogenous, non-homogenous and isolated regions respectively; depending upon the estimated value of noise parameters. This approach thereby provides a simple solution to overcome blurring across the edges during despeckling. Simulation results make it evident that the proposed despeckling algorithm yields better results as compared to other primitive filters.

Keywords Local statistics · Anisotropic diffusion · Conduction function · Kuan filter · Despeckling

1 Introduction

SAR image is a high resolution two dimensional image which results from the backscattering of coherent electromagnetic wave. SAR images are used to identify the land cover type, forest mapping, monitoring of land subsidence, wetlands etc.

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However, the main drawback of these images is the presence of speckle which is caused due to many elemental scatterers with a random distribution within a resolution cell. These images could also contaminated with Gaussian noise; but presently the focus is mainly concentrated toward speckle suppression. The coherent sum of their amplitudes and phase results in a strong fluctuation of a backscattering from one resolution cell to another. Consequently, speckled SAR image is not deterministic but follows an exponential uniform distribution. Speckle is a statistical fluctuation of each pixel in the image of scene which makes the radiometric and textural aspect less efficient for class discrimination [1–6]. For these reasons, pre-processing of SAR images is essential; however, it should not deteriorates the useful information (i.e., point target, texture etc.) during filtering. Adaptive speckle filtering is based on the multiplicative model and consider local statistics. The Local Statistic Mean Variance (LSMV) filter adapts itself as a function of local coefficient of variation and can be enhanced by fixing a minimum value for better speckle smoothing and point target preservation. The coefficient of variation are statistically sensitive to texture and speckle noise strength [5–9]. Kuan filter [10] achieves a balance between averaging and identity filter which depends on the coefficient of variation parameter inside the moving window. The Lee [11] and Kuan filters have the same formulation, as the output image is computed by the linear combination of center pixel and is replaced by the average intensity of the mask. In progression, techniques involving Anisotropic Diffusion (AD) were proposed which employs a variable diffusion coefficient for despeckling SAR images [12–14]. The Perona Malik Anisotropic Diffusion (PMAD) [15] filter uses a variable coefficient of diffusion in standard scale-space paradigm so that it has a larger value in homogenous region. This AD filtering model provides better preservation features but this can be achieved at high computational complexity [16–18]. In this paper, an improved Kuan algorithm has been proposed for despeckling of SAR images. The images are processed based on their classified regions using the calculated values of image and noise variation parameters. This leads to efficient speckle suppression in homogenous area thereby preserving point targets and detailed areas as well as curtail computational complexity. The rest of the paper is structured as follows: Sect. 2 elaborates the proposed despeckling methodology and the Image Quality Assessment (IQA) parameters used for performance evaluation of obtained results. Further, the simulation results and discussions are presented in Sect. 3 whereas the conclusions are drawn in Sect. 4.

2 Proposed Methodology

2.1 Background

Various image restoration and enhancement methods have been designed in both spatial and frequency domains which are based on the criteria like Minimum Mean Square Error (MMSE), Linear Minimum Mean Square Error (LMMSE), Bayesian, Non-Bayesian, etc. [2, 19]. The adaptive Kuan filter uses a MMSE calculation for estimating the center pixel in the filter window. It is an approximation of Lee filter and uses a simple method for calculating the signal estimate from the local mean (m) and variance (Sd). The Kuan filter operates by averaging the random noise in the flat areas and preserves the edge sharpness using the filter window to measure the spatial activity. The various non-stationary image statistical parameters needed for the Kuan algorithm are effective number of looks, noise variation of coefficient, image variation of coefficient, threshold and weighting function. If μ and σ denotes the global values of computed mean and standard deviation respectively; the aforesaid parameters are determined using the mathematical expressions given under Eqs. (1)–(5) respectively. These parameters depend upon the Non-stationary Mean, Non-stationary Variance (NMNV) image model [10]. The gross structure of an image is described by the non-stationary mean, while the edge and textural information is characterized by the non-stationary variance [4, 10, 15, 16].

$$\text{Effective No. of Looks } L = \frac{\mu^2}{\sigma^2} \tag{1}$$

$$\text{Noise Variation of Coefficient } C_u = \sqrt{\frac{1}{L}} \tag{2}$$

$$\text{Image Variation of Coefficient } C_i = \frac{Sd}{m} \tag{3}$$

$$\text{Threshold } C_{\max} = \sqrt{1 + \frac{2}{L}} \tag{4}$$

$$\text{Weighting Function } w_f = \frac{1 - \left(\frac{C_u}{C_i}\right)^2}{1 + C_u^2} \tag{5}$$

2.2 *Proposed Algorithm—Improved Kuan Filter*

It is known that various local statistics filters have been used for despeckling SAR images. The adaptive Kuan filter smoothens the homogenous areas but blurs the edges while PMAD filter although provides edge preservation features but this is only achieved at high computational complexity. Thus, the proposed algorithm amalgams the concept of PMAD filter and Kuan filter which yields better despeckling and edge preservation results at low computational complexity. The filtering procedure of the Improved Kuan filter is elaborated further. This involves moving a mask of size w over the speckled SAR image throughout; in this process of spatial filtering. Moreover, the image is characterized into three distinct regions i.e., the homogenous area where the scene feature and pixel intensity is constant, heterogeneous area where the scene and pixel intensity varies and isolated point targets where the pixel intensity abruptly changes. To elaborate further, based on the calculated values of noise and image variation parameters, the Improved Kuan algorithm processes the image as described under; where *cp* refers to the center pixel and *i, j* indicates the current pixel. At first, if the value of C_i is less than C_u, it is a homogeneous region and the pixel is processed by Kuan filter [10]. Thus the resulting transformed pixel will be calculated as under within the mask.

$$I_t(i,j) = cp(i,j)w_f + m\left(1 - w_f\right) \tag{6}$$

Secondly, if the value of C_i is greater than $C_{\max}$, it is an isolated point and the original pixel values are preserved, i.e.

$$I_t(i,j) = cp(i,j) \tag{7}$$

Lastly, if C_i is between the range of C_u and $C_{\max}$, it is a heterogeneous region and the pixel is processed as per the concept defined by PMAD filter. Thus, the transformed pixel in this region is computed using Eqs. (8)–(10). The PMAD filter uses gradient for the detection of the edges and is computed in 4 directions as follows:

$$\begin{aligned} \nabla_N I_{i,j} &= I_{i-1,j} - I_{i,j} \\ \nabla_S I_{i,j} &= I_{i+1,j} - I_{i,j} \\ \nabla_E I_{i,j} &= I_{i,j+1} - I_{i,j} \\ \nabla_W I_{i,j} &= I_{i,j-1} - I_{i,j} \end{aligned} \tag{8}$$

Using the gradients calculated in above 4 directions, the respective conduction coefficients are then estimated using Eq. (9) below.

$$c_N = \left(1 + \left(\frac{\nabla_N I}{Sd\sqrt{2}}\right)^2\right)^{-1} \tag{9a}$$

$$c_S = \left(1 + \left(\frac{\nabla_S I}{Sd\sqrt{2}}\right)^2\right)^{-1} \tag{9b}$$

$$c_E = \left(1 + \left(\frac{\nabla_E I}{Sd\sqrt{2}}\right)^2\right)^{-1} \tag{9c}$$

$$c_w = \left(1 + \left(\frac{\nabla_W I}{Sd\sqrt{2}}\right)^2\right)^{-1} \tag{9d}$$

Now, based on the calculated values of gradient and conduction function, the transformed pixel is modeled as Eq. (10).

$$I_t(i,j) = I(i,j) + \lambda\Delta t(\nabla_E I \cdot c_E + \nabla_W I \cdot c_W + \nabla_N I \cdot c_N + \nabla_S I \cdot c_S) \quad (10)$$

With the above working, it can be assimilated that the proposed Kuan algorithm as explained in Eqs. (6)–(10) is dependent jointly upon the local statistics as well as the parameters of PMAD filter. That is, the coefficient of variation and conduction function are two primary factors which have been incorporated not just to reduce speckle but also to preserve radiometric information content. The procedural working of the proposed Improved Kuan algorithm has been summarized under Algorithm 1.

Algorithm 1: Steps for Despeckling SAR Images using Improved Kuan Filter.

	Begin		
Step 1:	*Input*: Noisy image (*I*) of size MXN.		
Step 2:	*Input*: Window size (w).		
Step 3:	*Compute*: global parameters : Standard Deviation (σ), Mean (μ) Noise Variation of Coefficient as given in Eq. (1) Effective No. of Looks as given in Eq. (2) Threshold as given in Eq. (4)		
Step 4:	*Process*: Image (*I*) spatially with window (w).		
Step 5:	*Compute*: local parameters : Standard Deviation (*Sd*), Mean (*m*) Image Variation of Coefficient as given in Eq. (3) Weighting Function as given in Eq. (5) within the window.		
Step 6:	If	$(C_i \le C_u)$	Refer Eq. (6)
	If	$(C_i \ge C_{\max})$	Refer Eq. (7)
	If	$(C_u < C_i < C_{\max})$	Refer Eq. (8), (9) and (10).
Step 7:	*Process*: the mask sequentially until it reaches the last pixel of the image.		
Step 8:	*Display*: the denoised image (I_t).		
	End		

Lastly, the despeckled SAR image is then processed to carry out IQA in order to assess the performance of the proposed algorithm. The main performance parameters used for the evaluation of despeckled SAR images are Peak Signal to Noise Ratio (*PSNR* in dB) and Structure Similarity Index Map (*SSIM*). *PSNR* [19] defines the quality of the image in terms of the power of the original and denoised images. More the *PSNR,* better is the filtering output. *SSIM* [20] is used to compare luminance, contrast and structure between the original and denoised images. The *SSIM* value should be closer to unity for optimal measure of similarity. Now the proposed algorithm is implemented to obtain its quality parameters so as to check its reliability and validity [9, 21, 22].

3 Results and Discussions

SAR images of a moon crater (named as test image 1 and test image 2) has been taken in the simulation to validate the performance of proposed algorithm. The simulated procedure is initiated by normalizing the input SAR image. The normalized image is then contaminated with simulated speckle noise of different variance's ranging from 0.01 to 0.03. Prior to application of proposed Kuan algorithm on the noisy SAR image; the tuning parameters like mask size ($w = 3 \times 3$), step size ($\Delta t = 0.05$) and $\lambda = 1/n_s$ (where n_s is the number of neighbors from center pixel, generally taken as 4) are optimally determined. The proposed algorithm is efficient to overcome blurring at the edges and preserving subtle details than other conventional filters. The obtained results from test image 1 with the proposed Kuan algorithm are shown in Fig. 1. Subsequently the performance is not degraded by the every 0.01 increment in speckle content with decrement in *PSNR* (in dB) and *SSIM*. Also from Fig. 1, it is evident that along with the smoothing in homogenous areas, the edges are preserved and are visually effective. The performance is determined further using IQA metrics like *PSNR* and *SSIM* which are enlisted in Table 1.

In order to benchmark the performance of the proposed algorithm, a test image 2 of moon crater has been compared with few other filters of the literature commonly being Lee [11], Frost [3], Kuan [10] and PMAD [15] filters as shown in Fig. 2. It can be observed that the Lee filter enhance the visual perception of SAR image but at the cost of over smoothening the edges whereas the Frost filter deteriorates the visual perception by blurring the SAR image. The Kuan filter is an approximation of Lee filter showing similar result as Lee that is blurring at edges but proves to be a better despeckling technique. The aforesaid local statistics filters employ primitive criteria's that averages the pixel intensity of the mask to remove speckle but proves

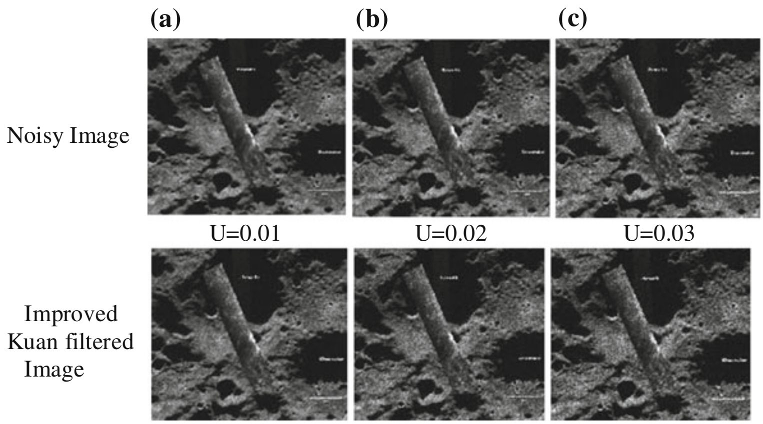

Fig. 1 Despeckled SAR images (test image 1) obtained by the proposed algorithm for different speckle magnitudes (0.01–0.03)

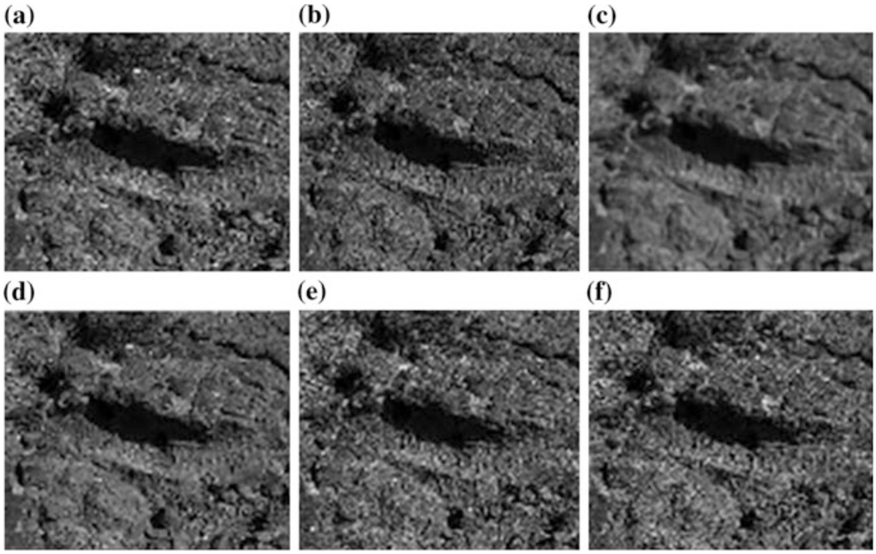

Fig. 2 **a** Speckled Image (test image 2 with speckle variance U = 0.01), Despeckled SAR images using **b** Lee filter **c** Frost filter **d** Kuan filter **e** PMAD filter **f** Improved Kuan filter

Table 1 IQA values at different speckle magnitudes for an improved Kuan algorithm

Speckle variance	PSNR (in dB)	SSIM
0.01	24.5145	0.9708
0.02	23.3691	0.9626
0.03	22.5024	0.9551

inefficient in edge detection and preservation. PMAD is an efficient filtering algorithm for edge detection and uses an edge stopping function for preserving texture and other fine details of the image but at high computational complexity. The proposed algorithm thereby overcomes the above limitations and gives better despeckling results. The Table 2 enlist the IQA parameters at various speckle magnitudes (0.01–0.03) for validating the aforesaid results.

From the above analysis, it is observed that the Improved Kuan gives better values of *PSNR* and *SSIM* as compared to other conventional filters even at higher speckle variance. Therefore, it ensures that the use of gradient and conduction function along with the Kuan filter has proved a useful tool for image smoothing and edge preservation.

Table 2 Performance comparison of the proposed Kuan algorithm with other speckle filters using IQA metrics

Noise variance	PSNR (in dB)					SSIM				
	Lee	Frost	Kuan	PMAD	Improved Kuan	Lee	Frost	Kuan	PMAD	Improved Kuan
0.01	15.7416	17.7405	15.8277	22.0996	24.5145	0.7471	0.8344	0.7824	0.9431	0.9708
0.02	15.1288	16.6990	14.6543	21.1610	23.3691	0.7402	0.8335	0.7776	0.9313	0.9626
0.03	14.4580	16.0478	13.4831	20.4193	22.5024	0.7361	0.8319	0.7721	0.9205	0.9551

4 Conclusion

Speckle is the major undesirable artifact present in SAR images which deteriorates the visual perception of the image. In this paper, the conventional Kuan filter has been improved which is validated by IQA metrics. The proposed algorithm hybridize the concept of Kuan and PMAD filter which comes forth to be a great tool for despeckling of SAR images. Also, the proposed work shows improved results when compared to other conventional filters with better restoration and edge preserving feature. Moreover, the proposed algorithm is quite simple and curtails computational complexity when compared to other advanced Bayesian methods. Therefore, the proposed algorithm defines an interesting approach which turns out to be a remarkable despeckling technique enabling speckle reduction in homogeneous areas, scene feature preservation and absence of artifacts.

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