Volume 8, No. 3, March – April 2017
ISSN No. 0976-5697
International Journal of Advanced Research in Computer Science
RESEARCH PAPER
Available Online at www.ijarcs.info

A New Computationally Improved Homomorphic Despeckling Technique of SAR Images

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Abstract: Speckle noise is the universal distortion problem in synthetic aperture radar (SAR) images. Despeckling method resolves this problem. This article presents an improved and enhanced homomorphic filtering technique using wiener filter to avoid blurring and to increase the computational time of execution. The proposed method is enhanced by applying log transform after the discrete wavelet transform (DWT) only at the detailed part. This saves the overall time of computational process and the results are also satisfactory and easily acceptable. This scheme is proposed in db2 type wavelet transform. Wiener filter is applied on the approximate part. The performance of the scheme is evaluated by calculating PSNR, SSIM and computational time. The performance of the resulting improved homomorphic filtering technique is compared with some standard methods and filters, and it shows better results in terms of numerical and visual comparison.

Keywords: homomorphic filtering; dwt; wiener filter; speckle noise; SAR image

I. INTRODUCTION

Satellite image processing is continuous emerging field of the image processing, where satellite SAR images are captured from synthetic aperture radar, it is an kind of radar that is permanently mounted on the satellites and aircraft that captures the high resolution images of the broad areas of the earth surface. SAR images are shaped by the unfailing interaction of the produced microwave radiation with target. This unfailing interaction originates arbitrary constructive and destructive nosiness resulting into multiplicative kind of noise known as speckle noise all over the image. There are many despeckling methods available in spatial and frequency domain to restore noisy SAR images by maintaining the important information of image like edge, boundary and corners. Some standard traditional method for despeckling purpose in the arena of satellite imagery like, frost filter [1], kuan filter [2], kuwahara filter [3], [4], lee filter [5],[6], mean filter [7], and median filter [8]. Further developed methods in homomorphic and non-homomorphic filtering are operative and adaptive. It is practically seen that bayesian approaches in transform domain illustratesimprovedoutcomes than bayesian approaches in spatial domain. But there some non-bayesian approaches that gives as better results as bayesian approaches in transform domain.

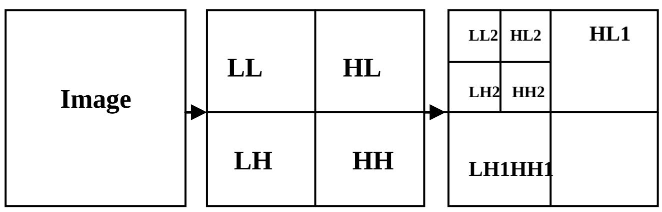
Homomorphic and non-homomorphic filtering are bayesian schemes in transform domain that deliver stop systems in wavelet domain and are widely used mainly in the domain of satellite imagery. Homomorphic filtering [9]; [10] transforms the multiplicative noise to additive using log operations, while non-homomorphic filtering [11]; [12]; [13] are hard to implement and less frequently used and seen in literature as it directly works on multiplicative speckle noise without transforming it to additive in nature. Homomorphic filtering is frequently used in last two decades as after transforming the multiplicative noise to additive, other additive noise restoration models are adaptive and can be used easily and effectively to restore the speckled SAR images, it is easy to understand, while non-homomorphic filtering methods directly works upon multiplicative noise. This technique is relativelyhard to work upon. Essentiallyhomomorphic filtering is used for refiningnon-homogeneous brightness in images. Classical hard and soft thresholding methods [14] were applied in [15]. The undecimated wavelet transform and the MAP standard have been implemented in the issue of SAR image despeckling [16].Some non-bayesian methods such as bilateral filtering [17]; [18]; [19], sigma filter [20] and non-local filtering [21], [22] which gives acceptable and satisfactory outcome in terms of visual appearance and edge preservation.

This article is organized in the following way: Section II explains the wavelet based despeckling methodology. Section III describes the proposed scheme. Section IV describes the numerical experiments with detailed discussion. Section V concludes the article and section VI mentions the used references.

II. WAVELET BASED DESPECKLING PROCEDURE

SAR images are corrupted by speckle noise which is multiplicative in nature. Most of the restoration models are additive in nature as mostly other occurring noises are additive. So, these additive noise restoration models cannot be used to handle speckle noise. It is either needed to use multiplicative noise restoration model which are rarely used and have low performance issues, or to convert this multiplicative speckle noise into additive in nature. This nature transformation operation can be performed by image enhancement methods. The best way is to use log operation [26], later its inverse operation is performed by exponential transform.

Wavelet transform plays a role of major tool in the applications of image and signal denoising due to its meritorious features like localized in both frequency and time domain and multi-resolution analysis. 2D-DWT transforms the image into two components, approximate part (LL) and detail part (LH, HL and HH) as shown in below Figure 1.



SAR images are distorted by speckle noise with zero mean and different variances. Here speckle noise is modeled as:

$$I(i,j) = S(i,j) \times N(i,j) \quad (1)$$

Speckle has a negative influence on SAR images. Speckle noise [27] is specified as product of clean image pixel $S(i,j)$ and multiplicative noise, $N(i,j)$. $I(i,j)$is degraded pixel of the image.

Before applying DWT in image denoising, there are two points to be taken care of. First of all, wavelet family basis is needed to be chosen for every decomposition layer like, db2, haar etc. Secondly, level of decomposition is needed to be decided. Although in image denoising, image can be decomposed up to any level, but it is observed in most of the cases that the denoising results are best from 3-5 level. Wavelet based denoising is performed by following three steps:

Step 1: Perform DWT on input speckled SAR image to obtain approximate and detail parts.

Step 2: Perform the denoising using following steps:

i. Estimate noise variance.

ii. Calculate threshold.

iii. Apply thresholding on detail parts.

Step 3: Apply inverse DWT to obtain final despeckled SAR image.

Threshold choice method comprises of universal threshold, sub-band adaptive threshold and spatially adaptive threshold. The proposed scheme practises the universal threshold where threshold value is exclusively chosen for all wavelet coefficients [23, 24].

Threshold λ is calculated using,

$$\lambda = \left(\frac{{\sigma_\eta}^2}{\sigma_Y}\right) \quad (2)$$

Noise variance is estimated as:

$$\sigma_\eta^2 = \left[\frac{median(|X(m,n)|)}{0.6754}\right]^2 \quad (3)$$

where, $X(m,n)\epsilon LH_L$, $X(m,n)\epsilon HL_L$ and $X(m,n)\epsilon HH_L$, and L is the level of decomposition in DWT. The standard deviation of noise less image (σ_Y) can be estimated as:

$$\sigma_Y^2 = max\left(\sigma_X^2 - \sigma_\eta^2, 0\right) \quad (4)$$

where, $\sigma_X^2 = \frac{1}{b}\sum_{i=1}^{b} X_i^2$, and b is the patch size of the input image.

Hard and Soft thresholding are two thresholding procedures for thresholding purpose. The proposed scheme uses soft thresholding.The soft thresholding is equated as:

$$\hat{Y} := \left\{\begin{cases} 0 & if\,|X| \le \lambda \\ sign(X)(|X| - \lambda) & if\,|X| > \lambda \end{cases}\right. \quad (5)$$

III. PROPOSED METHODOLOGY

Wiener filter is the linear filter mainly used for reducing additive noise and avoid blurring. Wiener filters are commonly practised in the frequency domain [20, 23]. Here it filters the approximate component of the image up-to three level of decomposition using below Eq 6.

$$W(f_1, f_2) = \frac{H^*(f_1,f_2)S_{xx}(f_1,f_2)}{|H(f_1,f_2)|^2 S_{xx}(f_1,f_2) + S_{\eta\eta}(f_1,f_2)}) \quad (6)$$

The Wiener filtering is implemented on SAR image with a cascade implementation of the noise smoothing and inverse filtering. The despeckled SAR images are tested with the PSNRs and MSEs [25]. It is noticed that the despeckled SAR image is better-quality in terms of the visual performance, but the MSEs don't specify that, the reason is that MSE is not a good metric for deconvolution [25]. The inefficiency of MSE boosts to use another performance parameter like SSIM which gives better analysis. The framework of the proposed methodology is shown in Figure 2.

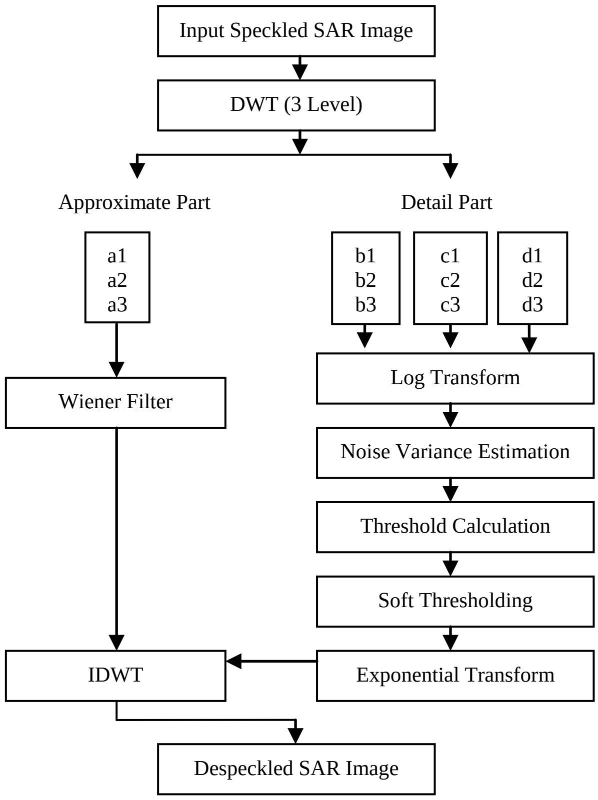


Figure 2.Flowchart of proposed algorithm

The proposed algorithm has following steps:

Step1: Input speckled SAR image, S.

Step 2: Apply DWT up to 3 level of decomposition on S.

a) Decomposition into 4 sub bands, approximate part (a1, a2, a3) and detail part (b1 c1 d1), (b2 c2 d2), (b3 c3 d3).

b) Apply 2D adaptive wiener filtering on (a1, a2, a3) sub bands using 3×3 neighborhood mask using Eq 6.

c) Perform transformation operation and thresholding on the detailed part (b1 c1 d1), (b2 c2 d2), (b3 c3 d3) using following step:

   i. Apply log transformation on detailed part.

   ii. Estimate noise variance using Eq 3.

   iii. Threshold calculation using Eq 2.

   iv. Apply soft thresholding using Eq 4 and Eq 5.

   v. Apply exponential transform.

Step 3: Apply inverse DWT.

Step 4: Finally obtained despeckled SAR image.

IV. RESULTS AND DISCUSSION

Here, numerical and experimental results with their performance results are shown on some real SAR images in order to verify the effectiveness of proposed algorithm. The real SAR image is shown in Figure 3 and Figure4 shows speckled SAR image at σ = 20. The SAR image is taken from open public database[1].

[1]http://eo.belspo.be/directory/SensorDetail.aspx?senID=152

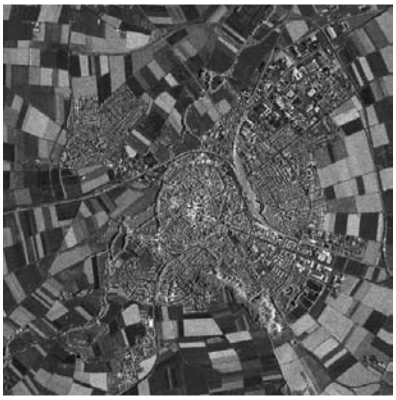


Figure 3. Original SAR Image

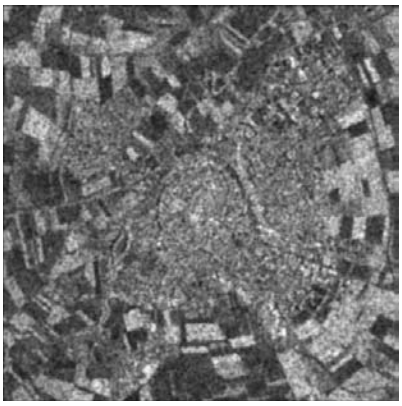


Figure 4. Speckled SAR Image (σ = 20)

The proposed method resizes the SAR images to 512×512 images for the faster execution of below algorithm. It uses db2 type wavelet basis in dwt2 function of matlab. The proposed method is implemented on MATLAB version=8.3, name=R2014a on Intel(R) Core(TM) i5-2410M CPU @ 2.30 GHz, 4GB RAM and 64-bit operating system. It is necessary to note down system configuration because it helps to compare the execution time of the proposed algorithm with other standard methods.

The proposed algorithm is validated by comparing with standard filters and methods like frost, homomorphic frost, kuan, homomorphickuan, lee, homomorphic lee, mean, hard and soft thresholding, universal threshold, visu thresholdusing PSNR and SSIM performance metrics.

PSNR is universally used performance metric in denoising. Higher the value of PSNR, PSNR should be as high. High value indicates better results. PSNR is computed by:

$$10\log_{10}\left(\frac{255 \times 255}{MSE}\right) \tag{6}$$

Structural similarity index (SSIM) is used measure the similarity between despeckledimageand reference image. It depends upon three parameters, luminance, contrast and structural. The overall index is a multiplicative combination of the three terms.

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \tag{7}$$

The range of SSIM varies from -1 to 1 according to the literature [19].

Table I. Comparison of Proposed method with other standard methods and filters on the basis of PSNR and SSIM

	Technique	PSNR	SSIM
Speckled SAR Image Figure 4. σ = 20	Frost	17.8979	0.8236
	Homomorphic Frost	17.8731	0.8139
	Kuan	17.6573	0.8392
	HomomorphicKuan	17.1243	0.8611
	Lee	17.9826	0.8772
	Homomorphic Lee	17.2839	0.8195
	Kuwahara	18.6739	0.9374
	Mean	16.1291	0.8101
	Soft Thresholding	18.4749	0.9120
	Hard Thresholding	17.8241	0.8573
	Universal Threshold	18.1529	0.9111
	Visu Threshold	16.7342	0.7931
	Proposed method	**18.9769**	**0.9481**

Table I. shows the performance chart of the proposed method in comparison to other standard works on the basis of PSNR and SSIM values and Figure 5. shows the despeckled SAR image using proposed method. It is clear from these results that proposed method performs better than all compared methods in terms of visual quality and numerical experiments as the values of PSNR and SSIM of proposed method is highest among all other compared methods.

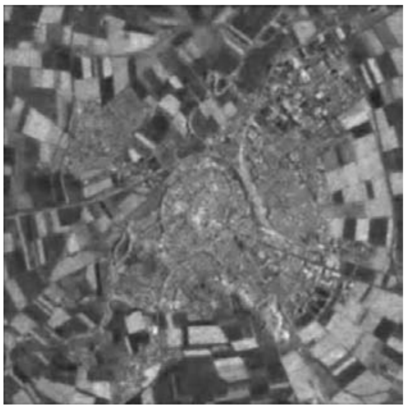


Figure5. Despeckled SAR Image by proposed algorithm

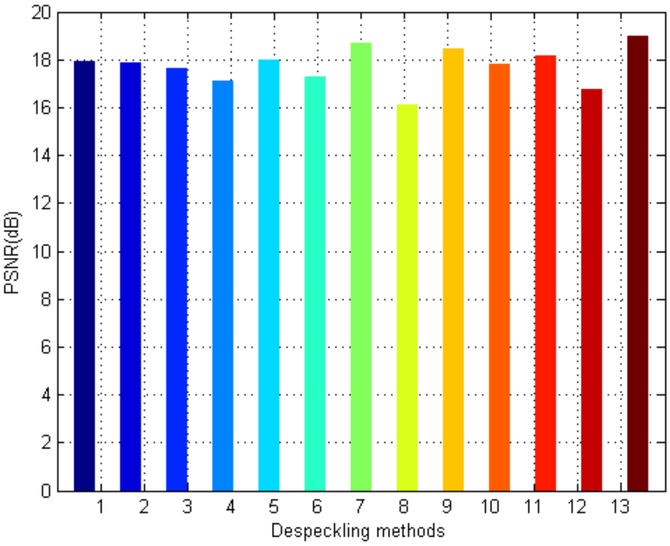


Figure 6. Comparison of proposed method with other standard methods using bar chart on the basis of PSNR

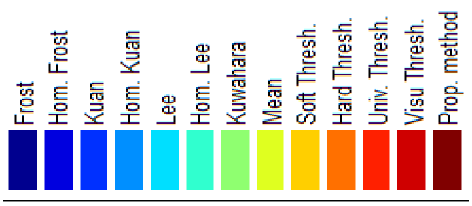


Figure 7.Despeckling method identification using color patterns in bar chart of Figure 6, 8 and 9.

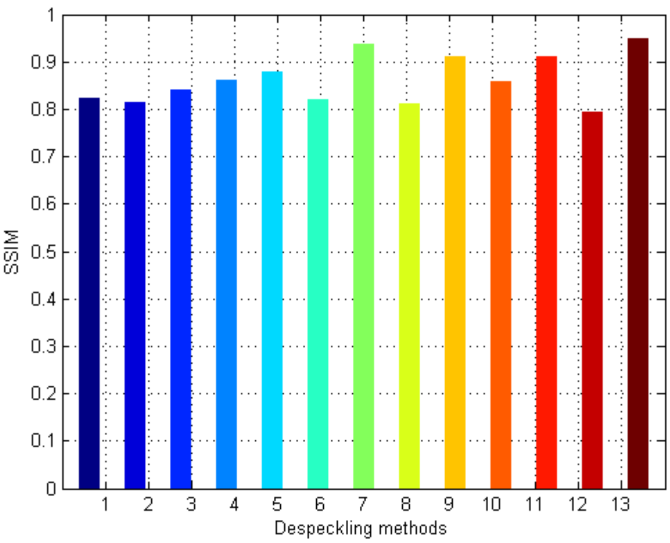


Figure 8. Comparison of proposed method with other standard methods using bar chart on the basis of PSNR

Table II. Execution time of despeckling techniques (in seconds).

Technique	Time
Frost	17.5550
Homomorphic Frost	18.2365
Kuan	24.6968
HomomorphicKuan	24.0043
Lee	36.6102
Homomorphic Lee	37.5858
Kuwahara	25.0012
Mean	4.1341
Soft Thresholding	8.0083
Hard Thresholding	5.9466
Universal Threshold	12.0085
Visu Threshold	3.7729
Proposed method	**2.7924**

Apart from validating the performance of proposed method to other compared standard methods on the basis of PSNR and SSIM, it can also be compared on the basis of computational execution time of the algorithm. The main aim of this research is to minimize the computational time of the homomorphic filtering using wavelet domain by applying the log transform only on the detailed part of the image within DWT rather than on whole speckled image. The proposed algorithm is computationally checked with other standard works and the computational time is shown in Table II.

It is clear from the table that the computational time of the proposed algorithm is smaller than other standard works. Although execution time of the mean, visu and hard thresholding methods are closer to the proposed method but still more than proposed method but on comparing the proposed method with them numerically, they are behind to proposed method.

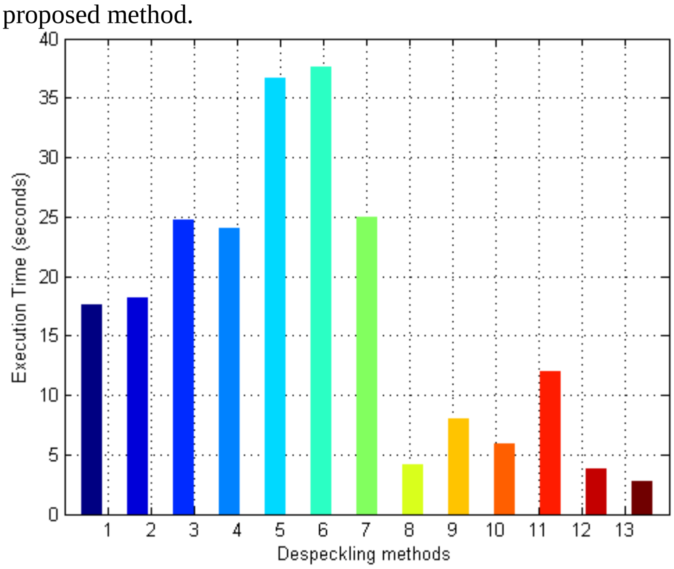


Figure 9.Execution time of despeckling techniques in seconds using bar chart

In order to visually analyze the effectiveness of the proposed method with other standard works, Figure 6-9, easily specifies the performance of proposed method in terms of PSNR, SSIM and computational time of execution.

V. CONCLUSION

In this paper, a new scheme is proposed based on homomorphic filtering using wiener filter to improve the computational execution time of the despeckling algorithm in homomorphic methods. Here instead of applying the log operation on whole speckled image, the operation is performed only on the detailed part of the SAR image within DWT. Final results of proposed method are better in terms of speckle noise reduction, removal of artifacts and edge preservation. The outcomes of proposed algorithm are compared with standard methods. In maximum cases, the computational and numerical performance of proposed algorithm is giving improved values in terms of PSNR and SSIM. Apart from performance metrics, the visual appearance of proposed algorithm of SAR images is also better. Numerical results validate that our proposed algorithm: (i) successfully remove the speckle noise in SAR images, (ii) preserve the edges and (iii) reduces the computational time.

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