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Wavelet-Based Despeckling of Synthetic Aperture Radar Images Using Adaptive and Mean Filters

Syed Musharaf Ali, Muhammad Younus Javed, and Naveed Sarfraz Khattak

***Abstract*—**In this paper we introduced new wavelet based algorithm for speckle reduction of synthetic aperture radar images, which uses combination of undecimated wavelet transformation, wiener filter (which is an adaptive filter) and mean filter. Further more instead of using existing thresholding techniques such as sure shrinkage, Bayesian shrinkage, universal thresholding, normal thresholding, visu thresholding, soft and hard thresholding, we use brute force thresholding, which iteratively run the whole algorithm for each possible candidate value of threshold and saves each result in array and finally selects the value for threshold that gives best possible results. That is why it is slow as compared to existing thresholding techniques but gives best results under the given algorithm for speckle reduction.

***Keywords*—**Brute force thresholding, Directional smoothing, Direction dependent mask, undecimated wavelet transformation.

I. Introduction

SYNTHETIC aperture radar is a radar technology that is used from satellite or airplane. It produces high resolution images of earth's surface by using special signal processing techniques. Synthetic aperture radar has important role in gathering information about earth's surface because it can operate under all kinds of weather condition (whether it is cloudy, hazy or dark).However acquisition of SAR images face certain problems. SAR images contain speckle noise which is based on multiplicative noise or rayleigh noise.

Speckle noise is the result of two phenomenon, first phenomenon is the coherent summation of the backscattered signals and other is the random interference of electromagnetic signals [1].Speckle noise degrades the appearance and quality of SAR images. Ultimately it reduces the performances of important techniques of image processing such as detection, segmentation, enhancement and classification etc. That is why speckle noise should be removed before applying any image processing techniques.

There are three main objectives of any speckle filtering. First is to remove noise in uniform regions. Second is to preserve and enhance edges and image features and third is to provide a good visual appearance. Unfortunately 100% speckle reduction is not possible. Therefore, tradeoff has to be made among these requirements. Speckle reduction usually consists of three stages [2] First stage is to transform the noisy image to a new space (frequency domain). Second stage is the manipulation of coefficients. Third is to transform the resultant coefficients back to the original space (spatial domain).Currently many statistical filters are available for speckle reduction. Such as Mean, Kuan, Frost, Lee and MAP filter etc. Results show that statistical filters are good in speckle reduction but they also lose important feature details. Additionally prior knowledge about noise statistics is a prerequisite for statistical filters.

In recent years, there has been active research on wavelet-based speckle reduction because wavelet provides multi resolution decomposition and analysis of image. In wavelet sub bands noise is present in small coefficients and important feature details are present in large coefficients. If small coefficients are removed, we will get noise free image.

Previously most of the researchers use discrete wavelet transformation [1]-[7] for reduction of speckle. Draw back of discrete wavelet transformation is that it is not translation invariant [8]. That means it will lose lots of important coefficients during translation from original signal to sub bands. In order to solve this problem and to save the coefficients, derivated form of discrete wavelet transformation is used called undecimated wavelet transformation. Basic idea is that it does not lose any coefficients, all coefficients remain intact. That is why it is also called redundant wavelet transformation. It requires more storage space and need more time for computation. Whether discrete or undecimated wavelet is used, biggest problem is the selection of optimal thresholding .Some researchers use wavelet based hard or soft thresholding [1], [9].Other thresholding techniques were also used such as VisuShrink, SureShrink, OracleShrink, OracleThresh, NormalShrink, BayesShrink, Thresholding Neural Network (TNN) etc. [10]-[13].But there are some draw backs of using those thresholds as shown in [4].

Therefore we implement a new technique for speckle reduction of SAR images that use the combination of undecimated wavelet transformation, wiener filter and mean

Syed Musharaf Ali did MS in Software engineering from College of Signals, National University of Science and Technology, Rawalpindi, Pakistan;(e-mail: mushali2001@yahoo.com)

Muhammad Younus Javed did his PhD from University of Dundee UK. Now he is head of department of department of computer engineering at college of electrical and mechanical engineering, National University of Science and Technology, Rawalpindi, Pakistan (e-mail: myjaved@ceme.edu.pk).

Naveed Sarfraz Khattak did his MS from Michigan State University (U.S.A).Now he is Head of Department of computer science department at College of Signals, National University of Science and Technology, Rawalpindi, Pakistan (e-mail: naveed-khattak@mcs.edu.pk).

filter. For thresholding we use brute force thresholding that always gives best results as compared to above mention thresholding techniques but the only drawback of brute force thresholding is that it is relatively slow.

In section II speckle model for SAR images is described. In section III propose method is explained that include directional smoothing, brute force thresholding and proposed algorithm. In section IV general overview of assessment parameters that include peak signal to noise and mean square error is given. In section V results are discussed. In section VI conclusion is made. In the last section references are given

II. Speckle Model for SAR Images

Speckle noise is typically modeled as multiplicative noise (Rayleigh noise), therefore final output signal is the product of original signal and speckle noise

Let I (i, j) be the degraded pixel of an observed image and S (i, j) is the noise-free image pixel to be recovered. With the multiplicative noise model,

$$I(i,j) = S(i,j) * N(i,j) \qquad (1)$$

In which N (i, j) represents the multiplicative noise with unit mean and standard deviation [2].

Most of researchers convert multiplicative noise into additive noise by homomorphic filtering before speckle filtering of SAR images as shown in [5],[14],[15],[16] etc. But research shows that there is no significant impact of homomorphic filtering on any speckle filtering Algorithm. So it is not necessary to convert speckle noise to additive noise. Additionally, mean of log transformed speckle noise does not equal to zero. Therefore necessary corrections and adjustments have to be made before any further processing. So homomorphic filtering is not recommended step for speckle filtering.

III. Proposed Method

A. Directional Smoothing

During despeckling, edges are blurred so to protect edges from blurring directional smoothing filter is used [17].

- Select mask of size 3×3 or 5×5 or 7×7
- Take the average of pixels of each direction as shown in Fig. 1 and store in array v(n) where n =4

$$v(n) = 1/R \sum_i \sum_j y(m-i, n-j) \qquad (2)$$

- Find V1(n) such that

$$V1(n) = abs(v(n) - x(r,c)) \qquad (3)$$

For each mask. Where x(r,c) is central pixel of mask.

- Find index of V1(n) that gives minimum value such that

$$Index = \min(V1) \qquad (4)$$

- Replace the pixel value of x(r,c) by v(index)
- Repeat the whole procedure until whole image is scanned by mask.

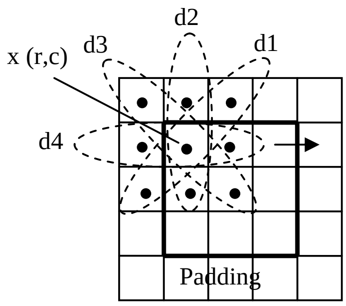


Fig. 1 Directional Smoothing

A. Brute Force Thresholding

Brute force thresholding always outclass other existing thresholding techniques in terms of better results. Algorithm for brute force thresholding is given

- Input wavelet sub band.
- Find maximum (max) and minimum (min) value of sub band coefficients.
- loop through (threshold=min to max) and execute desired algorithm
- save the results in array for each loop such that F=[threshold,result]
- When loop completed, select the (threshold) that gives best result.

B. Proposed Algorithm

- Let assume that A is the original speckled SAR image. B is the wiener filtered SAR image of A and C is the mean filter SAR image of A
- Decompose the images A, B and C into wavelet sub bands $S_{i,A}^{(\in)}$, $S_{i,B}^{(\in)}$ and $S_{i,C}^{(\in)}$ using undecimated wavelet transformation. Where (i) is decomposition level and ($\in$) denotes the detail sub bands such as horizontal detail, vertical detail and diagonal detail sub bands respectively. Decomposition up to level 3 is enough.
- Process each level of detail images of A by the following steps
  1) Find minimum (min) and maximum (max) value of coefficients of each detail sub band at each level.
  2) Loop (threshold = min to max) for each detail sub band at each level
  3) Determine whether each pixel of $S_{i,A}^{(\in)}$ is High level or Low level. If (pixel < threshold) then it is low level other wise pixel is high level.

4) If pixel is low level then replace the value of pixel of $S_{i,A}^{(\epsilon)}$ by the corresponding pixel value of $S_{i,C}^{(\epsilon)}$

5) To determine whether there exists edges around the pixels that are classified as high level pixels, a direction dependent mask is used as shown in figure 2. If the dark portion of mask or window contains at least one high level pixel, then keep the original value of pixel intact else replace the value of pixel of $S_{i,A}^{(\epsilon)}$ by the corresponding pixel value of $S_{i,B}^{(\epsilon)}$.

6) Apply the directional smoothing to each detail sub band of $S_{i,A}^{(\epsilon)}$ at each level as shown in figure 1.

7) Reconstruct an image from the processed sub bands of $S_{i,A}^{(\epsilon)}$ by using inverse undecimated wavelet transformation.

8) Save the results of each iteration in an array such as F= [threshold, result].

9) Return to step 2 until loop completed.

- Select the threshold value that gives best result and use that threshold for classification of high level pixels and low level pixels.
- Run the entire Algorithm and get the best results for despeckling of SAR images.

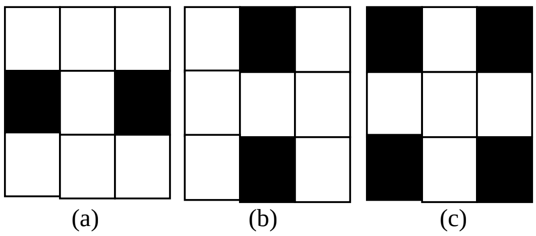


Fig. 2 Edge detection mask. (a) Mask for horizontal detail (b) Mask for vertical detail (c) Mask for diagonal detail

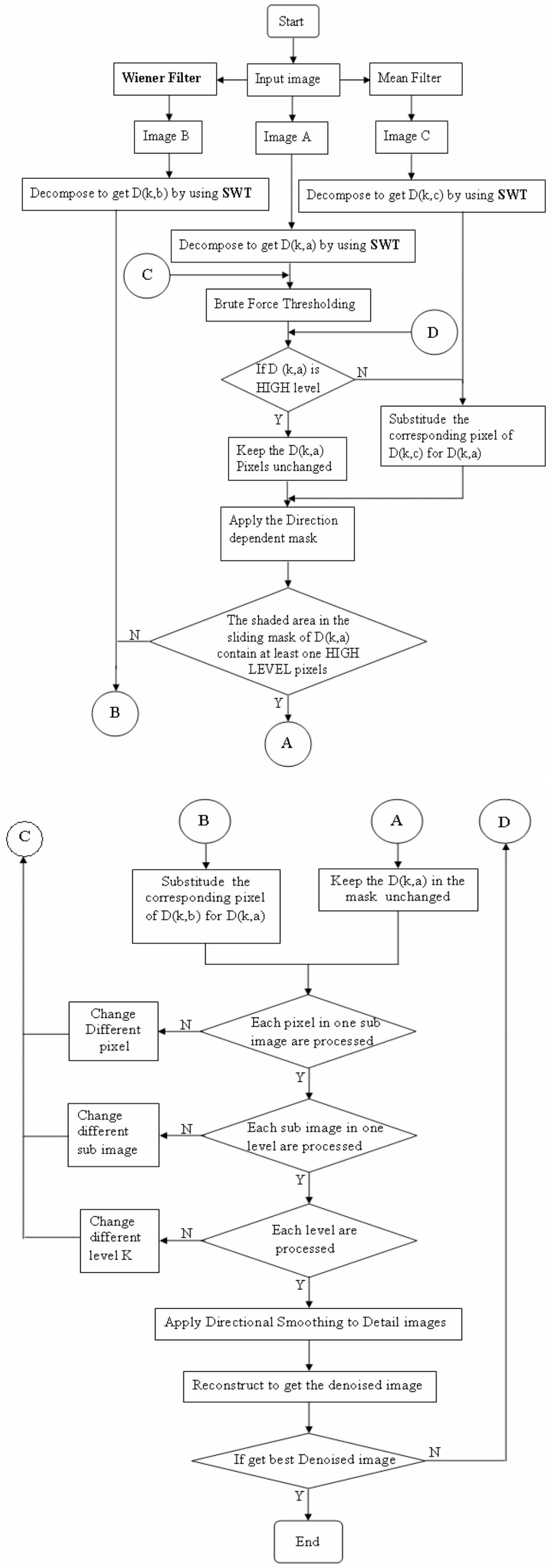


Fig. 3 Flow Chart of proposed Algorithm

IV. Assessment Parameters

Algorithm performance is evaluated with the help of following assessment parameters.

A. Mean Square Error (MSE)

MSE indicates average square difference of the pixels throughout the image between the original image (speckled) Is and Despeckled image Id. A lower MSE means that there is a significant filter performance. But small MSE values did not always correspond to good visual quality [7].

$$MSE = \frac{\sum (Is(r,c) - Id(r,c))^2}{R \times C} \quad (5)$$

where R*C is the size of image.

B. Peak Signal to Noise Ratio(PSNR)

The PSNR is most commonly used as a measure of quality of reconstruction in image compression and image denoising etc. The PSNR is given by

$$PSNR = \frac{10LOG(255)^2}{MSE} \quad (6)$$

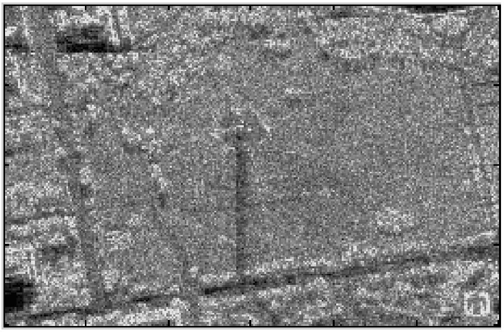
Greater the value of PSNR, better the speckle reduction of images.

V. Results and Discussion

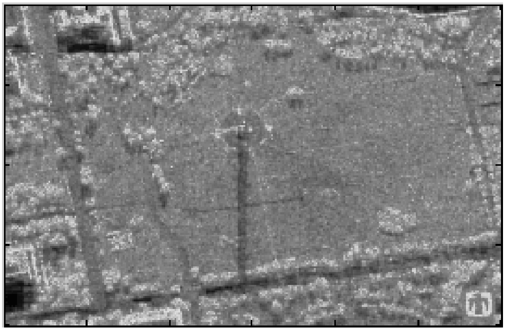
TABLE I
COMPARISON OF PROPOSED METHOD WITH OTHER COMMONLY USED TECHNIQUES

Technique	PSNR	MSE
Proposed Algorithm	**18.2079**	**1036.8**
Kuan Filter	17.7317	1096.2
Lee Filter	17.7267	1097.5
Homomorphic Kuan Filter	17.4639	1166.0
Homomorphic Lee Filter	17.4542	1168.6
Frost Filter	16.8922	1330
Homomorphic Frost Filter	16.7592	1371.4
Mean Filter	17.8248	1073
Homomorphic Mean Filter	17.4243	1176.6
Hard Threshold	18.0867	1096.3
Soft Threshold	18.0245	1079.6
Bayesian Threshold	17.0558	1280.8
Normal Threshold	17.0267	1289.5
Universal Threshold	17.0439	1284.4
Visu Threshold	17.0370	1286.4

Results are taken on image SAR image of size 400×600. Proposed algorithm is evaluated with two most commonly used assessment parameters. First is Peak signal to noise ratio and other is mean square error. Results shows that proposed algorithm shows better results than statistical filters and homomorphic based statistical filters. Same algorithm is executed with other commonly used thresholding techniques. But results proved that proposed algorithm that used brute force thresholding gives better results than other thresholding techniques. Only draw back of proposed algorithm is that it takes more time for computation .but with the advancement of technology, processing speed of processors increasing rapidly, so slightly slow execution time is no longer big issue.



(a)



(b)

Fig. 4 Visual Result (a) original speckled SAR image, (b) Despeckled SAR image by proposed Algorithm

VI. Conclusion

This paper proposed a new wavelet based method for despeckling of SAR images that uses combination of undecimated wavelet transformation, wiener filter and mean filter. Moreover instead of using existing thresholding techniques, it uses brute force thresholding that always outperforms the other existing techniques but only draw back is that it is slow.

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