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NOISE REDUCTION IN SAR IMAGES BY USING FUSION OF STATIONARY AND DISCRETE WAVELET TRANSFORMS

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Abstract—**A filtered base analysis will not provide an efficient design metric values, this is observed by karhunen-Loeve transform (KLT), by comparing the results with Lee and Homomorphic wavelet filters. For better de-noising in SAR images, we perform the combination of stationary wavelet transform and discrete wavelet transform (SWT+DWT) technique. By performing the above technique, the de-noising ratio is increased at the same time the image resolution is enhanced. All these filtration transform techniques were observed on multiplicative noise in synthetic aperture radar (SAR) images. The design metric values signal to noise ratio (SNR) and mean square error (MSE) were calculated and plotted in the result tabular form, by providing the theory with simulation results of filtering speckle noise images.**

***Index Terms*—SAR, speckle noise, KLT, Lee, Homomorphic, DWT, SWT.**

I. INTRODUCTION

THE synthetic aperture radar (SAR) imaging technique is popular for remote sensing and monitoring applications because of its usability under various weather conditions and its ability to provide high-resolution imagery. SAR image is generated by sending electromagnetic waves from a moving platform, spaceborne or airborne, toward the target surface and by coherently processing the returned backscattered signals from multiple distributed targets [1]. However, the coherent processing causes speckle effect [2] and gives SAR images its noisy appearance. Speckle presence appears as granular noise which reduces the image resolution [3] and may hamper the operation of image interpretation and analysis. Hence, noise filtering has become an essential part of SAR imagery systems. The objective of using a speckle reduction filter is to smooth homogeneous regions while preserving the useful textural in formation and structural features, such as edges. In subsequent paragraphs, we discuss the different types of adaptive filters that are used to reduce speckle noise in SAR images.

Principle of SAR

RADAR is an acronym for Radio Detection And Ranging. Radar works like a flash camera but at radio frequency. Typical radar system consists of transmitter, switch, antenna, receiver and data recorder. The transmitter generates a high power of electromagnetic wave at radio wavelengths. The switch directed the pulse to antenna and returned echo to receiver. The antenna transmitted the EM pulse towards the area to be imaged and collects returned echoes. The returned signal is converted to digital number by the receiver and the function of the data recorder is to store data values for later processing and display. Fig 1 shows the simply block diagram of a radar system.

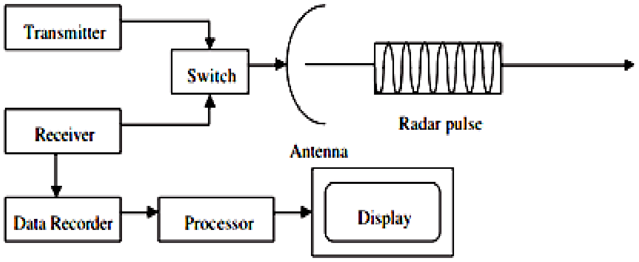

Fig. 1 Basic Block Diagram of Typical Radar System

The radar platform flies along the track direction at constant velocity. For real array imaging radar, its long antenna produces a fan beam illuminating the ground below. The along track resolution is determined by the beam width while the across resolution is determined by the pulse length. The larger the antenna, the finer the detail the radar can resolve. In SAR, forward motion of actual antenna is used to 'synthesize' a very long antenna. At each position a pulse is transmitted, the return echoes pass through the receiver and recorded in an 'echo store'. The Doppler frequency variation for each point on the ground is unique signature. SAR processing involves matching the Doppler frequency variations and demodulating by adjusting the frequency variation in the return echoes from each point on the ground. Result of this matched filter is a high-resolution image. Fig 2 shows the synthetic aperture length.

The Description of an Imaging Radar The geometry of an imaging radar is shown in Fig 2 The physical aperture of the radar with width Wa and length generates a RF beam whose

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angular across track 3dB beam width of antenna and angular along-track 3dB beam width of antenna is θV and θH respectively. θV is determined by the width and length of antenna, and wavelength of transmitted signal (λ). This relation is written as [2],

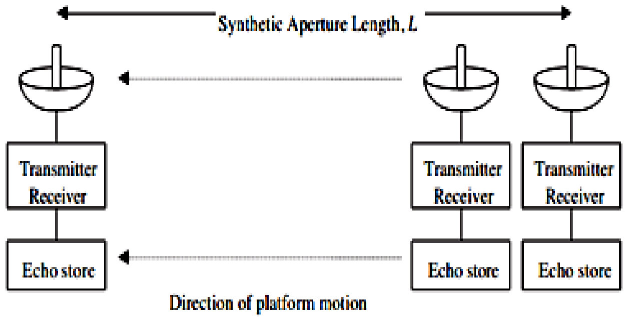

Fig. 2 Synthetic aperture

$$\theta V = \lambda / Wa \tag{1}$$

The antenna is mounted on a platform such as an aircraft that travels along a flight path with velocity v. It illuminates the shaded path (known as footprint) on the ground as the aircraft moves in the direction of flight path. The width of the ground path is simply given by

$$Wg = \lambda R \ Wa \cos \theta \tag{2}$$

Where θ is the incidence angle (look angle) of the beam, R is the slant range from the antenna to the midpoint of swath. The RF energy transmitted from antenna has a duration τp and is repeated at a given interval, pulse repetition interval (PRI) that can be inverted to obtain the pulse repetition frequency (PRF). The Resolution of a Real Aperture Radar Ground resolution is defined as the ability of the system to distinguish between two targets on the ground. Ground range resolution is shown in Fig. 2.4 as ρg. The range resolution of real aperture radar is given as [2],

$$\rho g = c \tau p \ 2 \sin \theta \tag{3}$$

Where τp is the pulse length and c is the speed of light. The range resolution is the function of pulse width and look angle but independent of height. Azimuth resolution is the minimum distance on the ground in the direction parallel to the flight path of the aircraft at which two targets can be separately imaged. Two targets located at same slant range can be resolved only if they are not in the radar beam at the same time.

Speckle noise [5] is the characteristic effect seen in ultrasound images that contribute to the visual noise. The image of a relatively uniform object with many scattering sources within a resolution cell will have pixel values that vary randomly with position due to constructive and destructive interference. Ultrasound images mostly get corrupted because of speckle noise. It is multiplicative noise, having granular pattern. Mathematically Speckle noise [6] is expressed as in eqn. (4)

$$g(m,n) = f(m,n) * u(m,n) + \eta (m,n) \tag{4}$$

Where g (m, n) is corrupted image, u (m, n) is multiplicative component and η (m, n) is additive component. For ultrasound images, it is necessary to remove additive noise but multiplicative can be allowed, given in eqn. (5)

$$g(m,n) = f(m,n) * u(m,n) + \eta(m,n) - \eta(m,n) \tag{5}$$

Also, speckle noise follows gamma distribution [7] which is shown below

$$F(g) = \frac{g^{\alpha-1}}{(\alpha-1)! a^{\alpha}} e^{\frac{-g}{a}} \tag{6}$$

Here a^{α} is variance and g is gray level. Gamma distribution is represented as in Fig.1.6 Speckle noise has following characteristics [7]:

1. Speckle noise is a multiplicative noise which is in direct proportion to the local gray level in any area.
2. The signal and the noise are statistically independent.
3. The sample mean and variance of a single pixel are equal to the mean and variance of local area.

II. DESIGN METHODOLOGY

Lee Filter

It is developed by Jong Sen Lee in 1981 [16]. It is better than above filters in edge preservation. It is based on multiplicative speckle model and uses local statistics to preserve details. Lee filter works on the variance basis, i.e. if variance of the area is low then it performs smoothing operation but not for high variance. That means it can preserve details in low as well as in high contrast hence it has adaptive nature. Mathematical model for Lee filter is given in eqn. (7):

$$Img\ (i,j) = Im + W^{*} (cp - Im) \tag{7}$$

Where, Img – pixel value after filtering
Im – mean intensity of filter window
Cp – Center pixel
W – Filter window, W = $\sigma^2 (\sigma^2 + \rho^2)$
σ^2 is the variance of the pixel calculated as

$$\sigma^2 = \left[\frac{1}{N} \sum_{i=0}^{n-1} (X_j)^2 \right]$$

N = size of filter window, X_j = pixel value at j.

ρ = additive noise variance, for M size of image and Y_j value of each pixel it is

Given as: $\rho^2 = \left[\frac{1}{M}\sum_{j=0}^{M-1}(Y_j)^2\right]$

For no smoothing filter output is the only mean intensity value (Im). Disadvantage of Lee Filter is it cannot effectively remove the speckle noise near edges.

HOMOMORPHIC WAVELET FILTER

If the image model is based on illumination-reflectance, then frequency domain procedures are not as easy to perform. To be able to improve appearance of an image by simultaneous brightness range compression and contrast enhancement it is necessary to separate the two components. An image can be modeled mathematically in terms of illumination and reflectance as follow:

$$f(x, y) = I(x, y)\, r(x, y) \tag{8}$$

KLT METHOD

Image-subspace-based approach for speckle noise removal from synthetic aperture radar (SAR) images is proposed. The underlying principle is to apply homomorphic framework in order to convert multiplicative speckle noise into additive and then to decompose the vector space of the noisy image into signal and noise subspaces. Enhancement is performed by nulling the noise subspace and estimating the clean image from the remaining signal subspace.

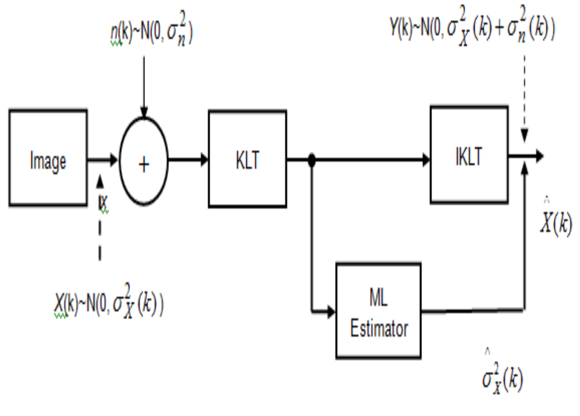

Fig.3 Block diagram of the de-noising algorithm.

The fundamental signal and noise model for subspace methods is additive noise uncorrelated with the signal. So a homomorphic framework takes advantage of logarithmic transformation in order to convert multiplicative noise into additive noise. However, this nonlinear operation totally changes the statistics of SAR images and induces bias in their mean values. For the purpose of radiometric preservation, the biased mean needs to be corrected, along with antilog operation.

SWT + DWT

Figure below shows the block diagram of proposed method. Here the proposed method is speckle noise reduction in SAR images by using stationary wavelet transform. The discrete stationary wavelet transform (SWT) is a un decimated version of DWT. The Stationary wavelet transform (SWT) is similar to the dwt except the signal is never sub sampled and instead the filters are up sampled at each level of decomposition.

In below figure, the SAR image is taken as input to the proposed block diagram of SWT. In SWT the input image is decomposed into three levels. After decomposition it gives the reconstructed image. In the reconstructed image the error rate is high, for decreasing the error rate; we implement the SWT+DWT technique.

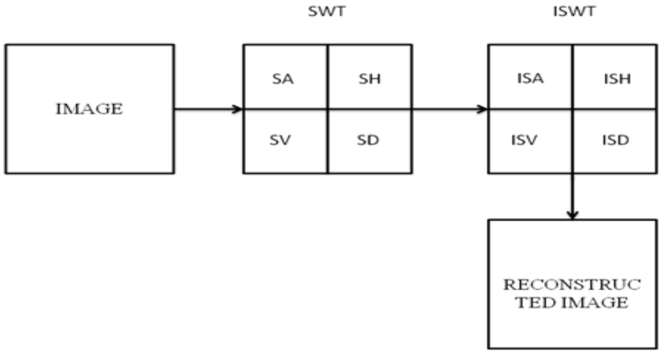

Fig.4 Block diagram of SWT

After applying the SWT technique, the input image is decomposed into four parts i.e axial, horizontal, vertical and diagonal. Again these four parts are decomposed into three levels, and finally it gives the reconstructed image. It has more error rate, for reducing the error rate we perform DWT on SA block of SWT. And then perform inverse DWT on SA. And finally it gives the reconstructed image with reduced error rate.The below figure shows the block diagram of SWT+DWT.

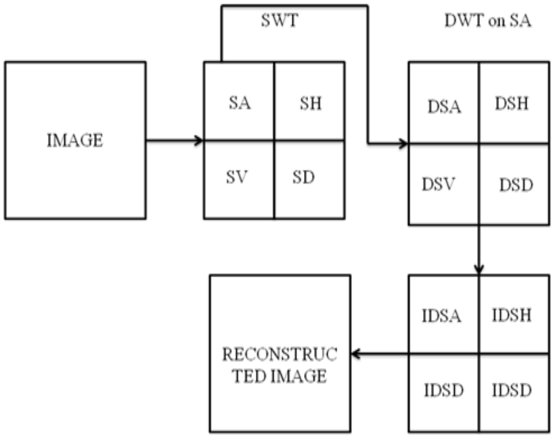

Fig. 5 Block diagram of SWT+DWT

Initially, the SAR image consists of speckle noise. In the existing method, the speckle noise is reduced, but there is no resolution in the output image. To improve the resolution in the image, we proposed the SWT+DWT technique. after applying the technique, the error rate is decreased, and PSNR is increased and finally the resolution is increased, and the image is enhanced.

III. ALGORITHM

Algorithm: Speckle noise reduction in SAR images.

Input: Original SAR image.

Output: Reconstructed original SAR image.

Steps:

- Start
- Input SAR image
- Decomposition using KLT
- Applying median filter
- Reconstruction of image using IKLT
- Stop

Implementation of Signal Subspace Approach for Uncorrelated Speckle Noise

- Apply the homomorphic transformation to the noisy image $Y_l = \log(G)$.
- Estimate the noise variance μ_n^2 .
- Compute the dimension of signal subspace *r*.
- Using the estimated r in step 3, apply eigendecomposition on R_{y_l} ; then, extract the basis vectors of signal subspace U_1 and their related eigenvalues $\Delta_x^\omega = \Delta_y^\omega - \mu_n^2$.
- Select μ according to the rule ; then,compute the optimum linear estimator
$$H_{SDC} = U_1 \Delta_{x1} \left((\Delta_{x1} + \mu \vartheta_n^2 I) \right)^{-1} U_1^T .$$
- Compute the clean image $X^\wedge_l = H_{SDC} Y_l$.
- Reverse the homomorphic effect by taking the exponential of $X^\wedge_l$ as follows: $X^\wedge = 10^{X^\wedge l}$.
- Apply bias adjustment.

IV. DESIGN FLOW

The design flow diagram for the reducing speckle noise in SAR image is shown in below Fig 6. The synthetic aperture radar image is taken as input to the KLT block diagram. In the second step the input image is decomposed by using KLT block diagram. After decomposition the decomposed image is applying to the median filter. Finally the original image is reconstructed by using inverse KLT block.

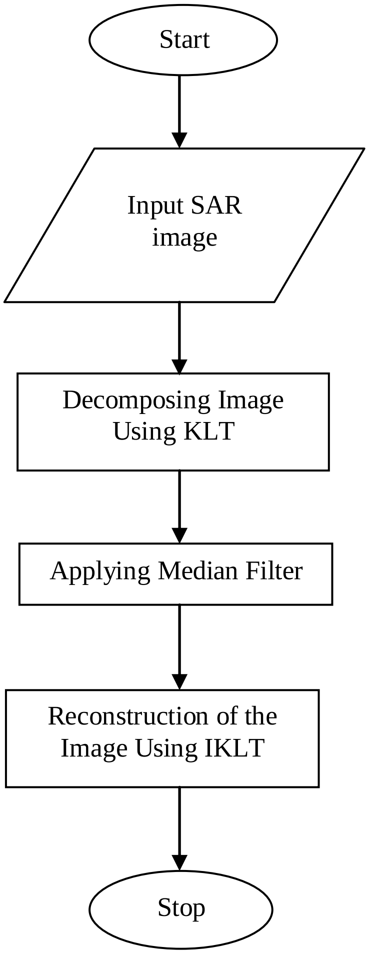

Fig.6 Design flow

V. RESULTS SUMMARY

Pentagon image

The result for a given image is illustrated in Fig 6

Input: It is a SAR image, nothing but synthetic aperture radar image .It is taken as input to the proposed KLT (Karhunen-Loève Transform) method .And the results of KLT is compared with Lee and Homomorphic wavelet filters.

Output: The synthetic aperture radar image is taken as input to the KLT block diagram. There is a inbuilt speckle noise in the image. Then KLT block diagram applying filtration schemes on the noised image. Then the KLT block calculate the SVD and Eigen values on the decomposed values of noised image. And finally the entire block gives the de-noised image at the certain threshold level.

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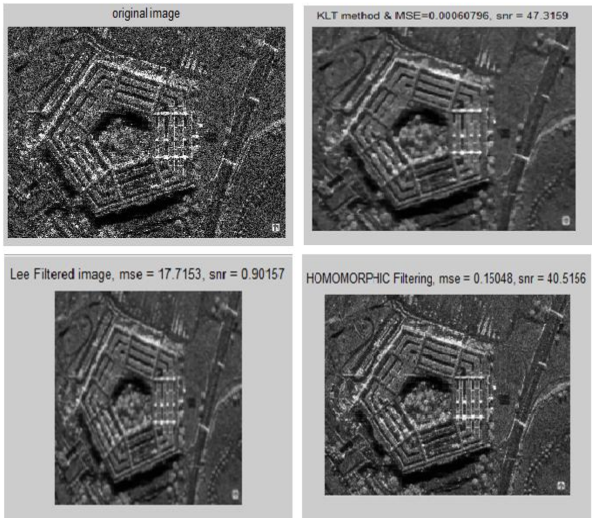

Fig. 7 Results of KLT, Lee and Homomorphic wavelet filters.

Observation: Initially, the input image consists of speckle noise, and then the several filtration schemes are applied on the noised image. After applying the filtration schemes, speckle noise is reduced in the original image. By observing the metric values in the De-noised image, the PSNR is improved and is of 47.3159 dB. And the results of KLT is compared with Lee and Homomorphic wavelet filters. By comparing Lee is of 0.90157 dB and Homomorphic is of 40.5156 dB. By observing these two methods KLT is better than of Lee and Homomorphic.

Pentagon image (SWT + DWT)

The results for proposed method is illustrated in Figure 6.

Input: The pentagon SAR image is taken as input to the proposed block diagram of SWT. In swt the input image is decomposed into three levels. After decomposition it gives the reconstructed image. In the reconstructed image the error rate is high, for decreasing the error rate, we implement the SWT+DWT technique.

Output: After applying the SWT technique, the input image is decomposed into four parts: axial, horizontal, vertical and diagonal. Again these four parts are decomposed into three levels, and finally it gives the reconstructed image. It has more error rate, for reducing the error rate we perform DWT on SA block of SWT. And then perform inverse DWT on SA. And finally it gives the reconstructed image with reduced error rate.

Observation: Initially, the SAR image consists of speckle noise. In the existing method , the speckle noise is reduced, but there is no resolution in the output image. To improve the resolution in the image, we proposed the SWT+DWT technique. By applying the SWT technique to the noisy image, the image is decomposed into three levels, and finally it gives the de-noised image. By observeing the metric values of SWT the PSNR is of 23.71 dB, and MSE is of 1.0895.

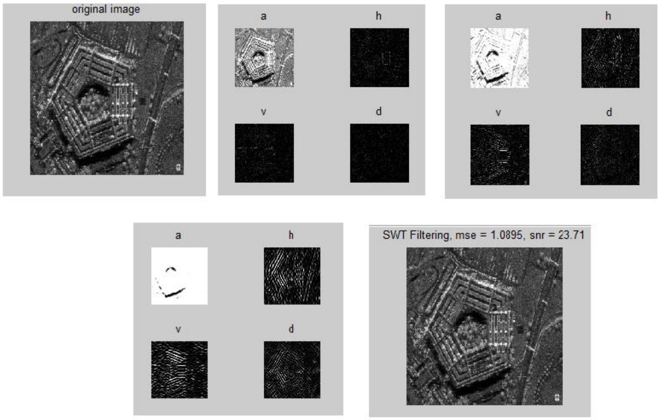

Fig. 8 Results of SWT method

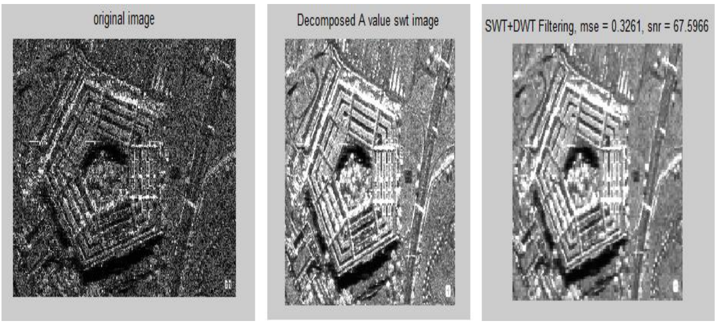

Fig. 9 Results of SWT+DWT.

Here the mse value is increased. for decreasing the error rate , apply the SWT+DWT technique to the noisy image . after applying the technique, the error rate is decreased and is of 0.3261, and PSNR is increased and is of 67.5966 dB. and finally we conclude that, the resolution is increased, and the image is enhanced when compared with previous methods.

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TABLE I
Comparison of metrics for set of images using different filters

S. No	Input Image	Metric	KLT	Lee Filter	Homomorphic Wavelet Filter	SWT	SWT + DWT
1	Pentagon	PSNR(db)	48.8481	0.5219	44.9565	23.3219	67.0673
		MSE	0.0005	15.037	0.0902	1.1914	0.3361
2	Libcong	PSNR(db)	47.3159	0.9015	40.5156	23.71	67.5966
		MSE	0.0006	17.715	0.1505	1.0895	0.3261
3	Chinalake	PSNR(db)	50.285	1.84	45.5779	23.0114	66.9537
		MSE	0.0004	12.920	0.0840	1.2797	0.3384

VI. CONCLUSION

In this paper, a multi resolution analysis-based de-noising technique for SAR images has been presented and tested. The proposed technique (SWT+DWT) is to estimate the clean image from the corrupted one with speckle noise. The capability of the proposed (SWT+DWT) technique in efficiently representing SAR images with reduced-rank values has been discussed and verified. Next, the performance of the (SWT+DWT) has been tested with different SAR images and compared with Lee and wavelet. The results indicate less noise variance reduction capability by (SWT+DWT) than Lee and wavelet but with less blur, less artifacts, and better preservation of the radiometric edges of the targets. And finally the image resolution is enhanced, and the metric values are improved.

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