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Impact of Dual Tree Complex Wavelet Transform in Synthetic Aperture Radar

Swami Vijayashanthi[1], P.Subbulakshmi[2], M.PonLakshmi[3], N.Sadhana[4]
U.G.Scholars, Department of ECE, Francis Xavier Engineering College, Tirunelveli [1,2,3,4]

Abstract: Synthetic Aperture Radar (SAR) is a coherent technology, recording both the amplitude and phase of the backscattered radiation. SAR images are inherently affected by a signal dependent and multiplicative noise, known as speckle. Speckle degrades the visual appearance of the image and severely diminishing the effectiveness of the automated scene analysis. The Dual Tree Complex Wavelet Transform (DTCWT) is a form of discrete wavelet transform which generates the complex coefficients by using two trees of wavelet filters in parallel. The DTCWT has improved directional selectivity, approximate shift invariance and perfect reconstruction over traditional discrete wavelet transform. In this project, the speckle noise is removed from the Synthetic Aperture Radar images using Dual Tree Complex Wavelet Transform and Maximum A Posteriori (MAP) Shrinkage rule, by exploiting the inter and intra scale dependencies across the wavelet coefficients. A comparative study is made on the performance of the Lee filter, Gamma MAP (GMAP) filter, Spatially Adaptive wavelet based method exploiting intrascale dependency and Bivariate Cauchy Maximum Aposteriori (BCMAP) exploiting the interscale dependency. Experimental results shows that the proposed method is superior to the conventional methods in terms of PSNR, MSE and ENL.

Keywords: Synthetic Aperture Radar, DTCWT, Gamma MAP, Bivariate Cauchy Maximum Aposteriori

I. Introduction

SARs produce a two-dimensional (2-D) image. One dimension in the image is called range (or cross track) and is a measure of the "line-of-sight" distance from the radar to the target. Range measurement and resolution are achieved in synthetic aperture radar in the same manner as most other radars: Range is determined by precisely measuring the time from transmission of a pulse to receiving the echo from a target and, in the simplest SAR, range resolution is determined by the transmitted pulse width, i.e. narrow pulses yield fine range resolution.

The other dimension is called azimuth (or along track) and is perpendicular to range. It is the ability of SAR to produce relatively fine azimuth resolution that differentiates it from other radars. To obtain fine azimuth resolution, a physically large antenna is needed to focus the transmitted and received energy into a sharp beam. The sharpness of the beam defines the azimuth resolution. Similarly, optical systems, such as telescopes, require large apertures (mirrors or lenses which are analogous to the radar antenna) to obtain fine imaging resolution. Since SARs are much lower in frequency than optical systems, even moderate SAR resolutions require an antenna physically larger than can be practically carried by an airborne platform: antenna lengths several hundred meters long are often required. However, airborne radar could collect data while flying this distance and then process the data as if it came from a physically long antenna. The distance the aircraft flies in synthesizing the antenna is known as the synthetic aperture.

A narrow synthetic beam width results from the relatively long synthetic aperture, which yields finer resolution than is possible from a smaller physical antenna. Achieving fine azimuth resolution may also be described from a doppler processing viewpoint. A target's position along the flight path determines the doppler frequency of its echoes: Targets ahead of the aircraft produce a positive doppler offset; targets behind the aircraft produce a negative offset. As the aircraft flies a distance (the synthetic aperture), echoes are resolved into a number of doppler frequencies. The target's doppler frequency determines its azimuth position. Transmitting short pulses to provide range resolution is generally not practical. Typically, longer pulses with wide-bandwidth modulation are transmitted which complicates the range processing but decreases the peak power requirements on the transmitter. For even moderate azimuth resolutions, a target's range to each location on the

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synthetic aperture changes along the synthetic aperture. The energy reflected from the target must be "mathematically focused" to compensate for the range dependence across the aperture prior to image formation. Additionally, for fine-resolution systems, the range and azimuth processing is coupled (dependent on each other) which also greatly increases the computational processing. The Speckle reducing anisotropic diffusion [1] for the speckled image is the edge sensitive diffusion method. A Partial Differential Equation(PDE) approach is used for the speckle removal which allows the generation of an image scale space without bias due to filter window size and shape. The SRAD encourages smoothening within the region in preference to the smoothening across the edges. This is achieved by setting the conduction coefficient as 1 within the region and as 0 near edges, however the main problem involved in this is the detection of the presence and absence of edges. So the conduction coefficient if chosen locally as a function of magnitude of the gradient of the brightness function of the image the edges can be determined. This allows smoothening of homogenous regions and prohibits smoothening near edges by preserving the edges.

Adaptive wavelet thresholding is a novel speckle reduction method [2] based on soft thresholding the wavelet coefficients of the logarithmically transformed speckled image. A method named Bayes-shrink is introduced for performing soft thresholding with data driven subband dependent threshold. The goal of this method is to find the soft threshold that minimizes the Bayesian risk, with squared error. Then inverse discrete wavelet transformation is performed to reconstruct the denoised image. And then exponential transformation is applied to reverse the logarithmic effect. The Spatially adaptive wavelet method [3] employs a Bayesian minimum mean absolute error (MMAE) estimator for despeckling the SAR images. The MMAE and MAP estimators are developed by employing a Cauchy PDF as a prior for modeling the coefficients of the log-transformed reflectance. The discrete wavelet transform is used to decompose the image into subbands. In this method, the intra-scale dependency of the wavelet coefficients with the Bayesian shrinkage processis exploited. The shrinkage value of a wavelet coefficient is modified using weights obtained from a closed-form expression that requires the inversion of a small-sized matrix. The inverse DWT is employed to reconstruct the denoised image.

The modified Gabor wavelet [4] uses a bank of wideband 2-D directive filters, based on modified Gabor functions. These two dimensional (2-D) filter have the ability to split the spectrum of the RF image in different frequency directions. When a whole set of filters is used, covering the spectrum in all directions, the input RF image can be split in different B-mode images, each one with the original structure information in a specific orientation. When these partial outputs are compounded, it results in an image in which the structure information is enhanced and speckle is drastically reduced. Selection of number of filters also play an important role in directive filter because with an increasing number of filters, the overlapping area among them also increases, resulting in redundant information that has small contribution in the quality of the final image.

II. PROPOSED METHOD

A. *Speckle Noise Model*

Speckle noise is a granular noise that inherently exists in images and degrades the quality of active radar, Synthetic Aperture Radar(SAR) images. It is a signal dependent and multiplicative noise. These noise models are mathematically more complicated to design.

The generalized model of the speckle noise is

$$g(x,y)=(f(x,y)*\eta_m(x,y))+\eta_a(x,y) \quad (1)$$

where

$g(x,y)$ - observed speckle image
$f(x,y)$ - original image
$\eta_m(x,y)$ - multiplicative speckle noise component
$\eta_a(x,y)$ - additive noise component

B. *Lee Filter*

The Lee filter [19] uses a least-square approach to estimate the true signal strength of the center cell in the filter window from the measured value in that cell. Lee filtering is a standard deviation based (sigma) filter that filters data based on statistics calculated within individual filter windows. The filter utilizes the statistical distribution of the DN_{in} values within the moving kernel to estimate the value of the pixel of interest. The Lee filter is based on the assumption that the mean and variance of the pixel of interest is equal to the local mean and variance of all pixels within the user-selected moving kernel.The calculated value is called as Digital Number (DN_{out}) and it is given as

$$DN_{out} = [\text{ Mean }] + K [\, DN_{in} - \text{Mean}] \quad (2)$$

where, Mean –Average value of intensity in a moving window.

$$K = \frac{var(X)}{[Mean]^2\sigma^2+var(X)} \quad (3)$$

σ- standard deviation of intensity within the window
var(x)-image variation coefficient.

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C. Gamma MAP Filter

The Maximum A Posteriori (MAP) filter[13] is based on a multiplicative noise model with nonstationary mean and variance parameters. This filter assumes that the original DN value lies between the DN of the pixel of interest and the average DN of the moving kernel. Moreover, many speckle reduction filters assume a Gaussian distribution for the speckle noise. Gamma MAP filter suppresses speckle in SAR images of forested areas, agricultural lands, and oceans by modelling them using a gamma probability density function. Natural vegetated areas have been shown to be more properly modelled as having a Gamma distributed cross section. It combines both geometrical and statistical properties of the local area. The filtering is controlled by both the variation coefficient and the geometrical ratio operators.

III. RESULTS AND DISCUSSION

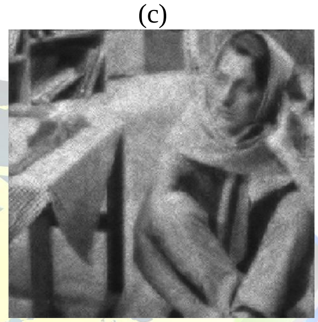
The performance of the proposed work based on using Dual Tree Complex Wavelet Transform by considering interscale and intrascale dependencies(for three level decomposition) is compared with Lee filter, gamma MAP filter, Spatially Adaptive Wavelet Based MAP(SAMAP) estimation and Bivariate Cauchy Maximum A Posteriori(BCMAP) estimation and the proposed work achieves superior results with performance evaluation factors.A synthetically speckled image is generated by multiplying a noise-free image with speckle noise. The experimental results for standard barbara with noise variance 0.04 is shown below.


(a)


(b)


(c)


(d)


(e)


(f)

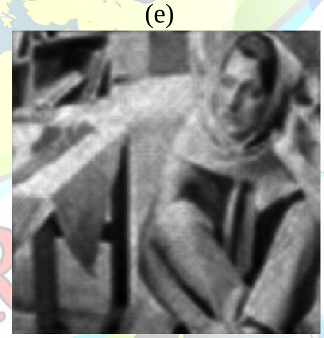
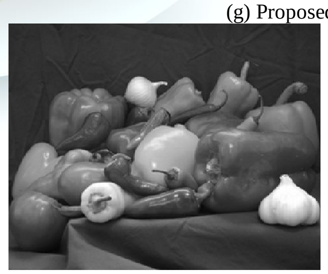
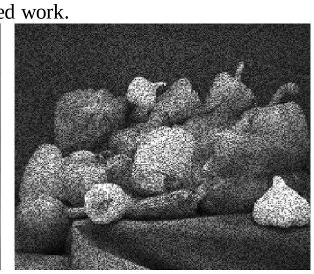
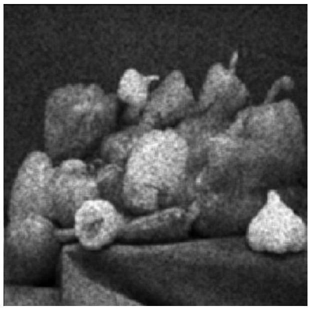

(g)

Fig.1. Results obtained with different filters applied on barbara image having noise variance-0.04. (a) Original SAR image (b) Noisy Image (c) Lee filter (d) Gamma MAP filter (e) SAMAP filter (f) BCMAP filter (g) Proposed work.


(a)


(b)


(c)


(d)


(e)


(f)

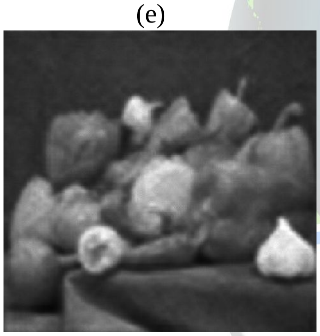
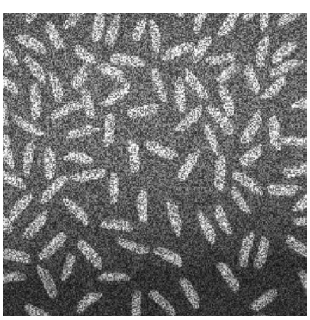
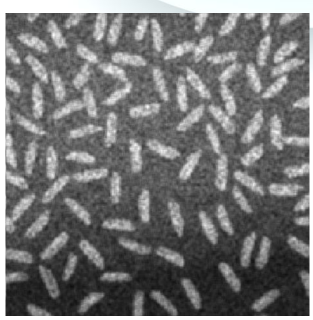
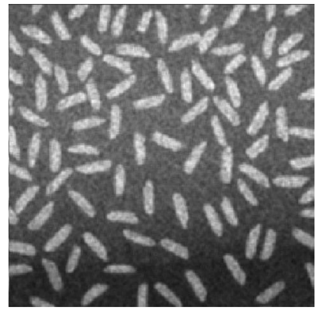
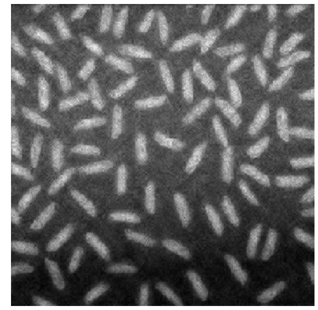

(g)

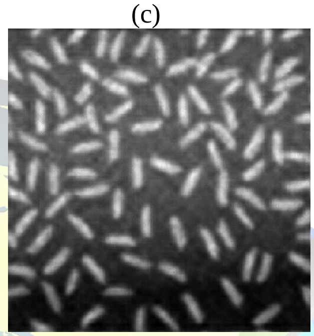
Fig.2. Results obtained with different filters applied on peppers image having noise variance-0.04. (a) Original SAR image (b) Noisy Image (c) Lee filter (d) Gamma MAP filter (e) SAMAP filter (f) BCMAP filter (g) Proposed work.


(a)


(b)


(c)


(d)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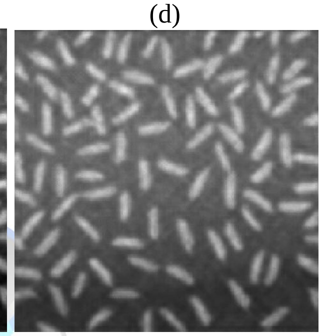
(f)

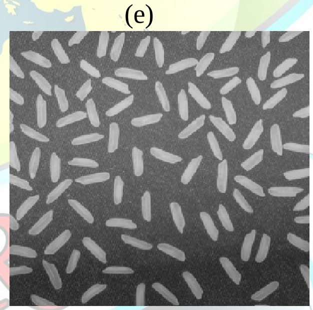
(g)

Fig.3. Results obtained with different filters applied on rice image having noise variance-0.04. (a) Original SAR image (b) Noisy Image (c) Lee filter (d) Gamma MAP filter (e) SAMAP filter (f) BCMAP filter (g) Proposed work.

TABLE I

PSNR AND MSE VALUES OBTAINED WITH SPECKLE FILTERS APPLIED TO THE STANDARD BARBARA IMAGE

FILTER	PSNR (dB)			MSE		
	var=0.04	Var=0.08	var=0.12	var=0.04	Var=0.08	var=0.12
Lee filter	20.34	19. 72	18.45	417.21	777.85	902.12
MAP filter	21.43	20.21	18.98	359.98	507.76	789.19
SAMAP filter	22.92	21.51	19.51	233.07	439.28	668.16
BCMAP filter	24.56	23.11	21.54	198.90	389.56	532.64
Proposed work	26.01	24.96	22.2	154.94	274.84	396.21

IV. CONCLUSION

Synthetic Aperture Radar (SAR) is a coherent technology, recording both the amplitude and phase of the backscattered radiation. SAR images are inherently affected by a signal dependent and multiplicative noise, known as speckle. Speckle degrades the visual appearance of the image and severely diminishing the effectiveness of the automated scene analysis. The Dual Tree Complex Wavelet Transform (DTCWT) is a form of discrete wavelet transform which generates the complex coefficients by using two trees of wavelet filters in parallel. The DTCWT has improved directional selectivity, approximate shift invariance and perfect reconstruction over traditional discrete wavelet transform. In this project, the speckle noise is removed from the Synthetic Aperture Radar images using Dual Tree Complex Wavelet Transform and Maximum A Posteriori (MAP) Shrinkage rule, by exploiting the inter and intra scale dependencies across the wavelet coefficients. A comparative study is made on the performance of the Lee filter, Gamma MAP (GMAP) filter, Spatially Adaptive wavelet based method exploiting intrascale dependency and Bivariate Cauchy Maximum Aposteriori (BCMAP) exploiting the interscale dependency. Experimental results show that the proposed method is superior to the conventional methods in terms of PSNR, MSE and ENL.

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