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Despeckling of SAR images by directional representation and directional restoration

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ABSTRACT

Despeckling algorithm for synthetic aperture radar (SAR) imagery, which uses directional representation and directional bases effectively to achieve comprehensive results. The directional representation directly relies on the multiplicative noise model and directional bases are used in coherent system model for restoration purpose. The proposed method is evaluated using qualitative analysis on real SAR data and quantitative analysis on simulated data. The results of the evaluation show that the proposed despeckling method outperforms the other despeckling algorithms.

1. Introduction

Synthetic aperture radar images are the high resolution images taken in all day all weather condition. The interpretations of SAR images are becoming difficult because of its characteristics. These difficulties are due to the presence of speckle in the active sensing mechanism which poses strong hindrances to all post-processing tasks. Speckle is mainly present in active imagery systems such as synthetic aperture radar (SAR) imagery, acoustic imagery, and laser imagery. The speckle generated in such imagery systems due to the fluctuations (Microscopic) leads to random interference over the object surface with resolution element [1]. Speckle is signal dependent and it is spatially correlated. For a fully developed speckle the SNR (Signal to Noise Ratio) is one, and the correlation of speckle noise depends on the coherent point spread function of the imaging system and the original image intensity [2]. Speckle basically formed based on two conditions. Condition 1: convolution of two parameters mainly Object conjunction and Point spread function. This usually leads to the superposition of the image and we call it as speckle interference. Condition 2: based on the random phase variations or interferences by different phasors. Usually the condition 2 is not considered as a major problem because the polarimetric SAR imagery technique solves it to a good extent. Based on the condition 1 the noise model is generated which will be discussed in the next section.

One of the significant properties of a fully developed speckle is that mean of a speckle image is equal to the mean of incoherent image of original object. Significance of this particular property holds the base for frame averaging techniques, in which the multiple frames of uncorrelated speckle images of the same object are generated and averaged on an intensity basis [2]. The speckle noise is modelled as a multiplicative one and it is a mere approximation only; Sometimes it ignores the correlation of speckle. Hence the consideration during the modelling is based on both multiplicative and coherent property. The proposed model includes the statistical properties of the speckle which are needed in our restoration process. The major filtering techniques are based on the stationarity of the signal and noise. Imaging using radar signal is not a stationary one since the mean of backscatter changes are sensed. It is necessary to make the filter adaptive based on the local properties of the back scatter. The modelling of filter adapts proper distribution function using local observed mean and standard deviation. The despeckling techniques based on wavelet give promising results which usually follows the homomorphic filtering. The homomorphic filtering which converts a non-addictive noise into an addictive one by applying any inverse nonlinear operator.

There are some basic despeckling techniques which use adaptive filtering techniques by changing the window size to get good results. Some of them are Kuan filter [2], Lee filter[3], Improved Lee filter[4] and Frost filter[5]. The adaptiveness of these filters lead to preserve the edge information generally the gradient one but it will not preserve the details much. If the target is linear then the despeckling will result in blurred image, which in turn becomes tedious to detect. There are some homomorphic based despeckling techniques where the wavelets are used. The wavelets are having the property of time-frequency localization, which leads to good outcome in the homomorphic filtering. The preclude fact of these techniques are having higher time complexity compared to other

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techniques. Some of the non-homomorphic filtering techniques are used for despeckling where they have used stationary wavelet transform [6]. The main problem in deploying such methods are finding the PDF for the wavelet coefficients becomes a tedious one. There are some methods which are based on anisotropic diffusion for despeckling, such anisotropic based methods smooth noise at homogeneous areas but at the structural point its impacts are not gradable [7]. Further some methods which are based on the likelihood of pixels and likelihood of regions in which texture regions are considered [7].

Radar images are having low signal to noise ratio hence inverse filtering does not provide an acceptable output image. Therefore in this proposed system we are imposing a new restoration method which can produce directional bases called as vaguelettes. The drawbacks of wavelet dependent decomposition of images are overcome in this proposed system by using Non-subsampled Contourlet transform (NSCT). The directional representation is obtained with the help of NSCT. The correlation between the proposed system and SAR image properties are discussed in the later. The proposed system efficiency in despeckling is been verified by using real SAR data against other methods.

2. Noise modelling

The speckle can be modelled in two major aspects.

- Multiplicative model (intensity and amplitude)
- Coherent system model

Major despeckling methods are based on the multiplicative model and some other despeckling methods have taken the challenge of second aspect of coherent system model.

2.1. Assumption for multiplicative model

Statistically the noise and the original data captured are independent variables. Hence the multiplicative model is developed as follows. The general formation of noise in SAR images are shown in Eq. (1)

$$Oi = Ai \cdot Si + Ni \tag{1}$$

where Oi is the observed signal at pixel i, Ai is the actual signal in pixel i and Si is the multiplicative speckle at the pixel i, and Ni is the addictive noise usually it is a negligible one. Hence the Eq. (1) can be written as

$$Oi = Ai \cdot Si \tag{2}$$

These multiplicative noises hold different statistics use the properties of linearity and convolution. Distributions hold the property of linearity and convolution as follows

1. Gaussian (normal) distributions
2. Inverse Gaussian distributions
3. Gamma distributions
4. Fisher–Tippet distributions

The Gaussian distribution is having the PDF (probability density function) as shown in Eq. (3)

$$PDF = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-1}{2}} \left(\frac{x-\mu}{\sigma}\right) \tag{3}$$

where the expectation $E(X1) = \mu$ and $var(X1) = \sigma^2$ has to be determined. μ refers to the apriori mean which is lacking hence by using an adaptive method to reproduce the lacking value and is given by $E(X) - E(\overline{X})$. Where $E(X)$ is the global mean and $E(\overline{X})$ is the local mean. Variance is given by Eq. (4)

$$var(X1) = \frac{var(X) - E(X)\sigma_1^2}{1 + \sigma_1^2} \tag{4}$$

where σ_1 is the local variance (window) and var(X) is the global i.e. the observed original variance.

The inverse Gaussian distribution having the PDF is given by Eq. (5)

$$PDF = \frac{\lambda}{2\pi x^3}^{1/2} e^{-\lambda} \frac{(x-\mu)}{2\pi x^2} \tag{5}$$

where λ is the scaling factor which is undetermined in our case.

The Gamma distribution having the PDF is shown in Eq. (6). Usually gamma distributions is derived from the Gaussian (normal) distributions by assuming noise S_i which is having a unit mean and variance $\frac{1}{L}$ therefore the pdf is represented as Eq. (6)

$$PDF = \frac{L^L F^{L-1} e^{-LF}}{\Gamma(L)} \tag{6}$$

where Γ is a Gamma Function and $F \geq 0$.

In Eq. (6) when $L = 1$ the density function will become Fisher–Tippet density function [8].

Mean and variance for the same is calculated from Eqs. (7) and (8) respectively.

$$E(X1) = \varphi(L) - \ln(L) \tag{7}$$

$$Var(X1) = \varphi(1, L) \tag{8}$$

where $\varphi(.)$ is a digamma function and $\varphi(n, .)$ is called the Polydigamma function with degree n.

From the above analysis it is considered that speckle statistics i.e. the Speckle (Si) will have the density function of Gaussian (normal) distribution due to the following reasons. In inverse Gaussian distribution the parameter λ is undermined hence the noise will not follow the density function of inverse Gaussian distribution. The Gamma distribution is obtained by the assumptions of unit mean and predefined variance. The Fisher Tippet we have not considered since it is derived from the gamma distribution.

This multiplicative modelling of speckle and its statistical analysis has made from Eqs. (1)–(8). This multiplicative aspect of speckle and its corresponding homomorphic decomposition of the 2-D signal will be handled using the NSCT (Non Subsampled Contourlet Transform) and its discussions are made in Section 3.

2.2. Coherent system model

The scattering matrix for a polarimetric SAR imagery is given in Eq. (9)

$$S = \begin{pmatrix} S_{HH} & S_{HV} \\ S_{VV} & S_{VH} \end{pmatrix} \tag{9}$$

where H and V represents the horizontal and vertical scattering components.

$S_{HV} = S_{VH}$ due to the reciprocal back scattering hence the scattering matrix S is defined as Eq. (10)

$$S = \begin{pmatrix} S_{HH} \\ {S_{HV}}^{1/2} \\ S_{VV} \end{pmatrix} \tag{10}$$