Contourlet based Edge Enhancement and Detection in SAR Images

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***Abstract*—This paper presents a multiscale and multidirectional technique for edge detection in speckled synthetic aperture radar (SAR) images. In this work, a robust multi-scale algorithm is developed using a combination of contourlet coefficients. This method solves three problems of other edge detecting algorithms: speckle removal, limited directions and combining the detected edges at different scales. The contourlet transform is constructed as a combination of the Laplacian Pyramid and the Directional Filter Banks (DFB). The Laplacian pyramid iteratively decomposes a 2-D image into lowpass and highpass subbands, and the DFB are applied to the highpass sub-bands to further decompose the frequency spectrum. From the DFB based image decomposition, the scaled information is combined by scale multiplication. This captures smooth contours and edges at any orientation.**

Keywords—Edge Detection, Synthetic Aperture Radar (SAR); Speckle Lee Filters; Contourlet Transform (CT); Thresholding

I. INTRODUCTION

Remote sensing plays a key role in many domains devoted to observation of the Earth, such as oceanography, cartography or agriculture monitoring. Among the different acquisition systems, Synthetic Aperture Radar (SAR) imagery has broadly opened the field of applications in the past 20 years. Synthetic Aperture Radars (SARs) allow the observation during the day as well as night, independent from weather effects. These characteristics, gives a high-resolution capability, and it helps for the global observation of the Earth for environmental and security issues. The interpretation of the radar images is not consistent with a common visual perception. Different SAR images are shown in Fig. 1.

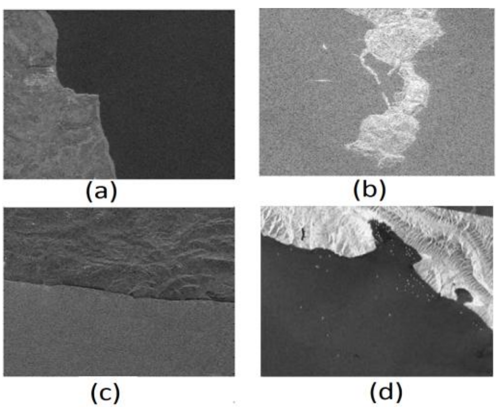

Fig. 1. Input Synthetic Aperture Radar (SAR) Images

Edges are the border or discrimination between two distinctly different regions. Edge enhancement enhances the local discontinuities at the boundaries of different objects in the image. Edge detection aims at segmenting the image by finding out the transitions between homogeneous regions than directly identifying them. They compute an edge map of the scene, in which the pixel intensity represents the presence of an edge at this position.

Robust edge detection techniques are based mainly on two steps: edge enhancement and detection. Since SAR images are highly heterogeneous than optical images, a robust edge detection method have to be proposed. This phase is performed through conventional edge detecting techniques such as Sobel filter [1], Prewitt filter [2], morphological gradients, etc. When apply these edge detectors in standard images, Prewitt and Sobel will give more accurate result than all other edge detectors. But in SAR images, these methods provide a limited efficiency due to the presence of multiplicative nature speckle. Thus SAR images are irregular and having a lot of discontinuities.

Another method for edge enhancement in SAR images based on the information provided by the wavelet coefficients [3]. This method includes edge enhancement and detection. Speckles are removed in the edge enhancement phase by applying logarithmic transformation on the input image. After that edges are enhanced and detected. In the past, several multiscale approachesbased on the information contained in the wavelet domain, have been proposed in [4] and [5]. A group of techniques is based on the evaluation of the ratio of averages over a sliding window [6] and [7]. These methods have low computational load, but they are highly dependent on the dimensions of the window and are not good in noisy data. For instance, the study in [8] proposes an edge detector based on a threshold operation of wavelet coefficients. This method also has a low computational cost and a good contrast but this will tackle at the same time the robustness and the precision issues of edge enhancement and detection.

The overall organization of the paper is described as follows. The general problem in detecting edges in SAR images is mentioned in Section II. Section III describes the proposed methodology for robust edge detection and in each subsection it has been explained in detail. Section IV demonstrates some simulation results. Finally, Section V will draw the conclusions of this paper and the future works have to be proposed.

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II. PROBLEM FORMULATION

Edge detection in SAR images is a difficult problem due to the presence of speckle in the image. Classical segmentation algorithms do not perform well on SAR images. So new robust methods, dedicated to speckled images have to be proposed. Many techniques including edge detection and region growing have been proposed. Speckle-dedicated edge detectors are important in SAR image segmentation because they are used in a large number of algorithms. The speckle corruption improves the development of new edge detectors.

Edge detection techniques are based on the two steps: edge enhancement and decision. The conventional edge detectors such as Sobel filter, Prewitt filter, morphological gradients, etc. provide a limited efficiency in SAR applications due to the presence of a speckle which is a multiplicative noise like pattern.

The problems with the speckle, wide dynamic range and the heterogeneous regions in the SAR image remain unsolved. The Logarithmic Transformation and Stationary Wavelet Transform solve the above mentioned problems. The speckle removal is done by Logarithmic Transformation step included in the edge enhancement process in the above method. But all the speckles are removed by this method and there are some limitations in the application of wavelet transform. Since wavelet is not multidirectional, some edge information remains unfound.

This paper aims at edge detection using contourlet transform. Directionality and anisotropy are the important characteristics of contourlet transform. Directionality indicates that having basis function in many directions, only three direction in wavelet. The anisotropy property means the basis functions appear at various aspect ratios whereas wavelets are separable functions and thus their aspect ratio is one. Due to this properties, Contourlet Transform can efficiently handle 2D singularities, edges in an image. The objective of this work is to design a novel method for edge detection in SAR images based on the exploitation of the information provided by the contourlet coefficients .

III. PROPOSED METHOD

The overview of the characteristics of SAR images and their processing through conventional methods are inefficient. Then, a multiscale algorithm for edge detection in SAR images based on Contourlet Transform(CT) is proposed. This method tries to solve three difficulties that edge finding algorithms must face: speckle removal, limited directions and combining the detected edges at different scales. Contourlet transform is new expansions of Wavelet transform that use directional filters in different scales. This captures smooth contours and edges at any orientation. The contourlet transform is constructed as a combination of the Laplacian pyramid and the directional filter banks (DFB) [9]. Contourlet Transform is the combination of two methods: Multiscale Decomposition and Directional Decomposition. Laplace Pyramid is used for multiscale decomposition and Directional Filter Bank (DFB) is used for directional decomposition.

The main steps involved in the method proposed in this work is pictorially represented using the block diagram shown in Fig. 2.

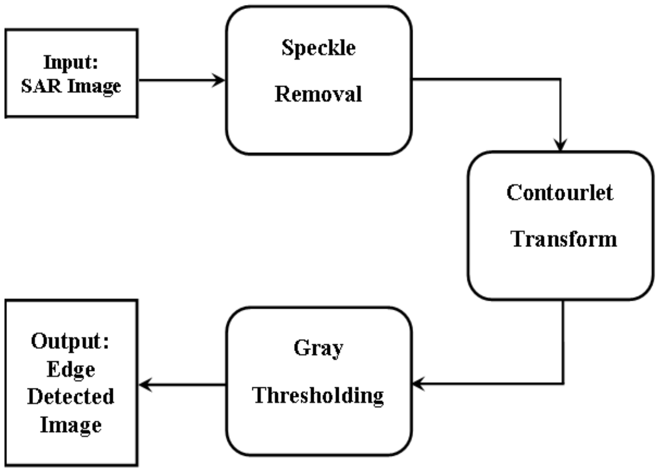

Fig. 2. Overview of Proposed System

In the proposed system, the speckle removal and edge detection in SAR images is presented. Here, the speckle removal is done by using Lee Filter and edge detection is based on the combination of contourlet coefficients. Proposed method has three main steps:

A. Speckle Removal

Speckles are the multiplicative noise which evenly spreads on the image. The main processing difficulty in SAR image is the presence of these noises. Speckle can be removed by the application of different filters and thus they named as speckle filters. Different Speckle Filters are Lee Filter, Median Filter, Kuan Filter, Frost Filter, Mean Filter etc. Apply Speckle filters to remove the multiplicative noise present in the preprocessed (gray scale converted) SAR image.

In this paper, we use the Lee Speckle Filters for clearing the noises present in the input image. This filtering technique is more better than Logarithmic Transformation. Lee filters are based on Minimum Mean Squared Error (MMSE) criterion. MMSE estimate is developed for additive noise models,

$$y = x + n$$

But multiplicative noise model is considered under the form,

$$y = x+(n-1)x$$

from which the corresponding linear filter is deduced.
The pixel value estimate is given by,

$$\hat{x} = \bar{y} + \frac{\sigma_x^2\,(y - \bar{y})}{\sigma_x^2 + y^2/L}$$

where,

$$\sigma_x^2 = \frac{L\sigma_y^2 - \bar{y}^2}{L+1}$$

B. Contourlet Transform

Wavelets are classified as a linear transform that is capable of displaying the transformed output at multiple resolutions depending on the point of time/space and at the desired frequency. In 2-D wavelet transform, there is limited

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directional information stored. Because of the separability limitations, only a horizontal, vertical, and 45 degree component can be easily determined. Incidentally, edges can be seen easily, but directional information about the edge is not known. Because of this, it takes more coefficients to do a proper reconstruction of the edges. Typically, a 2-D wavelet transform provides multiresolution capability.

There are many directional extensions of the 2-D wavelet transform that could be potentially examined that also possess directionality and anisotropy. The contourlet transform is a discrete extension of the curvelet transform that aims to capture curves instead of points, and provides for directionality and anisotropy. The illustration of contourlet transform (CT) is shown in Fig. 3.

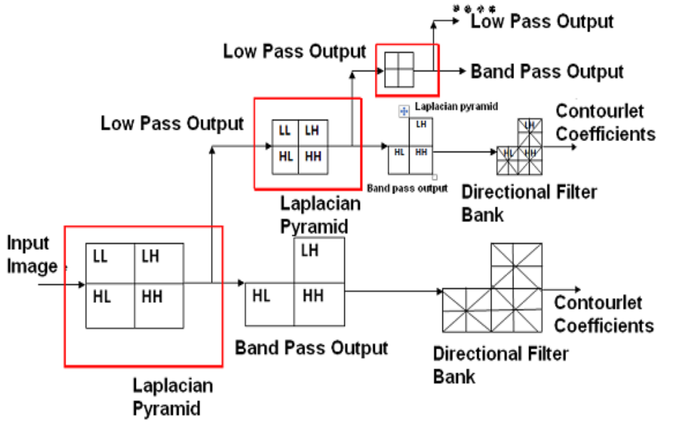

Fig. 3. Illustration of Contourlet Transform

The Contourlet Transform (CT) is a 2D directional multiscale image decomposition which has been introduced to overcome the DWT inefficiency in terms of directionality. It is constructed by combining two distinct and successive decomposition stages: a multiscale decomposition followed by a directional decomposition. First, a multiscale decomposition uses a Laplacian pyramid scheme to transform the image into one coarse version plus a set of Laplacian sub-images (LP). Second, a directional stage applies iteratively two dimensional filtering and critical down sampling to further partition each LP sub-band into different and flexible number of frequency wedge-shaped sub-bands, thus capturing geometric structures and directional information in real-world images.

1. Laplacian Pyramid

One way of achieving a multi-scale decomposition is to use a Laplacian pyramid (LP), introduced by Burt and Adelson [10].

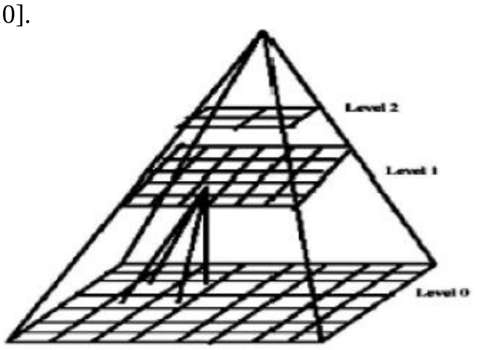

Fig. 4. Laplacian Pyramid Structure

The LP decomposition at each level generates a down sampled low pass version of the original and the difference between the original and the prediction, resulting in a band-pass image. Thus the Laplacian pyramid is a set of band pass filters. By repeating these steps several times, a sequence of images are obtained. If these images are stacked one above another, the result is a tapering pyramid data structure, as shown in Fig. 4. The Laplacian pyramid can thus be used to represent images as a series of band-pass filtered images, each sampled at successively sparser densities.

2. Directional Filter Bank (DFB)

The directional filter bank is a critically sampled filter bank that can decompose images into any power of 2's number of directions. The DFB is efficiently implemented via a *l*-level tree-structured decomposition that leads to *2l* subbands with wedge-shaped frequency partition. The original construction of the DFB involves modulating the input signal and using diamond shaped filters.

Furthermore, to obtain the desired frequency partition, an involved tree expanding rule has to be followed. As a result, the frequency regions for the resulting sub-bands do not follow a simple ordering. The DFB is designed to capture the high frequency components (representing directionality) of images. Therefore, low frequency components are handled poorly by the DFB. In fact, with the frequency partition shown in Fig. 5, low frequencies would leak into several directional subbands, hence DFB does not provide a sparse representation for images. The scheme can be iterated repeatedly on the image. The end result is a double iterated filter bank structure, named pyramidal directional filter bank (PDFB), which decomposes images into directional sub-bands at multiple scales. The scheme is flexible since it allows for a different number of directions at each scale.

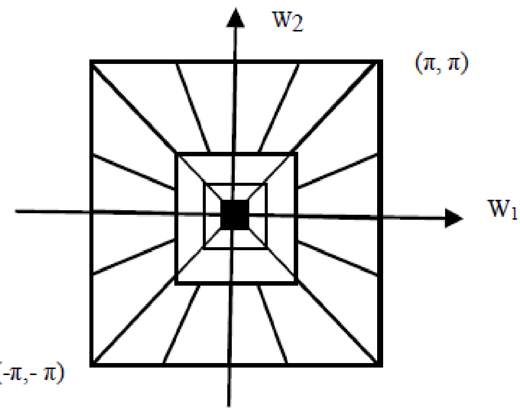

Fig. 5. Frequency Partitioning

C. Gray Thresholding

The gray threshold is the simplest and most widely used threshold method. It computes a global threshold that can be used to convert an intensity image to a binary image. This technique uses Otsu's method, which chooses the threshold value to minimize the intra class variance of the black and white pixels.

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The detailed description of the stages in the proposed method is given in the block diagram shown in Fig. 6.

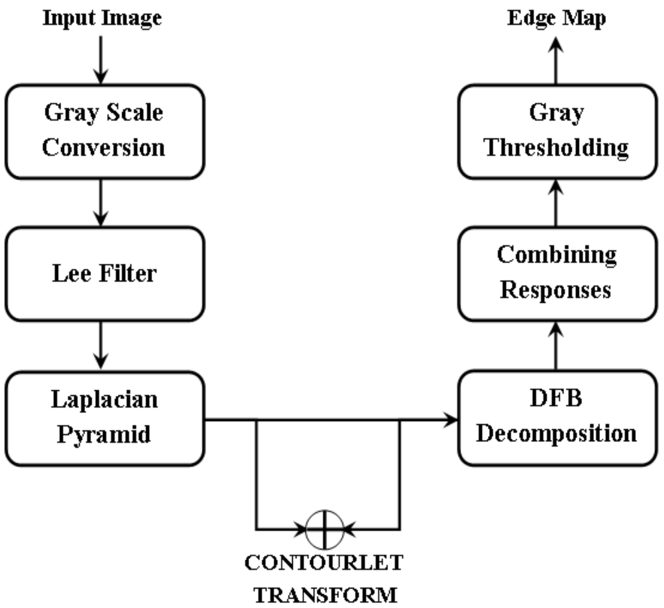


Fig. 6. Block Diagram of Proposed Method

First, the input SAR image is converted into gray scale image. After that apply Lee speckle filter to remove the multiplicative speckle noise present in the gray scaled image. These are the preprocessing steps. Then apply contourlet transform includes multiscale decomposition followed by directional decomposition. Multiscale decomposition is done by Laplacian Pyramid and it captures point discontinuities in the image. In multiscale decomposition, the preprocessed image is decomposed into a hierarchy of images and produces a low pass (LL) and a set of band pass (LH, HL, HH). Directional decomposition is done by Directional Filter Bank (DFB). It subsample each band pass components. Band pass components are fed into DFB and each component produces directional decomposed image.

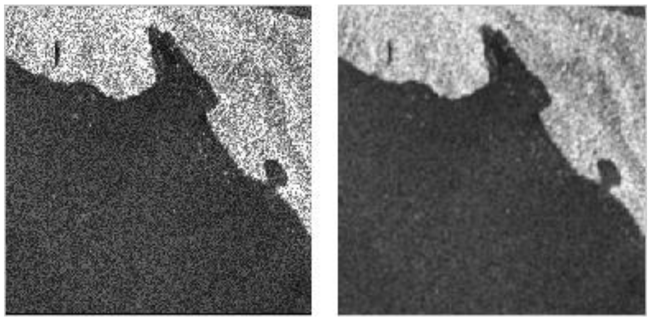
Then the decomposed images at various directions and scales are combined. Different scales contain noise removed broader edge information whereas some scales contain thin edges. The directional responses of both the scales are combined using scale multiplication. The purpose of combining two scales is to suppress noisy components and to enhance the edge information.

IV. RESULTS AND DISCUSSION

The following figures show the outputs of each step in the edge detection on simulated images based on contourlet transform.

A. *Speckle Filtering*

The input image is converted into grayscale image and speckle filters are used to reduce the speckle present in the SAR image. Fig. 7 shows the input SAR image and the speckle removed image by applying the Lee speckle filter. This reduces the multiplicative noise better than that of logarithmic transformation.



(a) (b)

Fig. 7. Speckle Removal in grayscale SAR image: (a) input SAR image, (b) Lee filtered SAR image

B. *Contourlet Decomposition*

Contourlet Transform is constructed by combining two distinct and successive decomposition stages: a multiscale decomposition followed by a directional decomposition. Calculates the decomposed images at various directions and scales. Different scales contain broader edge information and it is less prone to noise whereas some scales contain thin edges. The directional responses of both the scales are combined using scale multiplication to suppress noisy components and to enhance the edge information. Fig. 8 shows the three levels of contourlet decomposition of Lee filtered SAR image.

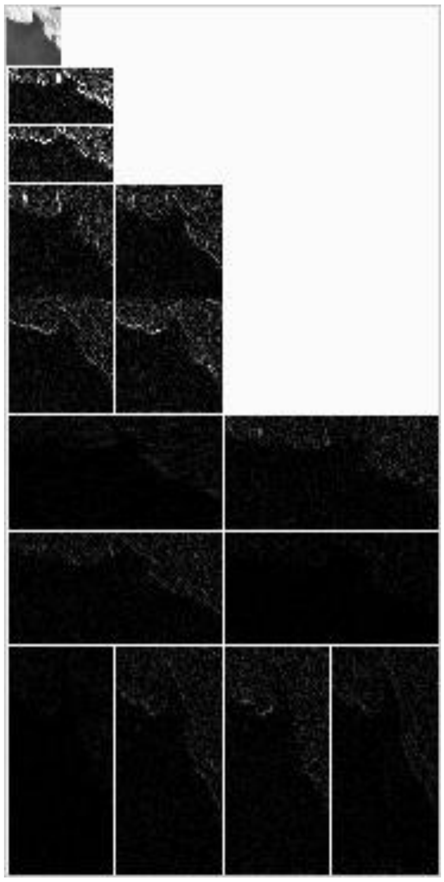


Fig. 8. Three Levels of Contourlet Transformed Image

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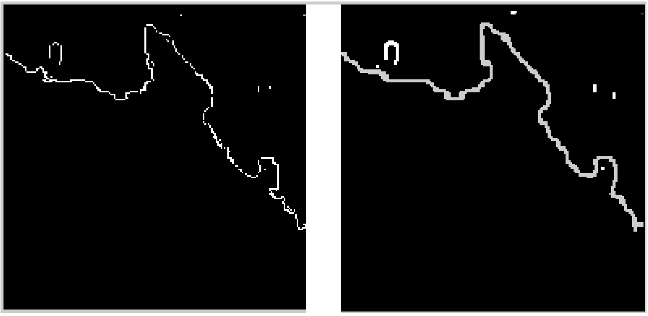
C. Gray Thresholding

Thresholding is applied to the combined DFB image and the result is the edge detected image. Fig. 9 shows the contoulet transformed image and edge detected Image using thresholding.



(a) (b)

Fig. 9. Edge Detection after Contourlet Transform and Gray Threshoulding: (a) Image formed by combining the responses of contourlet transform, (b) Edge detected image

V. CONCLUSIONS AND FUTURE WORKS

For edge detection in Synthetic Aperture Radar images, a multiscale multidirectional algorithm is introduced. It is designed specifically to deal with speckled SAR images. The method develops a robust edge detection algorithm based on the information provided by the contourlet coefficients. It is a multi-scale decomposition followed by directional decomposition. multiscale decomposition is done by Laplacian Pyramid and directional decomposition by Directional Filter Bank. This method helps the extraction of the coastline from SAR images by applying edge detection techniques. It solves the problems with speckle because it is used for denoising and also overcomes the limitations of wavelet transform. Moreover, this method could be effectively used for segmentation purposes in SAR data.

The future works include the speckle removal using better filtering algorithm other than the Lee Filer. Also the last step described in the proposed edge detection method i.e. Auto thresholding, can be replaced by Active Contour Methods.

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