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Segmentation of Dual-Frequency Polarimetric Sar Data For An Augment Area Cover Classification

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ABSTRACT
In this paper we have proposed Synthetic Aperture Radar (SAR) systems are effective tools for monitoring different land cover types. Radar systems are weather and sun illumination independent, two factors which usually inhibit the use of optical satellite imagery. This thesis investigates new segmentation methodologies for polarimetric SAR data. Two divisive segmentation methodologies are discussed, one for full polarimetric SAR data and a second one for dual polarized SAR data. The proposed methodologies for both cases, full and dual polarimetric SAR data, are nonparametric in terms of applying a nonparametric histogram thresholding algorithm. The proposed methodology for the full polarimetric case has the characteristic of preserving the information of the scattering mechanisms that the different land cover types represent.
A new agglomerative methodology is presented for full polarimetric SAR data segmentation. A new probabilistic distance is proposed for the agglomerative hierarchical merging of small clusters into an appropriate number of larger clusters. The proposed probabilistic distance measures the distance between two complex Wishart distributions, independently of the number of samples in each distribution.
Keywords: SAR Image, polarimetric, clustering

I. Introduction

Many studies have been presented for full polarimetric SAR segmentation using the divisive clustering scheme. Lombardo and Oliver (2002) and Pellizzeri et al. (2003) discussed a segmentation approach, called Polarimetric Segmentation Annealing or POLSEGANN, based on the maximum generalised likelihood approach and the Wishart distribution model. A joint logarithmic likelihood function for the whole image, assuming that it composites a predefined number of homogeneous regions, is derived and used as objective function in the simulated annealing maximization technique. The POLSEGANN was found to be appropriate for small region identification (Pellizzeri et al., 2003). A drawback of the discussed segmentation technique is that it requires the predefinition of the number of homogeneous regions in the image, which is not always a simple task. In addition, the previously mentioned studies assume the absence of texture (assume that areas are homogeneous), which is not always valid. Based on this assumption, the complex Wishart distribution is used. However, in the case where texture exists, the k-distribution is a better fit (Beaulieu and Touzi, 2004). In addition, it is not guaranteed that the resulting segments are homogeneous with regard to the scattering information. Thus, pixels of a single segment might exhibit different scattering mechanisms.

De Grandi et al. (2001) proposed a segmentation and labelling method of polarimetric SAR data based on a wavelet frame that works as a differential operator and generates piece-wise smooth approximations of the covariance matrix power term images. Segmentation of polarimetric SAR data into eight classes based on the entropy and alpha angle (H/α) plane was proposed in Cloude and Pottier (1997) and extended to sixteen classes by involving the anisotropy parameter (A) by Pottier and Lee (1999).

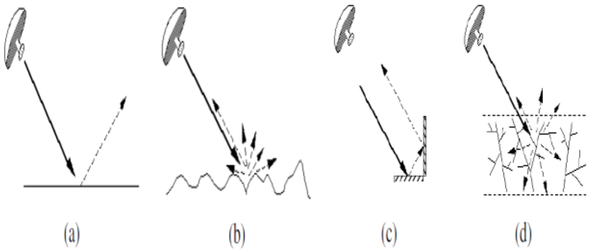
Herein, the two-dimensional space of H and α, which becomes three-dimensional by including the anisotropy A, is divided into eight and sixteen zones, respectively, based on arbitrary fixed zone boundaries. This sometimes leads to noisy segmentation results. In addition, the total backscattering power information is not considered in the segmentation process. An attempt to improve the segmentation results was presented in Lee et al. (1999) by applying the k-means complex Wishart classifier and Park and Moon (2007) by applying the fuzzy concept. It is important to mention that the previously discussed studies lack the concept of selective segmentation in the divisive clustering. Thus, segmentation of the polarimetric data is not performed hierarchically in a multilevel scheme where the user can choose the desired segmentation scale and has the choice of selecting segments of interest for further segmentation.

Segmentation approaches using divisive clustering were also applied on dual polarized data. Scheuchl et al. (2004) proposed an unsupervised segmentation algorithm for dual polarized data and tested its ability to distinguish sea ice types. The proposed algorithm uses the k-means Wishart classifier and a distance measure for pixel assignment.

Segmentation performance using the proposed algorithm was found to be limited in the separation of different sea ice types. Another study tested dual polarized SAR data of different ice types with a multivariate Gaussian maximum likelihood classifier and two neural network classifiers (Orlando et al., 1990). The Gaussian assumption was not always reasonable, especially for the case of icebergs. Neural networks classifiers were found to have a similar performance as the Gaussian classifier. Again, the user does not have the advantage of a multi-scaling approach which can be achieved by the multilevel segmentation of the data. Users can not select specific segments, which can be of interest for the case study, for further segmentation.

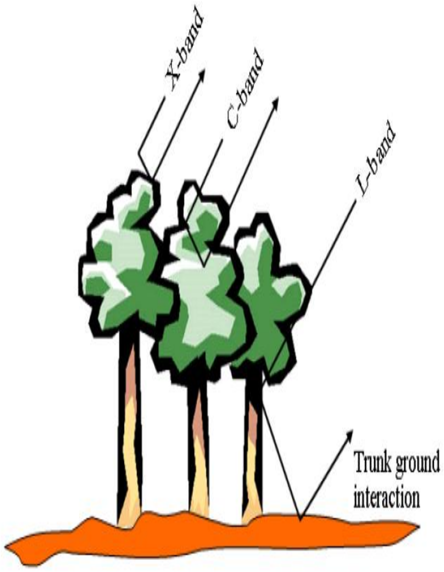
II. Polarimetric Scattering Mechanisms

In a radar image, each pixel represents an estimate of the radar backscattering from the corresponding area in the ground. Brighter areas in a radar image represent high backscattering due to the fact that larger fraction of the radar energy is reflected back to the radar while darker areas indicate that less energy is reflected. Backsc attering recorded on the image is a function of the surface roughness. In the scale of most remote sensing wavelengths, vegetation is treated as a rough surface and appears grey or light grey in a radar image. In urban areas, where the transmitted radar waves are able to bounce off the streets and then again bounce off the buildings (double bounce) and return back to the radar, they appear very bright in the radar image. Smooth surface, e.g., non wavy ocean, appears dark because of the reflection of the incident waves away from the radar. Four types of scattering mechanisms are discussed below, the smooth surface, rough surface, double bounce and volume scattering mechanisms; see Figure 2.1.



a) Scattering from smooth surface, b) Scattering from rough surface, c) Double bounce scattering, d) Volume scattering.

In general, the penetration capabilities and the attenuation depth of a radar signal in a medium, such as soil or forest canopy, increase with the increasing of the signal wavelength (Grandjean et al., 2001). Figure 2.2 presents the penetration of radar signals for different bands. As shown in Figure 2.2, a forest area exhibits volume scattering in the case of C-band signals due to the fact that signal penetration is limited, and thus the scattering process takes place in the forest canopy. In the case of L-band signals, the penetration capabilities are high. Herein, the scattering process is from trunk-ground interaction (double bounce). Very rough surfaces exhibit volume scattering in the case of short wavelength signals, X-band.



Radar signal penetration for different bands.

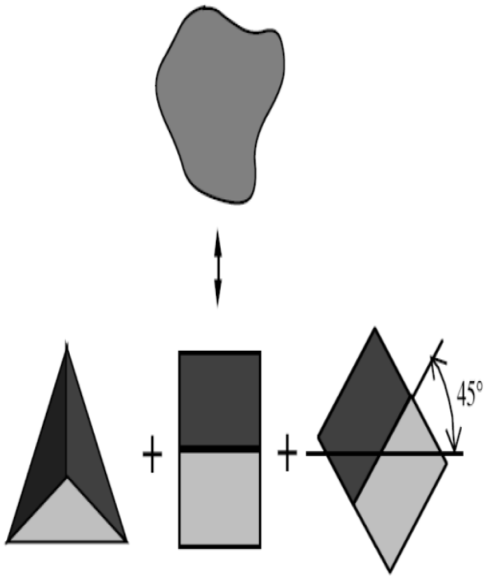
III. The Pauli Decomposition method

The Pauli decomposition method is one of the basic SAR polarimetric data analysis methods. It is a coherent decomposition method where the target scattering matrix is expressed in terms of the Pauli matrices (Cloude and Pottier, 1996). These matrices correspond to elementary scattering mechanisms that lead to a physical interpretation of the scattering process. This method interprets the surface, double bounce and 45o tilted double bounce scattering mechanisms, Table 2.2.

Pauli matrix	Scattering mechanism	Interpretation
$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$	surface	Surface, sphere, trihedral
$\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$	double bounce	dihedral
$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$	45^{o} tilted double bounce	45^{o} tilted dihedral

IV. Pauli matrices and their interpretation.

Thus, the backscattering from a general target can be seen as the sum of backscatter from a trihedral and two dihedrals with different tilt angles, Figure 2.3.



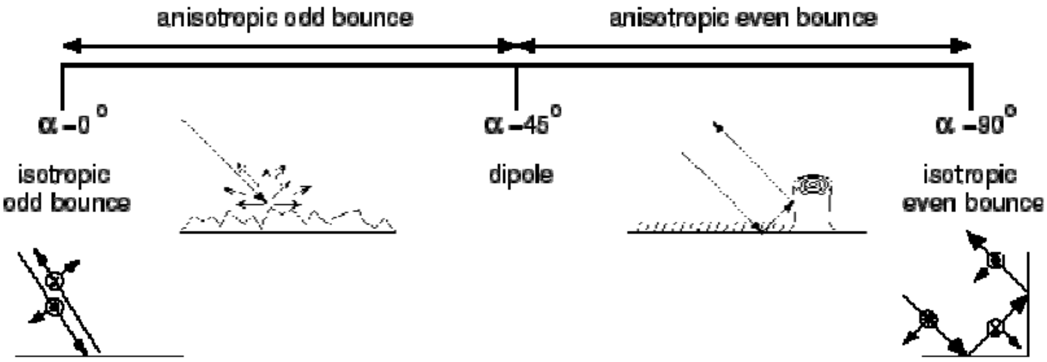
Backscattering decomposition into trihedral and two dihedrals with different tilt angles.

V. The Cloude-Pottier Decomposition Method

The anisotropy A yields additional information only for medium values of H. A high anisotropy signifies that besides the first scattering mechanism only one secondary process contributes to the radar signal. A low anisotropy signifies that both secondary scattering processes play an important role. Another polarimetric parameter is the alpha angle (α), which represents the type of the scattering mechanism and ranges between 0 and 90o. It is evaluated as (Cloude and Pottier, 1997):

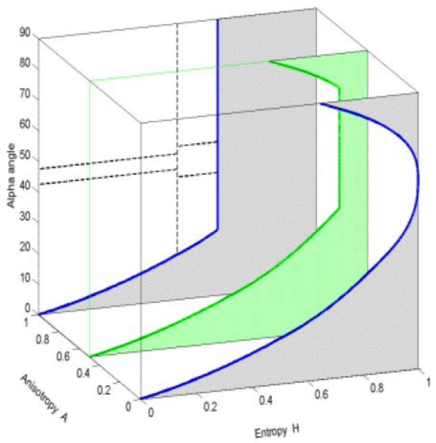
$a = P_1a_1 + P_2a_2 + P_3a_3$.

α = 0 indicates surface scattering, Figure 2.4. As the α angle increases, the surface becomes anisotropic. An α-value of 45o represents a dipole scattering. If α reaches 90o, the scattering process is characterized by double bounce interactions.

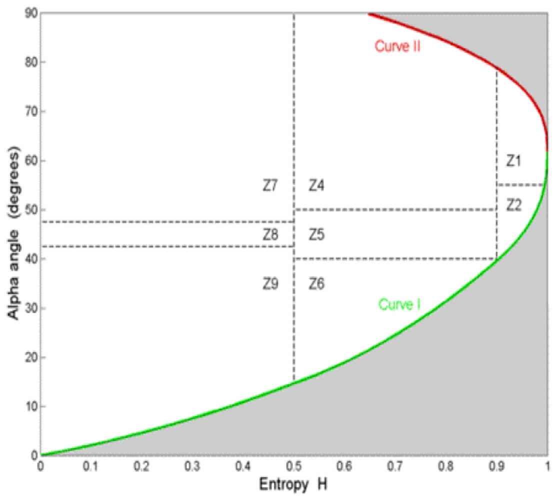


The α angle values and the corresponding scattering mechanisms.

The three parameters of the Cloude-Pottier decomposition are widely used in the unsupervised segmentation of polarimetric SAR data (Hellmann, 1999; Cloude and Pottier, 1997; Dabboor and Karathanassi, 2005; Park and Moon, 2007; Lee et al., 1999a; Cao et al., 2007; Pottier and Lee, 1999).



The entropy and alpha parameter can be combined together in a two-dimensional space. The two-dimensional space can be divided into eight zones (Cloude and Pottier, 1997) providing an unsupervised classification of the polarimetric SAR data into eight classes, Figure 2.5. The eight zones become sixteen by involving the anisotropy parameter and producing a three-dimensional space of the entropy, alpha angle and anisotropy (Pottier and Pottier, 1999). In this case, the polarimetric SAR data can be segmented into sixteen classes, Figure 2.6. Zone boundaries in the two/three-dimensional space are arbitrary fixed, resulting in noisy segmentation results (Lee et al., 1999a). However, the resulting segmentation is usually used as initial segmentation in different Polarimetric SAR segmentation algorithms (Lee et al., 1999a; Park and Moon, 2007; Cao et al., 2007; Dabboor et al., 2010c).



Segmentation of the polarimetric SAR data based on the entropy and alpha angle.

VI. ALOS Full Polarimetric SAR Data

The ALOS satellite carries a spaceborne polarimetric SAR sensor and was successfully launched in January 2006. It has three remote-sensing instruments: the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) for Digital Elevation Models (DEMs), the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) for precise land coverage observation, and the Phased Array type L-band (wavelength: 15-30 cm, frequency: 2.000-1.000 MHz) Synthetic Aperture Radar (PALSAR) for day-and-night and all-weather Earth surface observation. Since the ALOS full polarimetric SAR data will be used in this thesis, the polarimetric mode of the satellite is reviewed here. Table 3.1 summarizes the system parameters of the polarimetric mode (Shimada et al., 2005).

System Parameters	Values
Off nadir angles	$7.9^0 - 30.1^0$
Swath Width	30.6 km at off nadir 21.5
Range Resolution	30.2 m (ground range)
Azimuth Resolution	20 m (4 look)
Noise Equivalent Sigma-Zero (NESZ)	better than -30 dB

System parameters of ALOS polarimetric mode.

VII. Processing

The proposed segmentation methodology is applied to the available ALOS PALSAR polarimetric SAR data. An area of 333x329 pixels is selected with centre coordinates: 51o 12' 17.77" N and 3o 28' 39.81" W. Various land cover categories exist in the selected area, e.g., forest, cropland, urban area (town of Minehead), and sea (Bristol Channel), each one including subcategories, e.g., the settlements include urban and suburban areas. Categories and subcategory presents a different microwave scattering behavior, resulting in a specific color in the RGB polarimetric images, Figure 4.4a. Before segmentation, speckle reduction is a required step for the elimination of noise and smoothing of the SAR images. Lee's speckle filter which uses a multiplicative noise model, refined Lee filter (Lee et al., 1999b), and additive noise model (normal distribution with mean zero and standard deviation σ) was applied (Lee et al., 1991), and the Equivalent Number of Looks (ENL) (Anfinsen et al., 2008) were calculated in order to find the most appropriate filter and performance. Better noise despeckling was obtained using the multiplicative-noise-model Lee filter (mean ENL is 8, instead of 4 for the additive noise model). Thus, the Lee speckle filter with the multiplicative noise model is used in this study. Lee et al. (2001) has shown that the application of the refined Lee filter three times on simulated SAR data can better distinguish the different surface types (Figure 4.3).

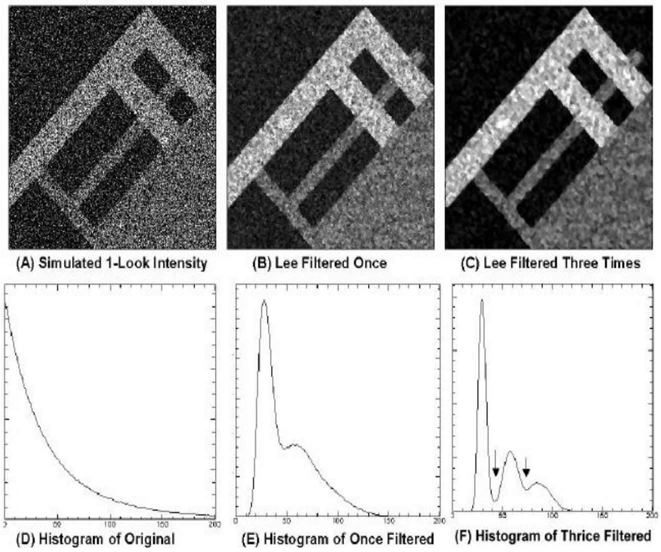


Image segmentation by speckle filtering using the refined Lee filter.

VIII. Conclusions

The main purpose of this research was the development of new segmentation methodologies for polarimetric SAR data which overcome some of the limitations of contemporary methods. To achieve this, we have developed new segmentation methodologies which can be grouped into: 1) methodologies using a divisive clustering technique and 2) methodologies using an agglomerative clustering technique. For the divisive case, two new segmentation approaches were discussed for full and dual polarimetric SAR data. In order to overcome the drawbacks of already existing divisive segmentation approaches, both divisive approaches were nonparametric, i.e., assumptions about the underlying distributions were avoided. This was accomplished by involving a nonparametric histogram thresholding algorithm in both segmentation approaches. This algorithm has the advantage of being able to automatically determine the number of modes in a histogram. The proposed segmentation methodology for the full polarimetric case was applied to the analysis images of Pauli and Freeman-Durden, in separate cases. Segmentation started by dividing the input data based on the dominant and the second most significant scattering mechanisms in the first and second segmentation levels, respectively. Afterwards, the nonparametric histogram thresholding algorithm was applied on the histograms of the dominant scattering mechanism for further segmentation, exploiting the inherent variations within the dominant scattering mechanism. Scattering information alone was found not sufficient to split data into segments that correlate well with the different RGB colors. Hence, amplitude information of the dominant scattering mechanism was necessary to obtain the required segmentation. The proposed segmentation methodology goes beyond the existing methodologies from two points of view.

Assessing the results of this research has shown that useful improvements in POLSAR segmentation have been made. Comparisons with contemporary methods were positive. Several lines of future work can be identified. The segmentation results can be directly used as input data for classifying segments into semantic thematic objects. It is important for the classification approach that transferring segments into thematic classes to exploit the advantages of the previously applied segmentation methodologies, e.g., maintaining the scattering information.

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